CONTRIBUTI DI RICERCA CRENOS

UNIVERSITÀ DI CAGLIARI UNIVERSITÀ DI SASSARI
CENTRE FOR NORTH SOUTH ECONOMIC RESEARCH
CRENoS
CENTRO RICERCHE ECONOMICHE NORD SUD

RESEARCH INFRASTRUCTURES AND REGIONAL GROWTH: THE CASE OF EUROPE

Leonardo Vargiu
Bianca Biagi
Maria Giovanna Brandano
Paolo Postiglione

WORKING PAPERS

2023/14

arkadia

Centro Ricerche Economiche Nord Sud
(CRENoS)
Università di Cagliari
Università di Sassari

CRENOS was set up in 1993 with the purpose of organising the joint research effort of economists from the two Sardinian universities (Cagliari and Sassari) investigating dualism at the international and regional level. CRENoS' primary aim is to improve knowledge on the economic gap between areas and to provide useful information for policy intervention. Particular attention is paid to the role of institutions, technological progress and diffusion of innovation in the process of convergence or divergence between economic areas. To carry out its research, CRENoS collaborates with research centres and universities at both national and international level. The centre is also active in the field of scientific dissemination, organizing conferences and workshops along with other activities such as seminars and summer schools.
CRENoS creates and manages several databases of various socio-economic variables on Italy and Sardinia. At the local level, CRENoS promotes and participates to projects impacting on the most relevant issues in the Sardinian economy, such as tourism, environment, transports and macroeconomic forecasts.

www.crenos.unica.it
crenos@unica.it

CRENoS – Cagliari
Via San Giorgio 12, I-09124 Cagliari, Italia
tel. +39-070-6756397; fax +39-070- 6756402

CRENoS - Sassari
Via MURONI 25, I-07100 Sassari, Italia
tel. +39-079-213511

Title: RESEARCH INFRASTRUCTURES AND REGIONAL GROWTH: THE CASE OF EUROPE

Prima Edizione: Dicembre 2023
ISBN: 978 88 68514 907

Viale Bonaria 98 - 09125 Cagliari
Tel. 070/6848663 - info@arkadiaeditore.it
www.arkadiaeditore.it

Research Infrastructures and Regional Growth: the case of Europe

Leonardo Vargiu*
Gran Sasso Science Institute
Bianca Biagi
University of Sassari & CRENoS
Maria Giovanna Brandano
Gran Sasso Science Institute
Paolo Postiglione
University of Chieti-Pescara

Abstract

The last decades registered a significant increase in Research Infrastructures (RIs) everywhere and in Europe. The EU supports these projects and their activities by implementing strategies and allocating financial resources for these costly projects. Although RIs main goal is to foster science, they produce relevant effects that go beyond scientific output including economic output, innovation, and social impact. These effects take place simultaneously at different geographic levels: regional, national, and international. RIs' hosting regions absorb a significant part of them. This phenomenon is the object of a stream of literature that analyses the several effects that single RIs have on the economy and society. However, little attention is paid to the aggregate dimension of these effects at the regional level and how it changes in different regional contexts. This work contributes to the main literature on RIs socio-economic effects by disentangling the aggregate economic growth effect driven by RIs in EU NUTS 2 regions for two periods: 2001-2020 and 1981-2020. The empirical analysis is carried out on an original database with information about 667 RIs. A spatial Durbin model estimates both the direct impact and spatial spillovers. The main findings suggest that RIs have a positive impact on regional economic growth over the two periods considered. However, spillover effects to neighbouring regions are not significant.

Keywords: Research Infrastructures; Regional economic growth; Socio-economic effects, European Regions; Spatial analysis
JEL Classification: O47, C31, R10

