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Centripetal and centrifugal forces in technological activities: linking regional innovation performances to EU Science & Technology policies

by

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Abstract

In this paper we analyse the technological activities of EU regions to assess the degree of technological concentration and asymmetries in the EU area and the role of the EC Programme for research and innovation - Horizon 2020 - at reducing or amplifying regional asymmetries. Technological capabilities are very unevenly distributed in the EU, and spatial concentration is much higher than that of GDP. Over the period examined (2001-16) some technological convergence of the most peripheral and least innovative regions of Europe has occurred even if it has been slow, involving almost exclusively the Eastern EU regions. Horizon 2020 seems to favour the integration of regions from peripherical countries. However, the focus on scientific excellence, particularly of the European Research Council, may instead contribute to exacerbate the technological gaps across EU regions. Our results suggest there is a trade-off between inclusion and excellence when designing research and innovation policies. This finding will help to inform policy makers and policy analysts in implementing the Horizon Europe scheme (2021-2027).

Keywords: Innovation Policy, Patents, EC Framework Programmes, Horizon 2020

Introduction: The distribution of technological competences in Europe as a challenge for EU policies.

In the latest two decades, the European economic and technological landscape has experienced profound transformations accompanied by centripetal and centrifugal forces. On the one hand, centripetal forces are driven by agglomeration economies and the increasing role of technological leaders in shaping the spatial distribution of innovative activities in the EU area (Iammarino et al., 2019). On the other hand, deep changes have occurred in the EU production and technological landscape, with new regional players emerging as a result of the enlargement (toward East) of the EU, the new opportunities for firms located in Eastern regions to be integrated within continental and global value chains, and the propensity to marginalize firms and regions located in southern countries (Stöllinger, 2016, Celi et al., 2018).

Public policies are likely to contribute to either centripetal or centrifugal processes. On the one hand, competitive science and technology (S&T) EU schemes may end up favouring leading players and regions since they aim to strength the role of EU innovation system in the global arena. On the other hand, cohesion policies aim at reducing the regional gaps across European territories, which in turn can also be favoured by the collaborative setting of part of the S&T policies aiming at the creation of an integrated European research area.

It is a typical case in which public policies may lead to contrasting directions. Policies that ex-post provide opposite outcomes might still be valuable, provided they are informed by an overall common strategy. Unfortunately, the empirical evidence on the role played by EU policies in favouring technological convergence, or alternatively technological polarization is still limited.

The aim of this paper is to start filling this gap by investigating the dynamics of technological activities of EU regions and getting preliminary evidence on the role played by the main EU Science and Technology policy scheme, i.e. H2020, in reducing or amplifying regional asymmetries. The results will complement those of studies focusing on cohesion policies, which have shown that positive effects on regional growth may be hampered by an unfavourable industrial structure, the lack of R&D capabilities in the receiving regions (Cappellen et al., 2003) as well as the poor administrative and political governance factors needed to take advantage of the availability of structural and cohesion funds (Incaltarau et al., 2019).

Specifically, this study aims at:

a) measuring the degree of technological polarization in the EU at a regional (NUTS2) level and its dynamics;

b) understanding to what extent the current and potential distribution of technological capabilities in EU regions is associated to national- or regional-specific factors. This, in turn, will help to understand when there are suitable conditions to allow an upgrade of backward regions;

c) analysing the regional distribution of the resources provided by the European Commission's Horizon 2020 Programme (H2020) – the EU's flagship instrument for science and technology policy – to assess their potential impact on regional convergence/divergence, providing evidence on whether the H2020 reinforces processes of technological concentration or is coherent with the objectives of EU cohesion policies.

While we are aware of the limited resources provided by EC Framework Programs (FPs) compared to those mobilized by other EU policies (i.e. cohesion funds), by national policies as well as by the business sector, we will argue that they are strategic and can have an impact possibly higher than the actual financial budget available.

The technological activities of EU regions will be analysed using REGPAT, a fresh patent database developed by the OECD allocating patents filed at the European Patent Office (EPO) to regions according to the addresses of inventors as reported in the patent documents; the analysis will cover a period of at least 15 years, up to 2016. The regional distribution of H2020 funds will be analysed using data provided by the Community Research and Development Information Service (CORDIS) of the European Union. The use of H2020 data present two advantages with respect to previous data on the EU FPs: i) it provides for the first time a breakdown of budget allocation at the level of project partners (previously the whole budget was allocated to the project coordinator) (e.g. Amoroso et al., 2018), and; ii) it allows to assess the relevance and potential impact of very different types of S&T policy schemes included in H2020, and in particular the role of the European Research Council (ERC), which represents an innovation in the traditional S&T EU policy framework. In fact, ERC is explicitly focused on the support of frontier research and excellence, in so doing abandoning the idea of research consortia and networks that traditionally characterized the previous EC FPs. We are here considering for the first time ERC, as part of H2020, also for his impact on regional cohesion.

Key issues addressed in this paper are the following: are laggard and peripheral EU regions catching-up with regard to the core and more advanced EU technological areas? Do clear macro-regional patterns emerge? Does the EU science and technology policy foster processes of technological concentration or is it coherent with the objectives set by EU cohesion policy? Do the different funding schemes show traces of possible heterogeneous effects?

The study is structured as follows. Section 2 defines the policy context in which this study is positioned and provides a survey of the relevant literature. Section 3 contains a brief description regarding the dataset used and the methodology used. Section 4 contains a descriptive analysis of the level and dynamics of technological concentration of technological activities in the EU area at a regional level, on the technological fields where technological polarization is higher and those where the innovation capabilities are more evenly distributed. Section 5 provides a descriptive analysis of the main geographical and macro-regional patterns of the distribution of patent activities in the EU area and the extent to which such patterns have changed over time. Section 6 assesses the potential impact on regional convergence/divergence of H2020. Section 7 concludes with some policy implications.

Policy context and relevant literature

Building a cohesive and competitive European Union has represented for several decades one of the most challenging and ambitious goal of our continental policy institutions, and one which is still far from being reached. Since the release of the Lisbon Strategy in 2000, fostering science, technology, innovation and human capital have been considered key ingredients and leverages of any strategy pursuing such a goal (Archibugi and Lundvall, 2002; Lorenz and Lundvall, 2006). Regions, rather than countries, have progressively increased their relevance as key spatial and socio-economic units as well as policy targets of cohesion policies (European Commission, 2010, 2011a; Boschma and Frenken, 2011). In the most recent years, regional innovation strategies for smart specialization (RIS3) have become a key component of the EU Cohesion Policy 2014-2020, supporting the thematic concentration of available resources and reinforcing the strategic programming and performance orientation policy action (European Commission, 2011a, 2014a).

