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**Innovating in Krugman's Footsteps – Where and How Innovation Differs in Europe: Static Innovation Indicators for Identifying Regional Policy Leverages**

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# Innovating in Krugman's Footsteps – Where and How Innovation Differs in Europe

Static Innovation Indicators for Identifying Regional Policy Leverages

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This paper introduces two indicators for innovation, showing the allocation of innovation and its inherent diversity. Both indicators can give insights for regional innovation policy conception. The first indicator measures the share of patents in research and development expenditure, proposing a locational innovation output indicator. It can show that innovation in Europe differs strongly among NUTS2-level regions, which points to regionally specific, place-based policies as a result of a strong dispersion in European innovation activity. The second measure, the innovation diversity indicator, shows the diversification of innovation in a region and is built upon Krugman's locational Gini coefficients. Here, the share of patents belonging to a particular IPC class is related to the dispersion of all patents in a region. Possible implications for policy are the construction of place-based, technology-specific programs, on either national or subnational (NUTS2-) level, where each country or region has to be considered carefully. Analyses underline that innovation in Europe is a highly regionally and technically diversified concept.

# 1 Introduction

As innovation is a broad concept and difficult to reduce to a few key principles its importance in the potential to increase economic growth is unquestioned (see for an overview e.g. Rhoden 2019, pp. 7-20). Based on previous research (e.g. Romer 1986; Lucas 1988; Shearmur, Carrincazeaux, and Doloreux 2016; Polenske 2007), its impact on growth can be assumed to be positive, which makes innovation crucially important for economic policymakers.

The aim to foster growth via innovation is the foundation for many economic analyses striving for identifying innovation indicators (Eckey 2008, p. 220). These indicators shall not only measure innovation and make it comparable but also give incentives and propose implications for policy. This is especially relevant if the regional aspect of innovation is stressed. Where to fund for the best results in the increase of innovation, and where to fund to not waste money and invest efficiently, are the main questions of this paper (OECD 2010, p. 1113; OECD 2011, pp. 30, 42-44).

Along with innovation allocation, innovation characteristics are investigated. The extent of different technologies constituting innovation or innovative efforts is immense. A policy can further improve the efficiency of funding if it considers the type of innovation and its need of a technology-specific policy program (Rhoden 2019).

This paper is a suggestion for applying two separate indicators to locate the degree of successful innovation output and characterize the amount of diversification inherited within this innovation, based on the different technologies innovation is composed of.

The first indicator can be considered as a measure for innovation success, while the latter provides an application for Krugman's locational Gini indices. The core principle should follow regional agglomeration theory and propose an analysis of innovation similar to Krugman's analysis of industry diversification, hence introducing innovation into regional economic geography.

To propose a robust set of leverages for regional innovation policy, innovation, geography, and economic growth have to be combined. Policy desiring an increase in economic growth can then draw conclusions from the projection of innovation on geography and relate both to the economy.

For founding the analysis, innovation is considered twofold: As indicator comprising the relation of patent applications to research and development (R+D) expenditure and as an indicator for the diversity of technologies in innovation via patent's IPC classes. All data originate from Eurostat's databases and consider European regions on NUTS2-level. Whenever the term of a region is used, the NUTS2-level is considered.

## 2 Followers of Krugman

Geographic concentration is a broad topic in literature and well covered throughout the decades. There exist several approaches that measure agglomeration and provide different concepts for the matter at hand. The development is founded often on the geographic concentration of economic activity, for example, industry allocation or networks. Clustering in the tradition of Porter (1990) and the innovation systems literature (Lundvall 1992; Nelson 1993) mark important milestones, as does the new economic geography (Krugman 1991).

Several streams in research exist which consider some type of regional relation of economic activity or innovation. Among them, knowledge externalities, spillovers, networks, and agglomeration

economies are to list. Clustering and economic causalities also occupy an important part (Rhoden 2019, pp. 7-20).

Agglomeration economies, which according to Hoover (1937) can be split in localization economies and urbanization economies are the basis for understanding the regional movement of economic activity. Marshall (1890) builds further upon these advantages of close spatial allocation of industries, which benefit from these externalities and are thus able to gain profits. Specialization economies and diversity economies (Jacobs 1969) are seen as the main drivers to the generation and diffusion of knowledge and thus, innovation (Paci and Usai 2000b, p. 2).