---

* Corresponding author. Email: leonardo.vargiu@gssi.it

1 Introduction

Over the last decades, the number of Research Infrastructures (RIs) has grown significantly in various scientific fields, including genomics, astronomy, space exploration, high energy physics, the chemistry of new materials, bio-molecular engineering, and several other fields (Florio 2019). Europe registers a considerable increase in the construction of RIs across the continent. The EU Commission pays special attention to such phenomenon by implementing strategies and tools to provide Europe with world-class sustainable RIs. Supranational institutional bodies and legal frameworks, such as the European Strategic Forum for Research Infrastructures (ESFRI henceforth) and the European Research Infrastructures Consortium, support the development of national and pan-European strategic roadmaps to prioritise the projects to be realized (Beck & Charitos, 2021; Cramer et al., 2020; Florio, 2019; Hallonsten, 2020). Mainly two key aspects have driven this relevant growth. First, the fact that science advances fast and, consequently, more cutting-edge high-tech instruments and centres need to be developed to run new scientific experiments. Second, research and innovation often play a pivotal role in many institutions' development strategies and policies triggering economic growth (Beck & Charitos, 2021; Cramer et al., 2020; Florio & Sirtori, 2016a; Hallonsten, 2020). Moreover, the number of extensive research facilities is becoming more significant, as well as the extent of the investments required for such capital-intensive projects (Florio & Sirtori, 2016a). Most of the financial resources deployed to support the development of these facilities in all their phases – design, construction, and operation – are public. Thus, in most cases, the leading promoters are national governments, intergovernmental collaborations, and regional governments, which must decide, among multiple competing projects, whether to invest and the amount of resources to allocate. As in the case of any public investment, there must be some kind of priority in the allocation process of these resources. Governments at any level must justify any decision undertaken by taxpayers (Beck & Charitos, 2021; Cramer et al., 2020; Florio, 2019). A well-established way to prioritise and "justify" public policies and investments is to quantify the *ex-ante* and *ex-post* socio-economic impact related to the investment decisions, even if it is not the only aspect considered to take the final decision. Therefore, both the political need and the specific features of each RI have led many academics to study and assess the different socio-economic effects that these research projects involve at their various stages (OECD, 2019; Florio, 2019). So far, most contributions focus mainly on analysing the socio-economic effects of single case studies (Del Bo et al., 2016; Florio et al., 2015; Florio & Sirtori, 2016a, 2016c; Helmers & Overman, 2017; Robbiano, 2022) or on the drivers of single effects (Castelnovo et al., 2018; Castelnovo & Dal Molin, 2020; Dal Molin et al., 2023; Dal Molin & Previtali, 2019; Scaringella & Chanaron, 2016). Very little is known about the aggregate effect that the activities carried out at RIs produce on the hosting region's economies and how it varies in regions with different socio-economic structures, innovation capacities, and geographical contexts. Hence, this work aims to disentangle the regional aggregate effect that RIs produce on the economic growth of regions that host them and to assess their spillover effect. More precisely, the present work investigates the impact of RIs on regional economic growth on a sample of 230 EU NUTS 2 level regions of which 139 regions across 26[1] EU

[1] Austria; Belgium; Bulgaria; Cyprus; Czechia; Germany; Denmark; Estonia; Greece; Spain; Finland; France; Croatia; Hungary; Ireland; Italy; Lithuania; Luxembourg; Latvia; Malta; Netherlands; Poland;

member states host at least one RI. The overall endowment of the analysed sample of regions is 667 RIs. To take into consideration the enlargement of the EU during the period under analysis as well as to test if the results hold also in the very long run and to exploit the availability of data, the effect on economic growth is studied for two periods. The 2001-2020 period is for the whole sample and the 1981-2020 period is only for the 148 NUTS 2 regions of 10 EU-12[2] member states. This research builds upon and extends previous work in the field, while also introducing some novel contributions. First, it provides a comprehensive aggregate analysis of the RIs regional socio-economic impacts. Second, it employs an original dataset containing a large and representative sample of the whole universe of the RIs in the EU. Such dataset is an updated version so far used only by Del Bo (2016) to estimate the rate of return on investment of the EU RIs. Another novelty is the spatial model used to study the economic growth impact induced by RIs. Finally, the focus on the EU regions is unique to this work thus far and worth it to consider as claimed by Robbiano (2022).
The paper is structured as follows. Section 2 provides a review of the main literature on the socio-economic effects of RIs. Section 3 explains the process of the RI site selection and the main mechanisms through which they trigger regional economic growth. Section 4 describes the main data source and the data used in the empirical analysis. Section 5 provides a description of the methodology and section 6 shows the main results of the analysis. Finally, section 7 summarises the main preliminary findings.