More precisely, the RIS3 initiative encourages regions and cities from different EU Member States to strengthen their technological bases and to collaborate and learn from each other through joint programmes, projects and networks with concrete impacts on every aspect of economic life including innovation, accessibility, education, business, employment and the environment. In this context, regions should be outward looking to be able to map and identify their strengths and weaknesses, position themselves in the European and global value chains, and, at the same time, improve their connections and cooperation with other regions, clusters and innovation players. This is deemed to be of crucial importance to favour the internationalisation of their companies, to achieve a critical potential of cluster activities and to generate inflows of knowledge relevant to the region's existing knowledge base.

The starting point is that, as shown and empirically documented by numerous contributions, technological capacities are far from being evenly distributed across industries, firms and even more at a spatial level (Meliciani, 2015). This is due to various factors, the most important being the cumulative nature of innovation and learning processes, the localized character of spillovers, externalities and systemic interactions in the process of generation and economic exploitation of technology (Evangelista et al., 2002). Furthermore, geographical, technological and institutional proximity is crucial for regional economic development and this contributes to accelerate and strengthen the processes of agglomeration and clustering (Von Lynker and Thoennessen, 2017). These features produce long-lasting spatial technological asymmetries that can, in absence of corrective mechanisms, produce not-reversible processes of polarization, leaving several regions in their technological backwardness.

Systematic and up-dated analyses on the level and dynamics of technological polarization in the EU area are still limited and even more so the studies looking at this issue from a regional perspective. Paci and Usai (2000), analysing main regional differences in a restricted number of EU countries in (labour) productivity and technological intensity (measured through patents per employee), have found a high level of regional technological concentration, although in presence of a declining trend in the regional dispersion of innovative activity over the 1980-90 decade, mainly due to changes in the distribution of technological capacities between Southern and Northern Europe.

Significantly, the dispersion of labour productivity is remarkably lower than that of innovative activities. While there is some convergence at the country level, this does not emerge at regional level. Moreno et al. (2006), looking at the 1994–1996 and 1999–2001 periods, have shown that innovations have been spreading to more regions in Southern Europe (Spain and the South of Italy especially) and in the Scandinavian countries but also that this process has not been homogenous across European regions and countries. Archibugi and Filippetti (2011) have shown that the 2008 financial crisis halted the convergence process across countries in innovation. A more recent study (Evangelista et al. 2016) has shown that the distribution of technological capabilities in EU regions is much more concentrated than that of gross domestic product (GDP). Dopke et al. (2017), on the basis of a set of regional quality ‐ of ‐ life indicators have shown that in the case of the EU regional inequality in "well-being" is lower than regional inequality in real GDP per capita (Incaltarau et al., 2019).

The spatially uneven distribution of technological activities and competences has also a sectoral dimension, with some sectors and technological fields more concentrated than others (Breschi 2000, Paci and Usai 2000, Moreno et al. 2006, Usai 2008). According to Paci and Usai (2000) spatial dependence in technological activities and performances is a phenomenon affecting all sectors but there are spatial and sectoral specificities which generates different types of specialized clusters across EU regions. In some sectors, technological competencies are highly spatially concentrated in all countries even when the spatial distribution of industrial activities is more irregular. Evangelista et al. (2018) find a high level of spatial concentration for the most promising technological field: fast growing technological fields (FGTs) and the so-called Key Enabling Technologies (KETs). KETs are highly concentrated in Central Europe while FGTs prevail in Scandinavian countries and in the UK. The study also shows the presence of some conditional convergence in KETs and, to a less extent, in FGTs.

There is a wealth of exercises which have tried to profile EU regions on a variety of indicators of technological capabilities (Navarro et al., 2009; Verspagen, 2010; Wintjes and Hollanders, 2011). The most recent regional taxonomic exercise is the one proposed by the European Commission (2014b) and identifying four main regional innovation groups: *Leaders*, *Followers*, *Moderate*, and *Modest*

Innovators.[1] These geographical patterns are in turn quite like those emerging when considering only the patenting activities of regions (Paci and Usai, 2000; Vezzani et al., 2018).

Regional taxonomies using multiple indicators represent a useful tool for mapping - at a pure descriptive level - the technological profile of EU regions. They are nonetheless less effective in assessing and monitoring the level and dynamics of technological polarization, which is the first topic investigated in this contribution. Furthermore, in these types of taxonomic exercises, as well as in most of the existing literature on the EU-regional technological landscape, the role played by EU S&T policies in influencing the profiles of the different regional groups as well as the dynamics of technological gaps has remained neglected. There are few exceptions: one is the micro-level study by Loredana Fattorini, Ghodsi and Rungi (2019) that finds that the European regional development fund supporting direct investments in R&D at regional level is associated with the improvement of firms' productivity while funding designed to support overall business is not; another one is the work by Muscio and Ciffolilli (2020) which uses regional data from the 7th European Framework Programme to investigate the factors underlying the capacity to participate to Industry 4.0 related projects. Their results suggest that regional economic competitiveness matters and that network participation is particularly relevant for less developed regions.

As a matter of fact, most of the literature on the EU Framework Programmes leverage the collaborative design of these funds to explore the effectiveness of EU network policies (Breschi and Cusumano, 2004), their success in favouring interdisciplinary research (Bruce et al., 2004), the role of collaborative network properties in generating and diffusing knowledge (Breschi et al., 2009), or the factors leading to regional R&D collaborations (Amoroso et al., 2018). All-in-all, these studies suggest that EU policies may have favoured the integration of the European research around poles of highly connected actors (places), but it may have been less successful in integrating some research areas, such as natural and social sciences. In addition, while network participation may depend on regional capabilities, its beneficial effect seems to be relevant particularly for less endowed regions.

Following up this last stream of literature, a second objective of this contribution consists of providing further fresh evidence on the effects of EU science and technology policy on the level of EU internal integration looking at the potential role played by the H2020 programme also considering the specificities of different pillars and actions contained in such ambitious policy scheme.

Data and Methodology

The technological activities of EU regions will be analysed using REGPAT, a patent database developed by the OECD where patents are linked to regions according to the home addresses of the inventors, allowing to identify the location

[1] In its latest version (Hollander et al., 2020) differences have been nuanced to assign regions to 12 groups, from Modest$^-$ to Leader$^+$.

of inventive activities. We will focus on the inventor localization to analyse the technological capabilities of European regions since this help identifying the area where technological activities are carried out and knowledge and competences accumulated. We will use the concordance between International Patent Classification (IPC)[2] and technologies, originally developed by Ulrich Schmoch (WIPO, 2013).

Although in principle REGPAT provides patent information at the NUTS3 spatial level, the analysis will be carried out manly at the NUTS2 (and NUTS1 for some regions) level since for a few small countries the regional breakdown at NUTS2 level is not available, either in REGPAT and in for most economic variables provided by Eurostat. Indeed, for some very small countries NUTS1 regions coincide with the entire nation.[3]

For patent activities of EU regions, the analysis focuses on the 2001-2016 period and, as usual when working at the regional level, data are aggregated on four sub-periods: 2001-04; 2005-08; 2009-12; 2003-16. This choice also allows us to reduce to the minimum the annual variability of the underlying data (particularly strong for patent data in the smallest unit of analysis) and to better describe the overall changes occurred during the period considered.