Furthermore, the transmission of knowledge which is simplified when firms locate close to one another is an important factor, as innovation depends on knowledge (Feldman 1993, p. 451). This is especially relevant considering tacit knowledge (Maskell and Malmberg 1999, p. 171), although, in a globalized, digitalized world, spatial proximity can be overcome by technology. Yet, this can apply to knowledge, but not necessarily to understanding in the sense of applicable comprehension (Morgan 2004, pp. 3-7).

Knowledge can be considered the prerequisite of innovation, and locally bound comprehension benefits from agglomeration and proximity, which can culminate in new products and services that can be considered as innovation (Wolfe and Vatne 2011, p. 45). The geographic location of innovation is thus always a location that attracts further human capital carrying knowledge, which thus reinforces innovation. As Feldman (1993) states, innovation is related to the concentration of its inputs, among them R+D spending, as a result of increasing returns to knowledge contributing to innovation (Romer 1986).

The geographical concentration of innovation and its specialization can be investigated with the help of several different indicators. Fornahl and Brenner (2009) build an important case on the reasons for the spatial clustering of innovative activities, proposing that industry concentration should follow innovation concentration, as innovation is the core impact factor of successful economic activity. Paci and Usai (2000a) or Zitt et al. (1999) also apply concentration indices for innovation.

Indices depending on Lorenz curves like Gini, Herfindahl-Hirschman, Theil, or Ellison-Glaeser index are common measures for detecting and measuring concentration (for an overview of the application for innovation see Fornahl and Brenner (2009, pp. 168-169)). What should be considered side by side with concentration and specialization is the importance, or rather, the relative degree of concentration. Therefore, for policy considerations, the indices should be considered within their context (Van Egeraat et al. 2018).

There exist several applications of either one of the indices or variations of them. Several studies use the locational index (or Krugman specialization index (Midelfart-Knarvik et al. 2000)) in its original function of measuring industry specialization, among them, for instance, Crescenzi et al. (2007) and Eliasson et al. (2010). Further investigations concerning indices are made by Giannitsis and Kager (2009) who compare technology differentiation and by Khramova et al. (2013) who also use a variety of indices measuring technology specialization. Van Egeraat et al. (2018) build a concentration index that locates substantial concentration and relates the concentration to their importance. They further propose that these should be the targets of regional policies. Fritsch and Wyrwich (Fritsch, Wyrwich, et al. 2020) use patents per capita as an indicator for identifying that agglomeration of innovation is not solely limited to urbanized regions, suggesting that policies should not only focus on cities. Using per capita for standardizing innovative activity is therefore considered to be not sufficient.

It has to be kept in mind that an individual policy for each region is not feasible, but regional conception shall be considered to some extent as regions are quite distinct. Regions have to, as Capello and Lenzi (2013, p. 150) find in their study, be able to identify their unique innovation profile for policy to be efficiently applied.

In this paper, with Krugman's work as a foundation, it is analyzed where innovation activity concentrates, how diverse it is, and what this implies for policymakers striving to increase innovation in creating new programs.

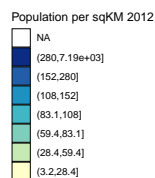
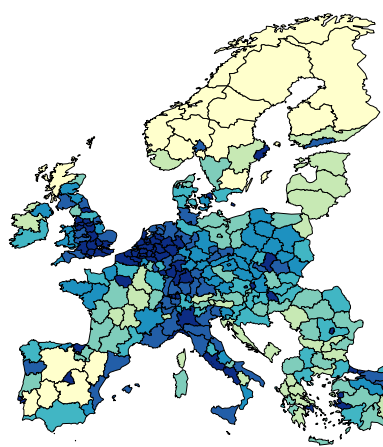
### 3 Data