2 Literature Review

The most recent literature on the socio-economic impacts of RIs mainly explores two significant aspects. On the one hand, the methodological assessment framework essentially investigates the types of impacts of RIs and the most suitable methodologies to disentangle those impacts better; on the other hand, the assessment of these effects provides an empirical analysis using quantitative and qualitative approaches. The following subsections present in detail the two strands of research.

2.1 Methodological contributions

Numerous works contribute to the categorization of the socio-economic impacts of RIs as well as to the identification of a common framework and methodology. In recent studies, there is a strong emphasis on the idea that the cost-benefit analysis is the most appropriate framework to overcome this issue and adapts well to different types of projects (Florio *et al.*, 2016; Clarke *et al.*, 2013; Pancotti *et al.*, 2015; Battistoni *et al.*, 2016; Florio and Sirtori, 2016b; Florio, 2019). This approach applies the standard evaluation way of capital-intensive projects to the specific case of research facilities. The general cost-benefit analysis framework is tailored taking into consideration the key features of the research infrastructures to quantify the net social and economic effect – expressed in monetary terms – that decision-makers need to

---

Portugal; Romania; Sweden; Slovenia. Slovakia is not included because we do not have data on Slovakian RIs.

[2] Belgium; Denmark; France; Germany; Greece; Ireland; Italy; Netherlands; Portugal; Spain. Luxembourg and the UK are excluded for a lack of regional data availability for the whole timespan considered.

know when they have to consider investing in a specific project (Florio & Sirtori, 2016c). To this end, both the economic and social dimensions are regarded by these approaches in the design of the evaluation framework. The economic impacts are less challenging to evaluate, and the methodologies are well established. The social impacts, on the contrary, are complex to estimate because of their unique nature and the difficulty of measuring them in monetary terms (OECD, 2019; Del Bo, Florio, and Forte, 2016; Florio, 2019). The first ones are estimated by computing the direct, indirect, and induced effects deriving from the financial information on the initial investment and the annual budget to run the RI activities. The social effects are, in most cases, characterized by the intangibility of their outputs, and the consequent difficulties in measuring them in economic terms have led to applying methods that capture their shadow prices (Florio *et al.*, 2016; Florio and Sirtori, 2016b). However, social effects are significant, as proved by recent contributions that further investigate the measurement methodologies of social costs and benefits (Florio & Sirtori, 2016b) and propose a social cost-benefit framework (Florio & Pancotti, 2020).

Other contributions provide alternative guide frameworks mainly based on identifying and categorizing the critical socio-economic impacts and the related indicators to assess them (OECD, 2019; Horlings *et al.*, 2012; Simmonds *et al.*, 2013; Cebr, 2019; Drooge and Elzakker, 2019). These authors propose a review and list of the critical impacts accruing from RIs construction and operating activities. This approach differs from the first because of the absence of costs in the analysis and framework. It solely refers to the sources of impacts and the related indicators to evaluate (OECD, 2019; Simmonds *et al.*, 2013). Both frameworks identify the same sources of effects and the related assessment methodologies. The economic impacts are studied in terms of direct, indirect, and induced effects that are expressed as an increase in economic output, value-added, and employment (Florio *et al.*, 2016; OECD, 2019; Simmonds *et al.*, 2013; Scaringella and Chanaron, 2016; Cebr, 2019). Due to their intangible nature, the social impacts are either expressed in monetary terms when quantitative estimates of the shadow prices can be applied or otherwise qualitative. They mainly refer to effects related to the scientific or knowledge creation and dissemination, innovation and technological development, human capital creation, social capital creation, and the area attractiveness for tourism (OECD, 2019; Simmonds *et al.*, 2013; Florio and Sirtori, 2016b; Florio and Pancotti, 2020).