We will analyse the regional distribution of H2020 funds using data provided by the Community Research and Development Information Service (CORDIS) of the European Union. This is the primary information source for projects funded by the EU's framework programs for research and innovation (FP1 to Horizon 2020). For the first time, the Horizon 2020 data provide information on the budgetary allocation of funds among different partners of a project. We exploit this information to allocate funding across the EU territories and have more detailed information than the counting of projects allowed by previous FPs.

Consistently with other works and for presentation purposes, in sections 4 and 5 a series of statistics will be presented aggregating data at the level of macro regional groups: North Europe (Sweden, Norway, Finland and Denmark), Central Europe (Austria, Belgium, Germany, France, Ireland, Luxembourg, Netherlands, UK), South Europe (Greece, Italy, Malta, Portugal, Spain) and East Europe (Bulgaria, Czech Republic, Croatia, Estonia, Hungary, Lithuania, Poland, Romania, Slovakia, Slovenia). In section 6 we will link past technological capabilities of regions (2010-14) to the H2020 funds received between 2015 and 2019. By doing so we will assess to what extent and how the distribution of (access to) funds across regions is dependent on the different technological capabilities of regions, possibly triggering processes of (increasing) accumulation or diffusion of knowledge capabilities.

[2] The International Patent Classification (IPC), established by the Strasbourg Agreement 1971, provides for a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain.

3 In particular, these countries are Cyprus, Estonia, Latvia, Lithuania, Luxembourg, and Malta.

Technological concentration in the EU. A regional analysis

In this section we investigate the level and dynamics of technological polarization in the EU area from a regional-distributional perspective. We use for this purpose the Gini coefficient, an indicator commonly used to synthesize the level of “concentration” and “inequality” of socio-economic phenomena and variables. This index has been computed on the distribution of patent applications across the 281 EU NUTS2 regions and covering the period 2001-2016.

Table 1 shows for four distinct sub-periods (2001-04; 2005-08; 2009-12; 2003-16), some indicators of technological and GDP concentration. GDP can be used as a sort of benchmark to compare the relevance and dynamics of technological polarization in the EU area. The first part of Table 1 shows the Gini coefficients for technology and GDP, indicating that the EU area is characterized by a strong spatially uneven distribution of technological capacities, which in all periods is higher than that of GDP. Over time, there is a small centrifugal effect leading to a slightly decrease in technological inequality, which however remain marginal. The table also reports the subdivision for five broad technological areas (Electrical engineering; Instruments; Chemistry; Mechanical engineering; Other technological fields), showing that the highest level of technological concentration is found in ICT and Electrical Engineering technologies.

The second part of Table 1 reports the concentration of technological activities and GDP in the top 10 regions. In the first period (2001-2004), ten regions concentrate a share of overall EU patents nearly double compared to GDP. Looking at the concentration among the leading regions, the centrifugal effect appears more marked for the technological development than GDP. Indeed, the share of patent of the top 10 regions decreases consistently (from 35.4% to 29.9%), while the share of GDP has even slightly increased over the 2001-2016 period.

Table 1: Technological and GDP concentration in the EU

Gini coefficients across NUTS2 EU regions and shares of top 10 regions

	2001-2004	2005-2008	2009-2012	2013-2016
Gini coefficients				
GDP	0.51	0.49	0.49	0.49
Patents	0.72	0.70	0.69	0.68
Patents by technology area:				
Chemistry	0.71	0.71	0.69	0.68
ICT & electrical engineering	0.79	0.76	0.75	0.74
Instruments	0.72	0.71	0.70	0.71
Mechanical engineering	0.72	0.72	0.70	0.69
Other technologies	0.65	0.67	0.66	0.66
Share of patents and GDP of top 10 EU regions				
Patents	35.4%	32.6%	31.0%	29.9%
GDP	18.9%	18.9%	19.3%	19.1%

Note: for some countries (CY, EE, LT, LU, LV, MT) NUTS2 level data are not available, for these countries NUTS1 figures are used. **Source:** Authors' computations on Regpat 2019a and Eurostat data.

Table 2 shows the levels and dynamics of the shares of EU patents and R&D expenditures by country groups, indicating that the bulk of patented inventions in the EU and resources devoted to R&D are generated in the Central Europe. Regions in the East Europe have more than doubled their share of patents and R&D. However, in the most recent period they still account for 3.1% of patents (in 2013-16) and 4% of R&D (in 2017-19) only. Patents are a capitalist institution that was rather meaningless in the former planned economies, but the fact that after three decades since the beginning of the transition to a market economy Eastern European countries have not generated a significant number of patents suggest that their inventive activities is still low. The share of patents and R&D expenditures of Southern regions has been decreasing in the last two periods, probably as a result of the particular heavy and long-lasting effects of the 2008 economic crisis.

Table 2: Shares of EU patents and R&D by country groups

	Shares of Patents				Shares of R&D expenditure				
	2001-04	2005-08	2009-12	2013-16	2001-04	2005-08	2009-12	2013-16	2017-19
North EU	8.8%	9.2%	9.8%	9.8%	12.3%	12.2%	12.4%	11.9%	11.4%
Central EU	79.7%	77.8%	77.1%	76.2%	72.9%	70.2%	69.3%	71.0%	70.9%
South EU	10.1%	11.2%	10.6%	10.8%	12.7%	14.7%	14.7%	13.1%	13.0%
East EU	1.3%	1.8%	2.5%	3.1%	2.2%	2.9%	3.6%	4.0%	4.8%
Total EU	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Authors' elaborations on Regpat and Eurostat data

Table 3 provides a breakdown of technological concentration in Europe presenting Gini coefficient indexes over the 4 sub periods for each of the 35 WIPO technological fields. There are significant differences across technological fields in the spatial distribution of innovative capabilities across EU regions.