The analyses are conducted with 2012 as base-year for 304 European regions on NUTS2-level. The data originate from Eurostat databases. The main variable of interest is innovation, which is approximated by patent applications per million employed population, by per million persons and by R+D expenditure per million inhabitants. Patents, in general, are often used for measuring innovation, as is pondered extensively in the literature (see for an overview e.g. Griliches (1998)). Furthermore, registering a patent requires an expected economic purpose of the invention, which can classify the invention as innovation in this context (although it is possible to consider patents only as incremental inputs (Acs, Anselin, and Varga 2002, p. 1069)). Moreover, not every innovation effort results in a patent and not every patent is a successful innovation (Feldman and Kogler 2010, p. 385; Pakes and Griliches 1980, p. 387). Still, patents reflect at least some part of innovation output in the process of technological progress (Griliches 1998). The patent data used is classified by the International Patent Classification (IPC). For each NUTS2-level region in Europe, the number of patents in each IPC class is calculated. A class in the hierarchical system corresponds to the section symbol (A, B, C, D, E, F, G, or H) and two digits consisting of the class. For these analyses, 121 classes are counted (Example: H 01 is the class "basic electric elements" of section H, "electricity") (WIPO 2020). As another possibility for indicating innovation, R+D expenditure is considered. The data represent the expenditure per million persons and are also available on NUTS2-level by Eurostat. Other variables used for introducing the map and for descriptive purposes to put the innovation data into context are population density and GDP per capita.

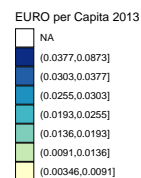
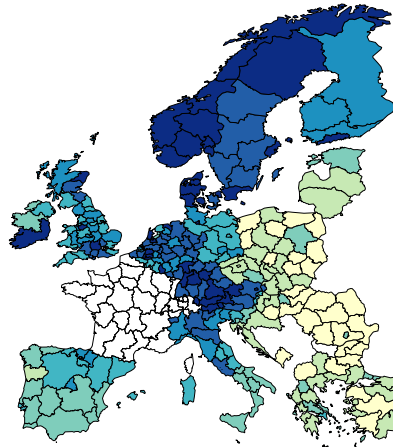
Figure 1a shows the population density across the European countries and their respective regions, where darker regions show higher values. The highest values are visible from England towards the Netherlands, Belgium, the south-west of Germany, and towards the north of Italy. There are some separate regions with high values, for example, Paris and Marseille in France and Madrid in Spain. Those regions exhibit values far above the EU-27 average, although they present exceptions, as most regions exhibit far lower values.

GDP per capita (1b) is strongly concentrated in regions in the western areas of Europe. Darker regions exhibit higher values. Hotspots are in Norway, Sweden, Ireland, as well as in England, the Netherlands, western Germany, and south across Austria, Northern Italy, Paris, and North-East Spain. Except for the eastern European regions, which are far below EU-average, most other regions reside approximately at the average.

R+D expenditure as depicted in figure 2a consists of spending in the industry, public, educational, and non-profit sectors in Europe. The highest values appear in Finland, Iceland, some regions in

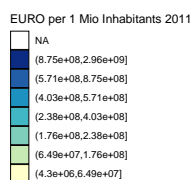
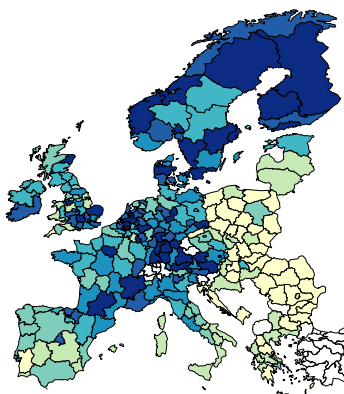


(a) Population Density 2012

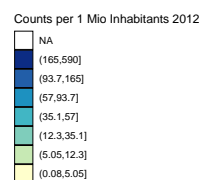
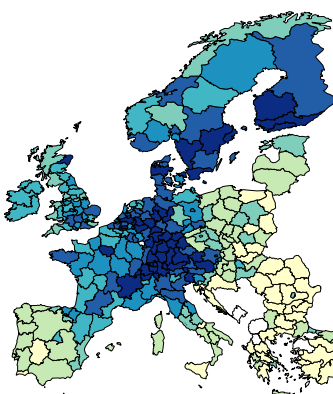


(b) GDE per Capita 2013.

Figure 1: Socioeconomic Indicators.



(a) R+D Expenditure 2011



(b) Patent Applications to the EPO 2012.

Figure 2: Indicators as Innovation Proxies.