2.2 Empirical contributions

Applied contributions utilize the frameworks mentioned above to assess and quantify the socio-economic impact that RIs can generate. These works provide evidence by carrying out single case studies of relevant existing research facilities (Atzeni et al., 2020; Florio et al., 2015, 2018; Helmers & Overman, 2017; Robbiano, 2022; Scaringella & Chanaron, 2016) or studying specific effects (Dal Molin & Previtali, 2019; Florio et al., 2018). Overall, it emerges that the type of impact varies according to the kind of scientific research activities carried out at the RI. However, the estimates of these effects show a common trend. More precisely, the social cost-benefit analysis proves that with a probability of about 92%, RIs produce a significant net contribution to society's welfare (Florio, Forte, and Sirtori, 2015; Pancotti *et al.*, 2015) that is driven by the economic impact, the technological spillovers, the creation of spinoff companies, the production of scientific outputs, the human capital development and the cultural effects related to the facility visits of young students and the general public. These sources of impact result also pivotal in other case studies that do not use the cost-benefit approach and assess them qualitatively by reviewing the central theoretical literature or taking interviews (COST, 2010; OECD, 2014; Simmonds et al., 2013; Zuijdam et al., 2011). One effect that emerges as relevant is industrial innovation driven by the technological transfer to RIs high-tech suppliers (Autio, 2014; Autio et al., 2004). Procurement collaborations between RIs and high-tech companies trigger learning-by-doing opportunities that induce more significant R&D efforts and innovative capacity, increasing the firm's productivity and profitability (Castelnovo & Dal Molin, 2020; Dal Molin & Previtali, 2019; Vuola & Hameri, 2006). However, this theoretical and empirical literature lacks an analysis of the aggregate level of the long-term regional macroeconomic effects driven by the presence of such facilities. The above-mentioned socio-economic impacts have a relevant overall impact on the economy of the hosting region that triggers economic growth. RIs, as in the case of higher education institutions, may result beneficial for regional economic performance by promoting regional innovation and development (Huggins & Johnston, 2009; Huggins & Kitagawa, 2009; Veugelers & Del Rey, 2014) and by contributing to increase the regional stock of high human capital asset (Abel & Deitz, 2012; Moretti, 2004). There is also a gap concerning the regional geographical implications. The regional overall economic effect produced by RIs socio-economic impacts may have a different marginal economic effect in regions with varying levels of development or geographical context. So far, the first gap is partially addressed by the work of Del Bo (2016), which provides a preliminary analysis of the returns to R&D investments in significant RIs in Europe. An aggregate study of the long-term effect is carried out on two measures: cost-effectiveness ratio and the citations of scientific publications produced within the RIs. They capture the return on investment in economic and knowledge creation terms, respectively. Overall, the return is higher the more extended the RI lifecycle is, suggesting that RIs with more extended duration experience some economies of scale (Del Bo, 2016).The dataset used contains information on all European RIs, and it is a previous version of the one employed in our study. However, the regional dimension and the geographical implications are not considered. The second gap is also partially addressed by the work of Robbiano (2022). The regional level economic growth impact is estimated for one public funded research institution (the Italian Institute of Technology) of which RIs are one specific type (See Llanos-Paredes, 2023). Results suggest that the GDP per capita of the hosting region is positively affected by the location of the Italian Institute of Technology (Robbiano, 2022).

This work contributes to the existing literature in two main ways. First, it offers a first attempt to study the RIs socio-economic effect at the aggregate regional level. Secondly, it evaluates the impact of RIs on the economic growth of the EU regions where they operate and how this effect varies according to different regional contexts. To do so, an original dataset that collects information on 667 RIs built-in between 1900-2019 in 148 EU NUTS 2 regions is combined with data from different sources. Data on RIs is provided by the Mapping of the European Research Infrastructures Landscape portal (MERIL henceforth). Data on growth, socio-economic conditions, innovation and geographical statistics are provided by Eurostat and OECD.

3 RIs' location choice and regional economic growth mechanism

3.1 Site selection process

RIs are projects whose design and development require a significant amount of time and coordinated work of experts in different fields. In recent years, roadmaps have gained popularity to facilitate their design and their development process. These are long-term strategic plans elaborated jointly by two main actors, namely the scientific community and the governmental authorities. Scientists' role mainly involves the organisation of bottom-up consultations required to choose among competing choices as well as the development and support with solid evidence of the scientific case for which the RI is built for. More precisely, they are asked to prove the scientific excellence and relevance, the socio-economic impact, the user strategy and access policy, and the e-needs (ESFRI, 2019). Policymakers oversee non-scientific relevant aspects such as political and societal goals, national and/or regional development goals, and links to innovation, economic competitiveness, technology development and job creation. As such, roadmaps are characterized by well-defined explicitly stated contexts, goals, procedures, and outcomes. Their purposes include the willingness to improve the policy-making process by avoiding lobbying of scientific communities, the participation in the general debate about future RIs, and the identification of projects, precisely to implement by reflecting the consensus of both policy makers and scientific communities (OECD, 2014).