Table 3: Technological concentration in the EU by technology fields

Gini coefficients across NUTS2 EU regions

Technological field	2001-2004	2005-2008	2009-2012	2013-2016	2013-2016 minus 2001-2004
Digital communication	0.804	0.809	0.812	0.820	(0.02)
Semiconductors	0.812	0.781	0.761	0.784	(-0.03)
Computer technology	0.795	0.766	0.775	0.771	(-0.02)
Organic fine chemistry	0.785	0.779	0.768	0.759	(-0.03)
Telecommunications	0.784	0.762	0.759	0.753	(-0.03)
Audio-visual technology	0.803	0.779	0.750	0.751	(-0.05)
Macromolecular chemistry, polymers	0.748	0.753	0.767	0.749	(0.001)
Optics	0.761	0.758	0.726	0.739	(-0.02)
Engines, pumps, turbines	0.777	0.755	0.737	0.739	(-0.04)
Micro-structural and nano-technology	0.734	0.735	0.730	0.738	(0.005)
Machine tools	0.717	0.727	0.742	0.735	(0.02)
Basic communication processes	0.776	0.731	0.759	0.732	(-0.04)
Transport	0.748	0.747	0.733	0.727	(-0.02)
Electrical machinery, apparatus, energ	0.742	0.736	0.728	0.724	(-0.02)
Basic materials chemistry	0.751	0.744	0.731	0.722	(-0.03)
Measurement	0.733	0.727	0.720	0.720	(-0.01)
Other consumer goods	0.696	0.703	0.715	0.717	(0.02)
Mechanical elements	0.725	0.752	0.732	0.712	(-0.01)
IT methods for management	0.717	0.707	0.704	0.710	(-0.01)
Biotechnology	0.719	0.714	0.713	0.709	(-0.01)
Medical technology	0.681	0.693	0.700	0.708	(0.03)
Textile and paper machines	0.729	0.742	0.712	0.705	(-0.02)
Pharmaceuticals	0.733	0.733	0.720	0.700	(-0.03)
Control	0.693	0.692	0.696	0.698	(0.01)
Materials, metallurgy	0.698	0.685	0.695	0.688	(-0.01)
Furniture, games	0.646	0.670	0.697	0.681	(0.03)
Handling	0.672	0.684	0.680	0.680	(0.01)
Food chemistry	0.663	0.684	0.660	0.680	(0.02)
Chemical engineering	0.688	0.693	0.680	0.680	(-0.01)
Analysis of biological materials	0.696	0.672	0.676	0.676	(-0.02)
Surface technology, coating	0.680	0.660	0.674	0.671	(-0.01)
Thermal processes and apparatus	0.681	0.689	0.679	0.666	(-0.01)
Environmental technology	0.663	0.661	0.690	0.660	(-0.003)
Other special machines	0.652	0.654	0.665	0.656	(0.004)
Civil engineering	0.623	0.649	0.643	0.652	(0.03)

Note: for some countries (CY, EE, LT, LU, LV, MT) NUTS2 level data are not available, for these countries NUTS1 figures are used. **Source:** authors' computations on Regpat 2019a data.

Table 3 confirms that the most polarized technological fields are related to ICT and digital technologies (Semiconductors, Basic communications, Digital communications, Audio-visual, Telecommunications). Among the least unequal technological fields we find the Pharmaceutical and Bio-technology areas (Pharmaceutical, Bio-materials, Bio-technologies and Medical technologies).

The already mentioned process of spatial re-balancing of technological capacities is a rather widespread phenomenon across the technological fields. In fact, in the 2001-2016 period, the level of technological polarization has decreased in most of the technological fields. The long-run decrease of technological concentration is particularly significant in the technological fields where the spatial distribution of technological capacities is more uneven.

Technological gaps and catching-up processes in the EU. A regional analysis

The rationale for examining the spatial distribution of technological activities in the EU at the regional level is based upon the hypothesis that science, technology and innovation are phenomena that take place in defined structural and institutional contexts, and are affected by factors that operate not only within a national system of innovation but also at a subnational level. Concepts such as "regional" or even "local" systems of innovation reflect such a perspective and there is a large empirical evidence supporting such a view (Howells, 1999; Evangelista et al., 2002; Asheim and Gertler, 2005; Iammarino, 2005). This perspective should not be seen as clashing with the fundamental fact that regional and local innovation systems are part of, and are institutionally and functionally embedded in, broader national science and technology systems. Moving further this line of reasoning, regional disparities might also be related to broader economic and geopolitical contexts, reflecting the heterogeneous historical roots and development patterns characterizing the different EU macro-regional areas.

Some hints on the relative importance or "pure regional factors" in explaining the observed spatial technological disparities in the EU – vis-à-vis the role played by drivers and factors acting at national or macroregional level – can be obtained by performing an analysis of variance (ANOVA) using two key indicators for the regional technological and economic performances: the number of patents and the level of GDP both normalized by the population. With the ANOVA is possible to disentangle the part of cross-regional variance in technological and economic performances accounted by differences in the strength of national or macro-regional economic and innovation systems where regions are located; the residual variance is therefore associated to differences in the regional innovation contexts.

Table 4 shows the results of ANOVA analyses carried on the four sub-periods considered in this study. The results confirm the importance played by both country and macro-regional specific factors in explaining the existing spatial technological and economic asymmetries within the EU area. "Country specificities" account for about 50% of the variance of both patent and GDP per capita at regional level with the remaining 50% of variance "explained" by differences in the technological strength of regions; a basic result that confirms the relevance of both the national and of the regional components in generating a successful innovation system. Furthermore, when considering patents per capita, the relative importance of these two components has not changed much over the 2001-16 period.

Differently, the "explanatory" power of the country context on GDP per capita has steadily decreased during the period considered, with regional idiosyncrasies becoming more relevant, somehow mirroring the increasing importance of regions in the EU policy. The results presented in Table 4 justifies the regional scope of this study but at the same time the need of recognising that a large part of regional technological gaps in Europe, as well as their dynamics, have to do with strong country differences within the EU in the quality and strength of the production and science & technology systems.

Table 4: Technological capabilities and GDP per capita at regional level. How much countries matter?

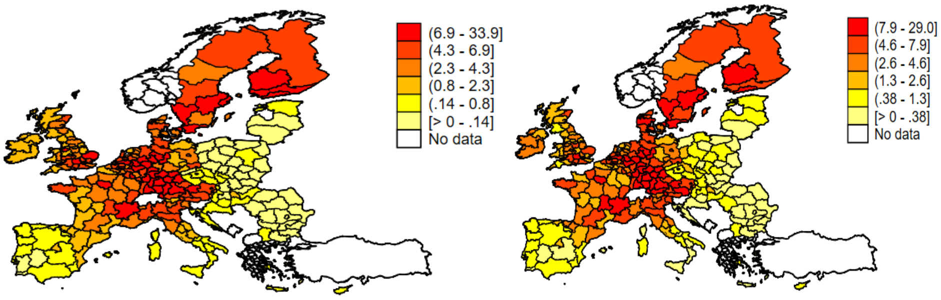
Analysis of variance

	2001-2004	2005-2008	2009-2012	2013-2016
ANOVA: country		*R-squared*		
Patent per capita	0.470	0.504	0.525	0.498
GDP per capita	0.557	0.498	0.498	0.474

Source: Authors' elaborations on Regpat and Eurostat data

The importance of regional and country specific factors in explaining technological asymmetries in the EU surfaces looking at Map 1, reporting the level of patent intensity (number of patents per capita) of EU NUTS2 regions in 2001-04 and 2013-16. The maps show both strong macro-regional differences in the patent intensity and a certain degree of technological inhomogeneity within most EU countries. The highest levels of patents per capita are found in the North and Central Europe but this area also extends to the North of Italy, while a more uneven regional pattern is found in France. The least innovative regions are in the Eastern and Southern Europe.