Sweden and Norway, England, and in the South of Germany. There are some additional hotspots in the south of France, but still, the lacking eastern European regions are apparent.

In figure 2b, patent applications to the European Patent Office (EPO) per million inhabitants are illustrated. Comparing the map to that of R+D intensity, most apparent is the relation of regions to their neighbors, which is more explicit here than with R+D intensity. Whereas R+D intensity is much more differentiated across the countries, patent applications spread more evenly. This can be seen especially in Germany and Spain and could point to some kind of knowledge spillovers occurring. These seem to be relatively independent of R+D expenditure. Setting R+D expenditure and patents into a shared context as innovation indicators, both can be used approximate measurement of innovation. R+D spending measures innovation more directly and independently from distinct registrable items as patents, as these are expenditures made by private or public companies and institutions which invest explicitly into research and development. These actions need not result in a patent but are also considered as an innovation. To account for the assumption that R+D efforts take some time to possibly manifest in a patent, the R+D data predates the patent data by a year (EPO 2000, Art. 93). Ensuing is the assumption that these R+D efforts are used to generate patents and thus, innovation output (e.g. Rhoden 2019, p. 4).

## 4 Locational Innovation Output Indicator

Concerning the question of this paper, this suggests that measured by patents, innovation dispersion is understated compared to R+D expenditure as innovation indicator. R+D efforts seem much more heterogeneously spread across a country, whereas patents are fairly evenly spread. This can point to necessary precautions that have to be considered when deriving policy measures from these results, as, hypothesizing place-based policy, could undergo the risk of not being applied efficiently enough.

The heatmap of the patent applications (figure 3 shows hotspots where innovation output is regionally concentrated). The center of activity lies in the northern center of Europe and spreads towards the north-west and south-east. In general, central Europe demonstrates the highest concentrations, and this confirms the situation indicated in figure 2. As the diverging density levels (depicted by the contours) show, innovation happens regionally inconsistent and not to an equal degree in each region. This implies that innovation policy has to be carefully conceptualized concerning the specific indicator used to approximate innovation. Innovation is a diverse concept, and funding it for fostering economic growth thus has to be considered as equally differentiated. Thus, by connecting both measures, the maximum information available can be processed. The following analysis shall determine whether the indicated dispersion between those two measures can be overcome by relating them. Concerning possible policy implications, this may suggest a differentiated approach with the funding recipient in mind. As the locational structure of innovation measured by both indicators is not equal and not exactly comparable, a new combined indicator is computed. It contains both measures, R+D expenditures in Euro in 2011 and patent applications to the EPO. The resulting measure is the share of patents in R+D spending, which can illustrate the effectiveness of R+D expenditure concerning innovation.

The calculation is possible for 255 NUTS2-level regions in Europe. The lowest patent success rate is around 0.01 and is located in Spain (the region Extremadura), the highest value is above 1.3 and is assigned to Luxembourg. Where the share is larger than 1, R+D spending seems to be relatively