In the EU context, new RIs projects are identified through two main types of roadmaps, European and national[3]. The former ones are developed by the ESFRI which is established to develop strategic roadmaps to prioritise RIs of pan-European relevance for the next 10-20 years. Most of these RIs, due to the relevance of their scientific case as well as their physical size, are supported and developed by more than one EU member state. This roadmap is updated on average every two years to include new RIs projects and to amend the status of those already on the previous roadmaps list. The ESFRI also encourages and supports EU member states in the development of national roadmaps. These include RIs that are strategic for single member states and enable countries to set priorities and to earmark funds for both national and pan-European RIs. National roadmaps are required to be linked to the regional Smart Specialisation Strategies (S3) as a pre-condition to the use of European Structural and Investment Funds. Within the roadmap development process, either European or national, the site (in some cases more than one) is selected following a step-by-step process. The selection process consists of two stages through which the competing sites are ranked. The first one is the site characterization, which implies mainly scientific analyses of the sites to verify to what extent the minimum requirements of the scientific case are met by each site. This phase is quite relevant for RIs whose activities' success is site dependent. For instance, the geophysics characteristics of the site are pivotal for underground RIs or sky clarity in the case of astronomical observatories. Once the scientific quality requirements of the competing sites are met, the final decision is taken by considering several key requirements of the sites that are of political relevance. They include 1) the presence of a strong and recognised scientific community in the field of the RI; 2) a relevant availability of financial resources to cover the construction and operating phases; 3) the quality of the organisational structure, and the scientific, technical and managerial leadership; 4) the capability of building an integrated system

[3] https://www.esfri.eu/esfri-roadmap

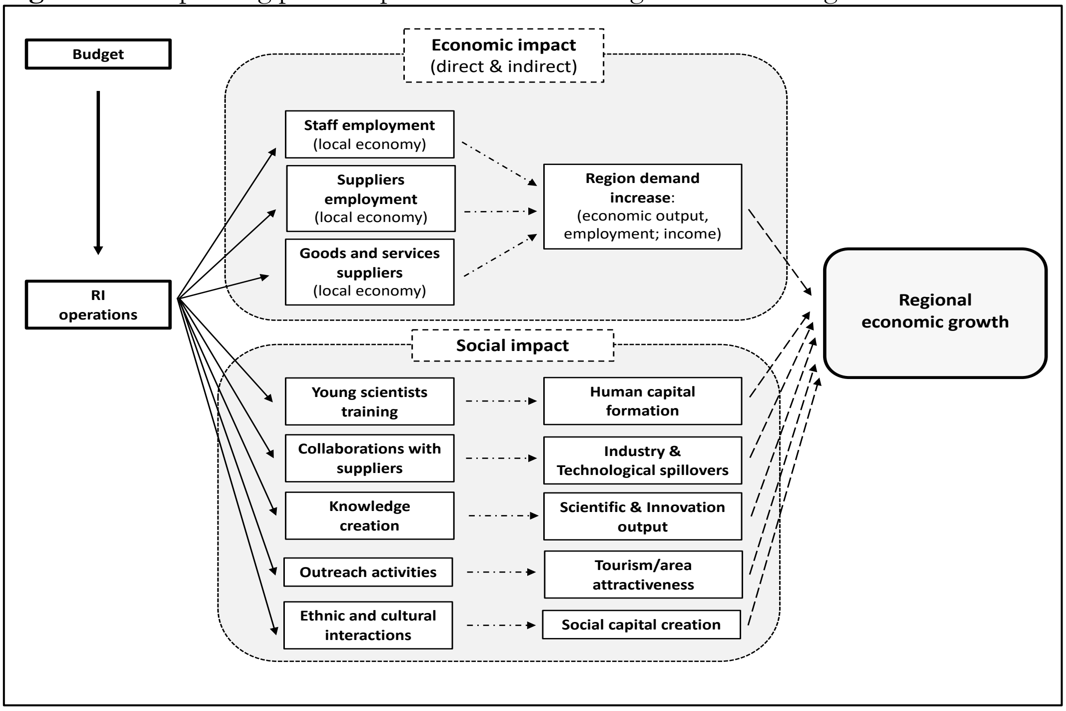
in support of firms, with other local and non-local actors such as research institutes, universities, governments and other public intuitions; and 5) the capability to build international partnerships [4]. Since there is not any official document that rules the site selection process, the RI supporting community – scientists, experts, and policy makers – defines their inner organisational structure and the rules of the game to take the final decision. Therefore, the RI hosting site is selected through the agreement of opposing site supporting communities in which the main role is played by the political aspects mentioned and the policy makers that fund the project. Such a political bargaining process acts as an exogenous policy change useful to understand the impacts of public funded research institutions, like RIs, on hosting regions (Robbiano, 2022).