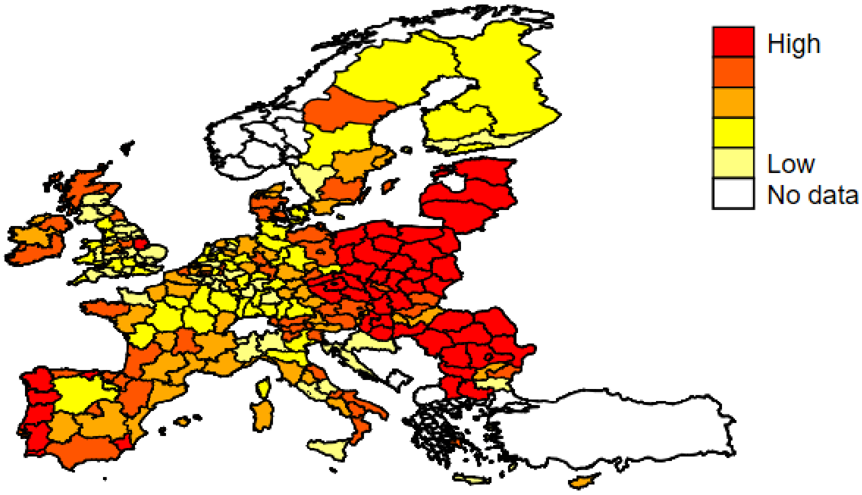
Map 1: Patents per 10,000 habitants: 2001-2004 (left) and 2013-2016 (right)



Note: Regions are split in five equally populated groups (quintiles, 20%) on the base of patent per capita. **Source:** Authors' computations on Regpat 2019a and H2020 data.

A comparison of the two maps show a high degree of stability of the EU technological landscape with the persistence of very large gaps between the lowest and highest performing macro-regional areas of EU: in synthesis, not much has changed between 2001 and 2016 in the EU spatial technological landscape, with Map 1 reflecting the well-known structural dualism within the broad EU area.

Map 2: Patent per capita growth

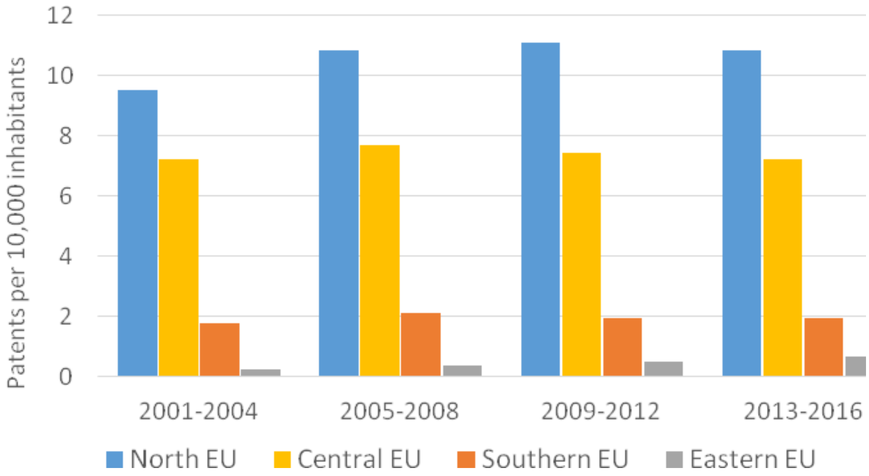


Note: Regions are split in five equally populated groups (quintiles, 20%) on the base of patent per capita growth comparing the 2001-2004 with the 2013-2016 period. **Source:** Authors' computations on Regpat 2019a and H2020 data.

However, a less static picture emerges when we look specifically at the rates of change over the 15 years considered. Map 2, reporting the rates of growth of the patent per capita index between the first and the last period, shows the presence of a catching up process in many traditionally backward regions. This is particularly the case of most East European regions as a result of a rapid integration of these regions into the capitalist intellectual property rights system and in the Central EU (Germany centred) production system. The apparently contrasting messages emerging from Maps 1 and 2 can be reconciled looking at Figure 1 showing the level and dynamics of the patent per capita index for the main EU macro-regional blocks. The figure shows the very low initial patent intensity of Eastern regions, which are closing the gap with Southern ones. The figure also confirms that regions in the North Europe and Nordic countries continue to be the technological core and engine of the EU.

Figure 1: Patent per capita across country group

Average patent per capita (weighted by population)



Source: Authors' computations on Regpat 2019a and H2020 data.

Technological polarization in the EU: a role for Horizon 2020?

To what extent could a policy instrument such as Horizon 2020 modify the regional distribution of regional technological capabilities, enlarging or contributing to closing the technological gaps shown in the previous section? Indeed, H2020 could act as a policy scheme favouring or mitigating technological polarization within the EU. While it is too early to directly assess the impact of H2020 on the technological trajectories of EU regions, in this section we will derive indirect evidence on this topic using data on the regional access to such program, and to some of its main funding schemes. In fact, H2020 is organized around different pillars and objectives, mapping into actions (the actual funding schemes) that are governed by specific rules, and that may have a differentiated distributional effect on EU organizations and the territories hosting them. Accordingly, In the next subsection, we describe the main features of the key actions of H2020, each one supporting different actors and phases of the research and innovation process and characterized by different potential effects on technological convergence and divergence in the EU; this will be functional to interpreting the macro-regional distribution of the different H2020 in the EU context and the results of the regression analysis aiming at shedding some light on the potential role played by the H2020 Programme in exacerbating or mitigating technological polarization within the EU.

The characteristics and logic of different H2020 funding schemes

Table 5 summarizes the main features of the four key funding schemes of H2020: the European Research Council (ERC), the Marie Skłodowska-Curie Actions (MSCA) the Research & innovation actions (RIA) and the Innovation actions (IA). All together these four actions account for about 80% of the total H2020 budget, almost 30% are channelled through the first two actions and more than 50% through RIA and IA actions.

The European Research Council is a relatively recent body within the EU research and innovation panorama. Established in 2007 with the FP7 (the 2007-2014 funding period), it was the first scheme allowing the support of research projects by single researchers or teams (European Commission, 2007) and for the first time we explore its impact at the regional level. Indeed, up to the FP7, collaboration among researchers/teams was the main purpose of the European Research and Innovation funds, with the idea of creating an integrated research space in the EU. The FP7 introduced the idea of scientific excellence and, under the H2020, the ERC was entitled with a budget of 13€ billion – about 18.7% of the overall budget - to foster frontier research within the pillar “Excellent Science”, which was not bound any more to the purpose of cohesion which, for other FP activities, implied also to generate collaborations in the same research projects across central and peripheral EU areas. The idea of excellence was translated in an evaluation of the programme based on the share of publications from ERC funded projects among the top 1% highly cited (European Commission, 2011b).