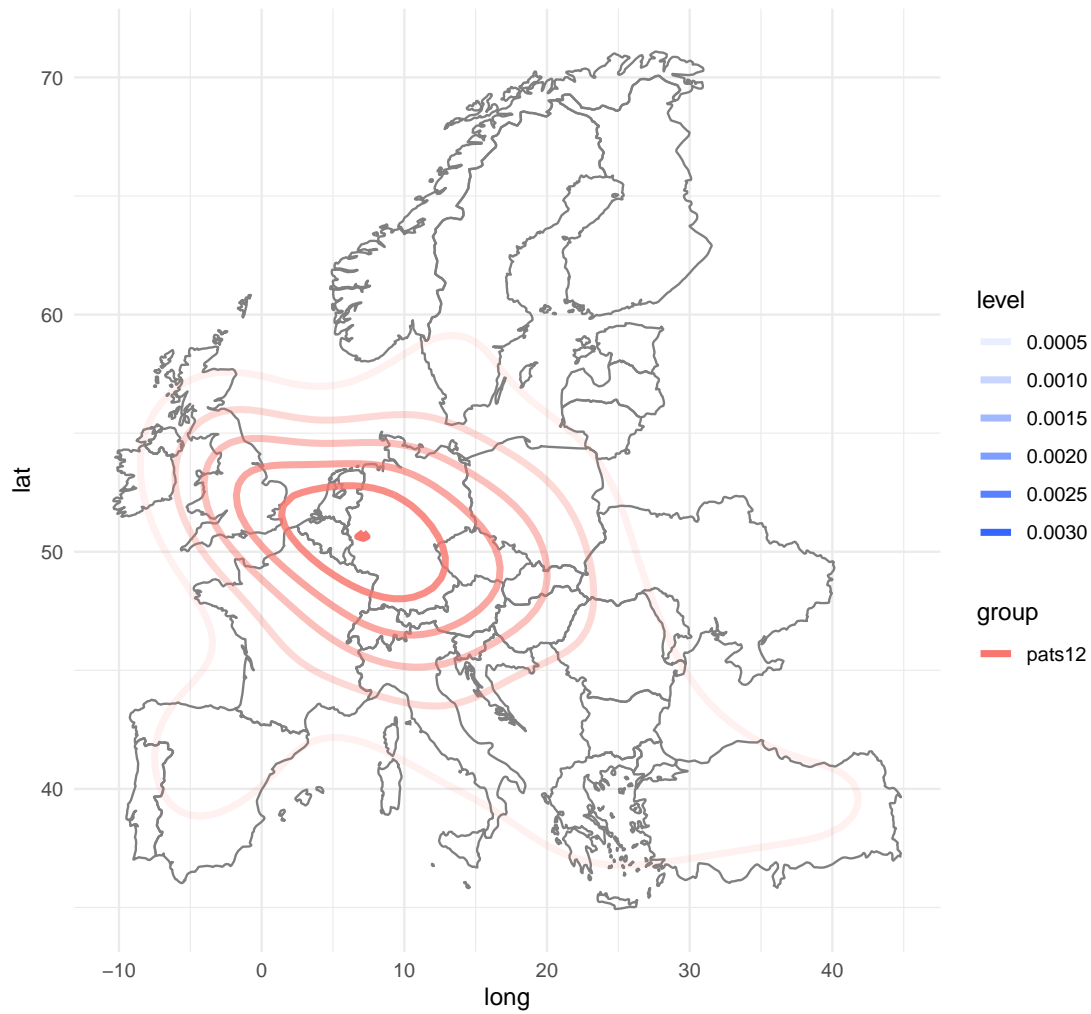


Figure 3: Patent Applications Heatmap 2012.

more efficient in leading to quantifying innovations as patents. This only happens in three regions, in Luxembourg, Lubusz in Poland, and Vorarlberg in Austria. Most regions stay below a value of 0.5, only 5% of the regions in the sample count above this value. Only 20% lie above 0.25. Generally, the success of patents seems diversified across the regions and countries, except for a few deviations. The need for a location-focused policy is therefore still reflected not only in the characteristic of the two separate indicators but also by calculating the standard deviation of the combined indicator for each country in the sample. The results show a relatively large dispersion around the mean among the NUTS2-level regions in the countries. This rather contrasts a finding by Archibugi and Pianta (1992), who conclude that only larger regions (measured by R+D expenditure) exhibit a high degree of technological specialization, as regions with less expenditure do not possess means for spreading