3.2 Mechanism of RIs' impact on regional economic growth

Once the construction phase is concluded and the RI starts to be operational, the activities carried out at the facility generate, as reported in section 2, several sources of socio-economic benefits at different geographical levels: local/regional, national, and global. Their overall aggregate local/regional portion is quite significant and leads to an increase in the economic growth of the hosting region. Figure 1 schematizes the mechanism through which the RIs operating activities yield different kinds of sources of effects to the regional economy and society and how they trigger economic growth. Every year an annual budget is allocated to remunerate and acquire the inputs needed to run the RI activities and precisely: the workforce including administration staff, researchers, technologists, engineers, trainees and so on; and goods and services provided by suppliers such as the software and equipment to run experiments, utilities, maintenance, canteen, and cleaning services et cetera. These expenditures produce distinct positive effects on the society and economy of the RI surrounding area, as well as the hosting region, country, and abroad. Although these facilities are often characterised by the national and global relevance of their scientific and innovation outcomes, the hosting region absorbs a significant part of these effects. The main reason is that a large part of the inputs procurement and more in general the activities carried, involve both local and regional actors including firms, universities, and other public and private research institutions (OECD, 2019; Simmonds *et al.*, 2013; Scaringella and Chanaron, 2016; Florio *et al.*, 2018).

[4] https://www.esfri.eu/esfri-roadmap

Figure 1. RIs operating phase impact mechanism on regional economic growth



Source: authors' elaboration

In general, two broad classes of sources of impact are identified according to the literature mentioned in Section 2, namely the economic impact and the social impact. Sources that belong to the first class are those characterised by a more direct effect in economic terms, such as the increase in employment related to the RI staff and suppliers, and the RI-driven increase in demand for goods and services. These trigger an overall demand increase – RI expenditure, employees' consumption, suppliers' expenditures, suppliers employee's consumption, and so on – increase that affects the whole regional supplying chain through a ripple effect explained with the Keynesian multiplier (OECD, 2019; Simmonds *et al.*, 2013; Scaringella and Chanaron, 2016; Florio, 2019). The outcome is an increase in the region's economic performance in terms of economic output, value added, income and employment. The social impact is yield by distinct effects whose source and outcome are less and indirectly linked to the economic effect. However, they are quite relevant to enhance the performance of an economy. As reported in Figure 1 five main sources generate social impacts:

I. Young scientists training;
II. Collaborations with suppliers;
III. Knowledge creation;
IV. Outreach activities;
V. Ethnic and cultural interactions.