Table 5: An overview of the main H2020 actions

Action	Eligibility Criteria	Funding	Activities	Target	% of H2020 *(% in sample)*
European Research Council (ERC)	*Based on experience & scientific track record, which depend on the type of grant:* • *Starting* • *Consolidator* • *Advanced* • *Proof of concept* • *Synergy*	*EU funding rate 100%*	Funding researchers looking to set up or consolidate their own independent research team or programme, as well as to already established research leaders. The ERC awards funding for a period of up five or six years depending on the type of grant.	(frontier) Research	18.7% *(19.3%)*
Marie Skłodowska-Curie Actions (MSCA)	Single researchers (but involving two institutions) or research networks, depending on the action	*EU funding rate 100%*	They encourage mobility, collaboration and sharing of ideas between disciplines and back initiatives that break down barriers between academia, industry and business (a small share is dedicated to public with events that promote the value and beauty of science).	Mobility Collaboration Networking Dissemination	8.8% *(10.1%)*
Research & innovation actions (RIA)	At least 3 legal entities, independent of each other and established in different countries	*EU funding rate 100%*	Activities aiming to establish new knowledge and/or to explore the feasibility of a new or improved technology, product, process, service or solution.	Research Development	*(38.1%)*
Innovation actions (IA)	At least 3 legal entities, independent of each other and established in different countries	*EU funding rate 70% (non-profits funded 100%)*	Activities directly aiming at producing plans and arrangements or designs for new, altered or improved products, processes or services.	Research Development Pre-production	*(17.9%)*

Note: we report the actual shares only for ERC and MSCA, because for these funding schemes the correspondence between H2020 budget and structure is straightforward (see https://ec.europa.eu/research/participants/docs/h2020-funding-guide/grants/applying-for-funding/find-a-call/h2020-structure-and-budget_en.htm#SO_widen). We check for consistency comparing budget figures with allocation of funds across EU regions as reported in our sample. The 4 funding schemes reported in the table cover more than 80% of the in sample H2020 budget.

It is reasonable to expect that the emphasis on excellence of the ERC may render particularly difficult accessing these funds for regions less endowed of knowledge capabilities, while the lack of a collaborative design may also hinder the inclusion of and the diffusion of knowledge toward lagging regions. Therefore, the funding scheme is likely to be the least aligned to the goals of cohesion policies.

Also the MSCA operates under the pillar of “Excellence Science” to distribute highly competitive and prestigious research and innovation awards allowing for career development and further training of researchers at all career stages through mobility to a hosting institution. The probability for a university to host MSCA grantees significantly increases in relation to its research performance and international orientation, despite some top universities have so far hosted fewer grantees than expected (Falk and Hagsten, 2020). Moreover, the MSCA sustains the diffusion of knowledge toward a series of programmes supporting research networks, staff exchange, and the promotion of research results to the public. Similarly to the ERC, we can expect that the excellence goal of this policy scheme may favour better endowed regions; however, the collaborative setting of some parts of this fund and the declared objective of favouring knowledge diffusion may soften its possible contribution to knowledge polarization.

Finally, the RIA and IA support basic and applied research to foster the development of new knowledge addressing the so-called societal challenges with the former slightly more oriented toward the earliest phases of the research and development process.[4] However, for the evaluation of both types of actions patents were conceived as a (the) key performance indicator (European Commission, 2011), reflecting a possible bias toward technological innovation in the policy design.

While the ERC and MSCA strongly stress the concept of scientific excellence, the RIA and IA actions are competitive funds reflecting the original collaborative logic of the Framework Programmes. From the one hand, we should expect that the competitive logic of this funds is reflected in a higher capability of more endowed regions to access them. From the other hand, the collaborative logic aiming at integrating more peripherical regions to develop an integrated research area may act as a counterweight. Therefore, their role of RIA and IA in contributing or mitigating knowledge polarization is ex-ante more ambiguous.

To have a first glimpse of the role played by the H2020 and its main 4 funding schemes, we present in Table 6 the budget allocation of H2020 funds across the main EU country groups during the period 2015-19. The table provides a first indication of the possible role of such programmes with respect to the existing technological asymmetries (proxied by the shares of patents reported in the last column).

The distribution of H2020 budget across country groups does not match closely that of patents. Southern and Eastern EU countries receive a share of H2020 budget that is about twice than that of patents. In other words, these areas have access to a higher share of funds than those we would expect assuming that the competitive logic leads to a distribution of funds proportional to the regional knowledge capabilities.

Table 6: Shares of the H2020 budget and patents by country group

Group	H2020	ERC	MCSA	RIA	IA	Patents
North EU	9.1%	8.7%	9.9%	8.2%	8.9%	9.8%
Central EU	60.6%	74.1%	60.5%	60.5%	54.9%	76.2%
South EU	23.3%	13.8%	21.7%	25.1%	29.7%	10.8%
East EU	7.0%	3.4%	7.7%	6.0%	6.5%	3.1%
Total	100%	100%	100%	100%	100%	100.0%

[4] The H2020 is based on a challenge-based approach to bring together resources and knowledge across different fields, technologies and disciplines.

Note: H2020 funds refer to budget allocated between 2015 and 2019, for comparison purposes we also report the share of patents during the 2013-2016 (as in the last column of table 2).
Source: Authors' computations on Regpat 2019a and H2020 data.

Among the specific actions, the ERC is the only one that tends to replicate the technological asymmetries of European areas discussed above. In the regression analysis we will explore these relationships exploiting the regional level information.

Regional technological capabilities and access to H2020 funds. An econometric analysis

As we said, the descriptive statistics reported in Table 6 provide only first insights regarding the potential role played by the H2020 in reducing the level of technological asymmetries in the EU. In this section we try to assess such a role in a multivariate regression framework using the following specification:

$$\log(\boldsymbol{h}2020_{i,2015-2019} + 1) = \alpha + \beta \log(patents_{i,2010-2014} + 1) + controls + u_i \quad (1)$$

where i indicates a generic NUTS2 EU region. In other words, we estimate the logarithmic relationship between the H2020 funds received by a region and its technological capabilities observed before the starting of the H2020. Once assessed the relationship for the overall H2020, we explore possible specificities across the different funding schemes presented in the previous section.

We use a log-log specification to directly estimate the elasticity - the relationship between the percentage changes - of H2020 with respect to patents. Where the estimated β is equal to 1, then a 1% increase in the technological capabilities of a region is reflected in the same increase of H2020 funds. With $\beta > 1$ the H2020 would increase more than patents, (over)prizing regions endowed with more technological capabilities, thus pointing to a possible polarizing effect; for $\beta < 1$ the H2020 would instead show an equalizing effect of this policy programme, with higher technological capabilities matched by less than proportional increases of funds.