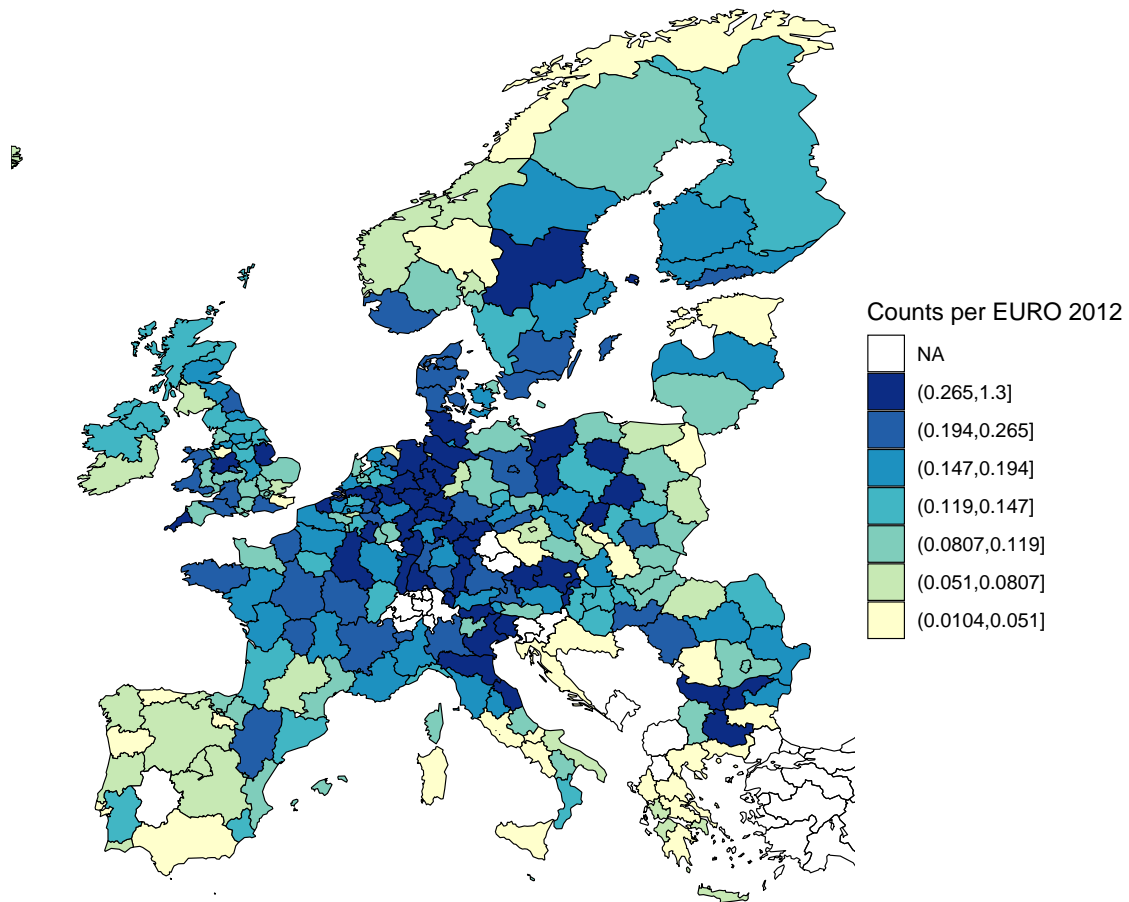


Figure 4: Regional Split of Locational Innovation Output Indicator.

their resources on many technologies. A comparison of the respective figures 2a and 4 shows, that where R+D spending is high, the propensity of that resulting in a similarly higher innovation output measured by patents is relatively low. Concludingly, regions should be considered individually when assigning policies and not just on the base of R+D expenditure.

## 5 Innovation Diversity Indicator

To further investigate innovation dispersion, a look at the type of innovation is executed. For this approach, patents per million working population are considered. For each NUTS2-level region,

different IPC classes are recorded. Thus, information about the technology type of innovations is obtained. This context is only available for patents, as no records about the objective of R+D expenditures are gathered. Using the regional IPC patent data, the construction of the innovation diversity index (IDI) follows Krugman's locational Gini index (Krugman 1991, pp. 74-76). Though, instead of a comparison of various industries in a region, different IPC classes of patents are applied to show possible disparities among innovation. First, the share of patents in an IPC class relative to all patents in a region is calculated. This results in locational innovation output indices. These can show the importance of a particular technology field and thus also hint at an essential innovative field for policy considerations. In a second step, the innovation diversity coefficients are calculated for each NUTS2-level region in Europe.

$$s_i = \frac{\frac{pats_i}{employees}}{\frac{\sum_i^N pats_i}{employees}} \quad (1)$$

with  $i = 1, \dots, N$  IPC classes.  $s_i$  is the share of patents in an IPC class relative to all patents in that class. *employees* is used to normalize the share by dividing per million of the working population. This then leads to the following coefficient.

$$IDI_j = \sum_i^N |s_i - s_i^*| \quad (2)$$

IDI stands for innovation diversity index and is calculated for  $i = 1, \dots, N$  IPC classes for each region  $j = 1, \dots, M$ .  $s_i^*$  is the average share of the respective IPC class. As a result, the dispersion of technology fields of European regions is presented. A relatively low IDI reveals a rather differentiated composition of innovation in a region, whereas a higher IDI depicts a less differentiated regional innovation portfolio.

## 6 Results and Discussion

In figure 5 the IDI coefficients are visualized. Where the color is darker, the index is higher, which means higher concentration on fewer technology fields that contribute to innovation. In these regions, technology is not very diversified, but rather concentrating in fewer specific technologies. This is the case in eastern European regions, Norway, Scotland, Portugal, and Spain.

rance is more differentiated, as there are regions where technology is more diversified than in other regions and in some regions, technology seems to concentrate in particular branches. The same applies to Italy, where a north-south division is apparent. The north is diversified, the south less so. Innovation in Scandinavia as well as in the United Kingdom is also rather specialized on fewer technologies.

In Germany, innovation happens fairly diversified, which is exhibited by a lower IDI. Innovation consists of several technologies, as patents are registered in many different IPC classes, more than in the majority of regions in Europe. All in all, the regions where technologies making up innovation are most diversified, thus pointing to a broad innovation portfolio are Germany, France, the north of Italy, southern regions in Finland, and Valencia in Spain.

Nevertheless, the values are no smaller than 0.5, which points to a moderately diversified technology profile in the regions that thus contains relatively large differences among technologies.

For regions where the IDI is higher, a policy can fund a broader spectrum of programs, since they do not have to spread among many technologies. In regions with a lower value of the IDI, funding has to be executed much more diversified, as several different technologies contribute to innovation and thus to growth.

Aggregating towards the national level, in countries where the IDI is not evenly spread in its values, it is especially important to consider each region separately for funding. In countries where all regions exhibit similar IDIs, a nationally executed innovation program may be able to increase funding efficiency. Additionally, the technology portfolio making up innovation in the respective country has to be closely dissected, as a similar IDI does not mean that the same technologies are present, just that the region is similarly diversified.

All in all, this still points to a location- and technology-specific innovation policy. A nationwide policy, therefore, has to be carefully considered and weighed against subnational programs. Furthermore, technological characteristics of different types of innovation also need to be factored into improving the effectiveness and the efficiency of regional innovation policies.

Generally, the EU exhibits a relatively heterogeneous pattern of technology, especially if a comparison on a national level is made. This supports, for example, the work of Giannitsis and Kager (2009, pp. 9-11) who look at technology differentiation among the EU countries.