We enrich the basic specification with a series of controls to account for possibly confounding factors and correctly identify the relationship at stake. As we saw, country specificities matter in determining technological differences within the EU regions. We therefore include a list of dummy variables to control for country specific fixed effects. Moreover, we cluster the standard errors at the country level to account for the fact that regions from the same country cannot be considered as independent observations; errors are likely to be correlated for regions belonging to the same country. In this way we control for possible differences in the strength and quality of the national innovation systems in which regions are embedded, and that can have a role in determining the capacity of regions to access H2020 funds beside their pure technological capabilities. Once controlling for the fact that observations are clustered within countries, we are quite confident that the country fixed effects will reflect – at least to some extent - the "integration-collaborative logic" guiding most of the EU funding schemes.

To try to partial out the effects of regional characteristics not directly related to technological capabilities, we also include the logarithm of the regional GDP per capita to capture those factors contributing to the strength of the regional system beyond strict technological capabilities, such as the strength of the scientific infrastructure as well as the organizational capabilities or soft types of innovation, making them more resilient (Filippetti et al., 2020). Finally, we also include a dummy variable for capital regions to capture the fact that in many countries' capital regions outperform other areas from a scientific and innovative viewpoint (Paunov et al., 2019) and have been among the areas driving regional competitiveness in the EU (European Commission, 2017). The strong presence in these regions of public services and most national higher-level knowledge-based functions (Mayer et al., 2017) could again represent an important comparative advantage in the participation to EU S&T competitive policy schemes and more specifically to the access to H2020 funds.

For each region Patents and GDP per capita are averaged over the five years (2010-14) preceding the beginning of allocation of the H2020 funds (2015-19). We first run our set of regressions on the overall H2020 funds accessed by EU regions, and then test the full specification on the specific sub h2020 policy schemes (ERC, MSCA, RIA and IA) to explore possible specificities of the relationship between technological capabilities and access to funds.

Regression results

In Table 7 we report the results of our least square estimations. In the first column we report the estimation of equation 1, excluding the control variables (GDP per capita, capital region and country dummies). The coefficient attached to $patents$ is in this case significantly smaller than 1 (see also the results of the test reported in the middle of the table). This suggests that the capacity of regions to accessing H2020 increases less than proportionally with respect their technological capability, a result consistent with the descriptive statistics presented in Table 6 (section 6.1). However, this result also suggests that the H2020 "overprize" regions less endowed from a technological point of view, which would be contrary to the competitive logic of the program.

When including the country fixed effects, β turns out to be not statistically different from 1, a result more consistent with the idea that the EU distributes competitive research and innovation funds proportional to the knowledge capabilities of each EU region. The result holds true also when adding the GDP per capita which seems to have a positive effect on the capacity to access H2020 funds. Interestingly, when we control also for capital regions, the coefficient attached to GDP per capita is not statistically significant anymore. This implies that Capital regions have more "explanatory power" than (and capture the variance explained by) the overall quality of the regional production and innovation system proxied by the GDP per capital indicator; the presence of a critical mass of S&T and public infrastructures in regions hosting large capital urban areas may be among the reasons explaining this finding.

Table 7 – H2020 funds at regional level, OLS estimations

Dependent variable: Log of funds allocated 2015-2019 (versus 2010-2014 variables)

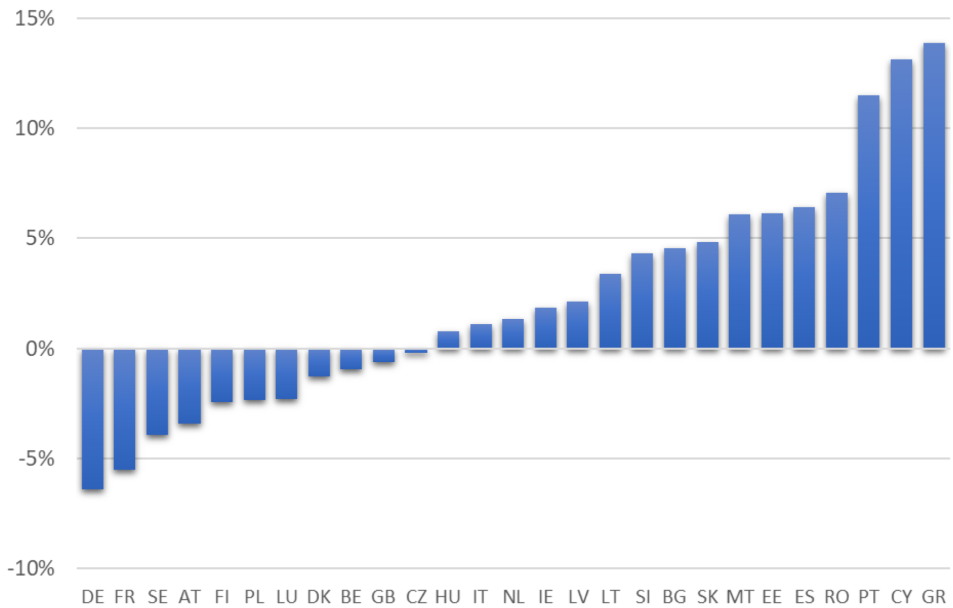
	(1)	(2)	(3)	(4)
Patents (log)	0.690***	1.060***	0.970***	0.946***
	(0.0951)	*(0.0580)*	*(0.0620)*	*(0.0593)*
GDP per capita (log)			0.760**	0.308

			(0.351)	*(0.354)*
Capital region				0.950***
				(0.231)
Country Fixed Effects	*No*	*Yes*	*Yes*	*Yes*
Constant	13.64***	11.50***	9.647***	11.11***
	(0.605)	(0.337)	(0.963)	(1.015)
Test beta patents = 1	0.003***	0.314	0.629	0.367
Observations	259	259	259	259
R-squared	0.525	0.740	0.750	0.763
F-stat	248.8	334	191.1	194.6
RMSE	1.189	0.927	0.912	0.889

Note: Standard errors clustered at country level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In there out of four specifications the t-tests does not reject the hypothesis of unitary elasticity of H2020 funds versus innovation capabilities of a region.

How to reconcile the unitary elasticity of H2020 funds to patents with the fact that the former seem to be less concentrated than the latter, favouring regions from Eastern and Southern countries (as shown in table 6)? The response to this question can be provided looking at the country fixed effects reported in Figure 2. The figure seems to confirm the presence of a rebalancing rational of H2020 with respect to the existing macro-regional technological asymmetries shown in previous sections. In fact, the figure shows that once controlling for their technological capabilities, regions in Nordic and Western countries tend to receive, on average, lower amounts of H2020 funds than regions located in Southern and Eastern countries. In particular, regions from Germany and France receive about 5% funds less with respect to the sample average. On the contrary, regions located in countries listed on the right part of the figure receive up to 10% or more than the sample average.