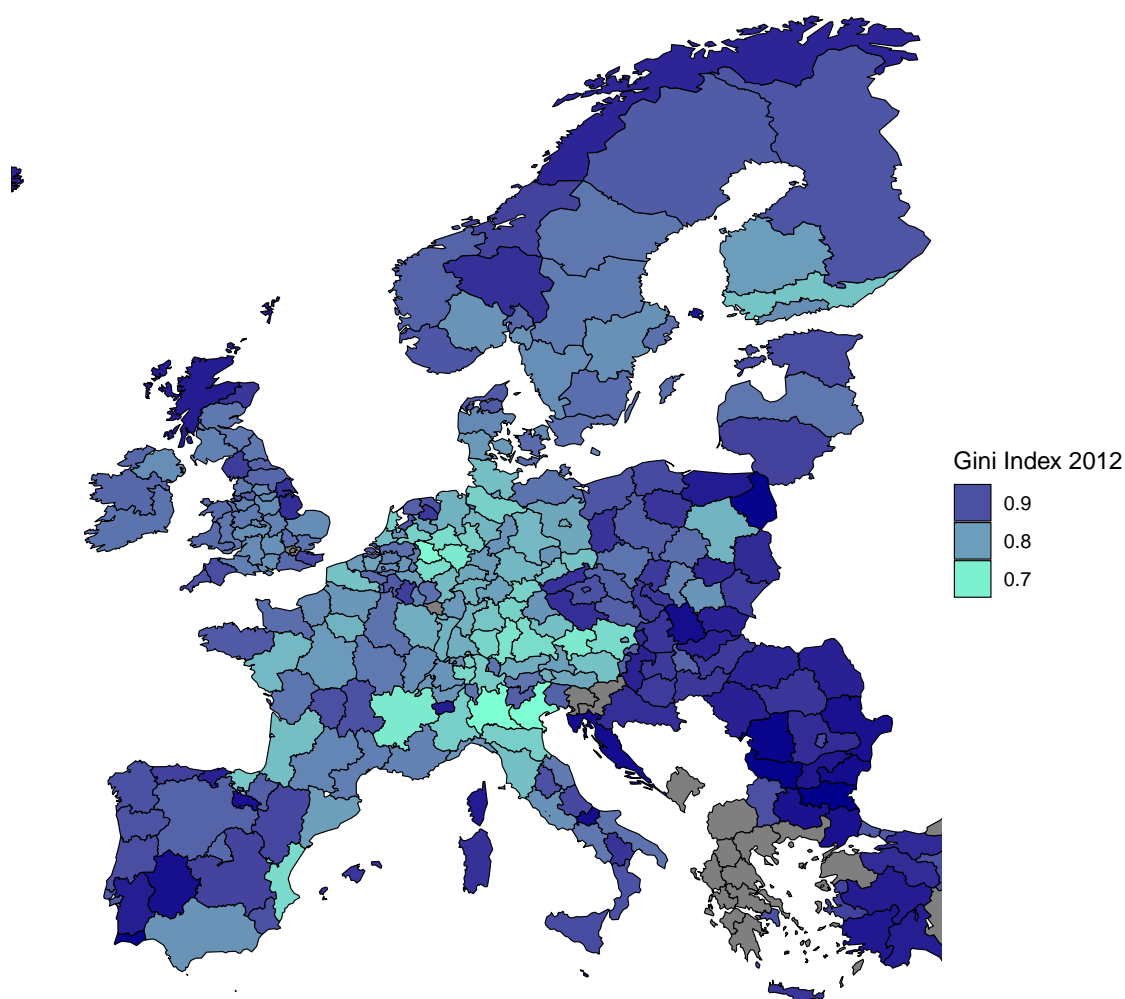


Figure 5: Regional Split of Innovation Diversity Indicator 2012.

## 7 Conclusion and Outlook

As a result of the two different analyses conducted in this paper, innovation is locally and characteristically diverse and policy, therefore, should be applied equally diversified to not face inefficiencies of spending.

Considering the innovation indicators patents and R+D expenditure separately, it can be said that both are similar, but not equal. This originates in the conception of the measures. They both account for different types of innovation at different stages of the innovation generation and commercialization process (Feldman 1993, p. 46). Therefore, in search of an adequate indicator for detecting innovation, policies shall carefully choose its measure, as with different indicators different regions

could be subject to funding. As this is a highly political matter which may result in regional competition (OECD 2011, pp. 34, 127), it is suggested to combine both variables.

An innovation location indicator illustrating the success of innovation is constructed as a result. The success is measured by calculating the share of patents in R+D expenditure, hence demonstrating the relation of patents and R+D efforts. There is a time lag included, as R+D data predates the patent counts by a year. The consequence is a regionally differentiated illustration of innovation efforts that suggests an equally regionally diversified policy for fostering innovation.

Regarding the innovation diversity indicator, which is based on Krugman's (1991) locational Gini concept, different technologies contributing to innovation outputs can be seen as different across regions. The degree of variety in innovation technologies shows whether innovation in a region consists of few or many technologies. This can indicate the necessity of the complexity of regional funding policies, as they either can be applied broadly or have to target distinct technologies. Furthermore, in countries where IDIs are similar across regions (this applies stronger when the value is high, pointing to less diversified innovation culture) policy could employ nationwide programs, whereas, in countries where regional innovation IDIs differ greatly, subnational programs could be more effective. All in all, the careful decision between national and regional innovation policy is also applicable when considering not only the variety of technology constituting innovation but also its allocation.

For a more detailed insight into technology dispersion across countries in Europe, a functional data analysis (FDA) could be executed. The change in locational innovation activity can be monitored over time and the IDIs will be represented as curves over a timeframe of several years. The analysis aims at increasing the level of stability of the analysis of dispersion. Comparisons of the European regions can be drawn and thus it is possible to comprise a new classification of European innovation regions. Additionally, the reliability of the results will be improved because of the dynamic approach (Zeebroeck, Potterie, and Han 2006, p. 492). This can add to policy understanding and, together with a prognosis, allow an improved conception for future policy program periods.

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