Figure 2: Country fixed from the estimation reported in Table 7 (col. 4)



Note: Country fixed effects from column 4 of table 7 are normalized by the sample average, they can be read as percentage national "premia" (or re-balancing mechanism) once accounting for technological and other capabilities.

All-in-all these results suggest that, while respecting a competitive (technologically based) logic, the H2020 funds have been able to not let behind regions located in least technological advanced countries. The objective to create an integrate research area through a collaborative design of the funding scheme may have helped balancing the distribution of funds, prevailing on the possible polarizing effect deriving from the existing asymmetries in the strength of the national innovation systems in which regions are embedded.

We have nonetheless argued that the different H2020 actions, given their different rational and targets, could differ in terms of their potential “polarizing” or “balancing” effects on the EU technological landscape. In order to explore this issue, we have replicated the estimation of equation 1 for the four H2020 main policy schemes (ERC, MSCA, RIA, IA). The results of these estimates are presented in table 8. The results, and in particular the different values of the beta coefficient, confirm the presence of differentiated effects of the four policy schemes.

For the two schemes operating under the scientific excellence pillar the coefficient attached to patents is statistically greater than 1. For ERC, the coefficient is particularly large, suggesting that an increase of the regional technological capabilities is matched by a threefold increase of funds’ availability. It is also worth noticing that the coefficient attached the capital cities is much large for the regression on ERC than for the other funds, suggesting that the focus on excellence may particularly favour capital urban areas. For the RIA and IA, the results are in line with the main regressions.[5]

[5] An inspection of the country fixed effects, not reported for reasons of space, reveals that for RIA and IA these match closely those reported in figure 2. Differently, the country fixed effects for ERC and MSCA does not show clear patterns. Finally, we should also point out that the number of regions accessing ERC funds in our sample is much lower than that accessing the other funds considered, further reinforcing the idea of a concentration of funds in the most technologically endowed regions.

Table 8 – Main H2020 actions allocation at regional level, OLS estimations

Dependent variable: Log of funds allocated 2015-2019 (versus 2010-2014 variables)

	ERC	MSCA	RIA	IA
Patents (log)	3.572***	1.613***	1.109***	0.944***
	(0.300)	*(0.219)*	*(0.170)*	*(0.126)*
GDP per capita (log)	-1.498	-0.929	0.563	0.582
	(1.715)	*(1.062)*	*(0.434)*	*(0.413)*
Capital region	3.629***	1.578**	0.917**	0.785***
	(1.207)	*(0.671)*	*(0.388)*	*(0.268)*
Country Fixed Effects	*Yes*	*Yes*	*Yes*	*Yes*
Constant	-5.110	7.924**	8.194***	8.432***
	(4.814)	(3.296)	(1.849)	(1.469)
Test beta patents = 1	0.000***	0.0097***	0.529	0.658
Observations	259	259	259	259
Adj. R-squared	0.501	0.333	0.563	0.518
RMSE	5.461	3.262	1.761	1.659

Note: Standard errors clustered at country level in parentheses *** p<0.01, ** p<0.05, * p<0.1. The t-tests strongly reject the hypothesis of unitary elasticity for the ERC and MSCA actions.

The inspection of the H2020-patent relationship across different funding schemes therefore provide evidence of a possible heterogeneous role of the different EU research and innovation schemes, and in particular of the main H2020 actions, with respect to regional convergence/polarization. Indeed, policy schemes aiming at prizing excellences (as in the case of the ERC action) seem to exacerbate the differences in the knowledge capabilities of regions and possibly contribute to the process of polarization between European regions.

Conclusions and policy implications: EU S&T policy and regional capabilities

The paper has confirmed that regional unbalances in technological capabilities in the EU are very severe. While some timid signs of convergence have occurred, the contribution of regions to the overall generation of new knowledge is very asymmetric. Eastern European countries, despite the attempt to be better integrated into the overall EU scientific and technological communities, have done small progresses in enhancing their own innovative capacity, indicating that the transition from planned to market economy, at least from a technological point of view, has been harder than expected. Southern European regions continue to be far away from the Northern Europeans and have accumulated delay in the aftermath of the 2008 crisis.

The empirical analysis we carried out using ANOVA has confirmed that these differences are due to both regional-specific and national-specific factors. This ratifies the view that it is important to act on both regional and national systems to upgrade the competences of specific geographical areas.

The major effort to reverse the inertial trend can be associated to both national and EU policies. In this paper we have assessed one policy instrument only, the H2020, in the hands of the EU, and not the effectiveness of national and local policies. We have also highlighted that the financial resources available under H2020 are rather small compared to the herculean objective of building a cohesive Europe, although its funding have a much greater strategic importance since it is project-specific and it is associated to a demanding evaluation process.

We have also argued that H2020 has a sort of impossible mission: on the one hand, it should foster the EU technological capabilities and areas of excellence vis-à-vis a fierce global competition with established nations such as the United States and Japan, and with emerging nations such as China and India. On the other hand, it should also increase EU cohesion by reducing technological disparities across its regions. The two objectives are somehow in conflict since the first may require a further agglomeration of competences in the already strongest areas to compete with Silicon Valley, Route 128, Toyota, Samsung town or Shenzhen, the second to nurture capabilities in the least developed regions.

It is true that H2020 it is one of the world largest public schemes supporting the development of new knowledge. But the yearly funds available through H2020 are comparable to what one of the top corporations spends in a year: while the year budget of H2020 is about 11 billion euros, large corporations such as Samsung (12.6 billion euros), Alphabet (12.5), Volkswagen (12.2), Microsoft (11.5) or Huawei (10.5) alone spend more or comparable amounts.

Our analysis suggests that H2020 has not managed, nor it could manage, to reverse the natural propensity towards the agglomeration of knowledge intensive activities carried out that occur in any customs union. But it has at least helped to contain a further increase in the gap, and it has sent a clear message to policy makers of the least developed regions: any attempt to enhance their own national capacity through endogenous effort would have found in the EC a constructive partner.

Our assessment suggests that, despite these difficulties, H2020 has supported activities in the areas of excellence, especially through the ERC, it has also managed to provide resources to the laggard regions, allowing them, especially thorough the IA e RIA pillars, to support their integration with the innovation systems of the strongest regions.

On the grounds of this evidence, we welcome the fact that the next Recovery Fund, which will imply that resources, including those devoted to science, technology and innovation, will be distributed and granted by national authorities, has not been funded by downsizing the next Framework Programme 2021-27, Horizon Europe. Still, we wonder if the resources available will be sufficient to satisfy the two main goals of fostering EU excellence in innovation and to help cohesion in science and technology. The fact that, in the past, the instrument has shown a certain efficacy in both respects may be a good reason to further increase its budget in the future.

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