RIs operate as hubs of talent by attracting graduate and doctoral students, postdoctoral fellows, trainees, and young scientists in general from the regional universities as well as from other regions and countries. They gain precious experience by working in a vibrant environment to solve challenging problems with experts in the field. The influence on their skills and knowledge is significant as well as the effect on their career (Florio, 2019). An emblematic example is that reported by Giacomelli (2019) of CERN Alumni survey (2018), young students and researchers that gained work experience at CERN facilities find occupations in several private sectors domains, apart from academia, such as information technology, telecommunications, engineering, electronics, energy, health, consulting and so on. The related social effect is the enhancement of human capital quality both within and outside the region. The third and fourth sources of effects concern the knowledge creation and dissemination processes that take place during RIs operations including research experiments and technological development. Two main kinds of knowledge accrue from these operations, codified knowledge, and tacit knowledge or knowledge spillovers. Codified knowledge is the main output of RIs which mainly refers to scientific knowledge through articles and reports, but also patents and licences (Florio & Sirtori, 2016a; Helmers & Overman, 2017). The two corresponding social effects of these forms of codified knowledge are the one to science and scientists by allowing science advancement and scientists' publications and careers; and the one to technological and industrial innovation triggered by the discoveries codified through scientific articles, patents, and licenses. The innovation effect accrues also from the second type of knowledge mentioned above. Codified forms of knowledge cannot avoid it to spill over from scientist to scientist, or from scientists to firms when interactions between these two parts happen. Tacit knowledge and knowledge spillovers produce positive externalities to firms and industries named technological transfer. This is defined as the movement that occurs both formally and informally of know-how, skills, technical knowledge, or technology from one organizational setting to another generating economic value and industry development (Zuniga, 2013). In the case of RIs, such effect goes beyond technology by fostering research and development management, organization practice, project accounting, commercialization techniques, etc. The channels through which it takes place include joint research projects between RIs and industry, contractual relations (consultancy, certification services, technology licensing to established firms, start-ups, spin-offs, and so on) (Florio, 2019). As mentioned in Section 2, an important mechanism of knowledge spillover is public procurement for innovation. RIs often collaborate with high-tech firms to develop new technologies and find solutions to equipment problems that are required during scientific experiments. This collaboration between scientists and firms gives the opportunity to RIs suppliers, as well as second-tier suppliers, to acquire precious knowledge that leads firms to increase their R&D efforts and innovative capacity and consequently their productivity and profitability (Castelnovo & Dal Molin, 2020; Dal Molin & Previtali, 2019; Vuola & Hameri, 2006). Outreach activities are another source of social impact. They include all initiatives whose main goal is to communicate, to the general public, the RI mission and achievements of research activities and projects such as seminars, open days, schools and public visits. RI facilities often have a visitors' venue with permanent exhibitions as well as a calendar of guided tours and public events. In addition, RIs disseminate their work and outcome through newspapers, magazines, television, and radio broadcasting as well as through social media. These communication strategies reach a large audience regardless of the background. The consequent social outcome, besides knowledge dissemination, is the increase in the attractiveness of the area in relation to the science tourism generated by the RI (OECD, 2019). Certainly, on-site visits and events involve smaller numbers of visitors compared to mass and social media, but they are able to increase the annual flow of visitors by some thousands to the local area and region even in the case of less known RIs (Florio, 2019). Finally, RIs attract to the surrounding area and region high-quality personnel – that move permanently or for a short period – possibly from other regions or abroad, with different cultures and religions. The interactions between them and the local community and cultural environment contribute to building a cosmopolitan community that is beneficial for many aspects identified as drivers of social capital increase (Beck & Charitos, 2021; Florio, 2019; Simmonds et al., 2013). Social capital refers to a wide range of social activities and connections – understandings, customs and informal rules – between individuals and groups or other entities, as well as shared norms and values that facilitate economic actors, and individuals in general, to trust each other and work together more efficiently and pursue shared objectives (Putnam, 2000; Leonardi, Nanetti and Putnam, 2001; OECD, 2001).

These six main effects – economic and social – are channels of regional economic growth. The increase in demand is a determinant of economic growth as explained in the Keynesian growth model (North, 1955). The presence of high human capital assets is associated with higher regional economic growth because it is more productive and it generates positive spillovers on peers that foster innovation and growth (Abel & Deitz, 2012; Faggian et al., 2019; Moretti, 2004). The nexus between knowledge spillovers, innovation and regional economic growth is also proven to be positive (Crescenzi & Rodríguez-Pose, 2011; Malecki, 2018; Rodríguez-Pose & Crescenzi, 2008; Rodríguez-Pose & Villarreal Peralta, 2015). The relationship between tourism and growth is also positive (For a complete literature review on this topis see: Brida, Cortes-Jimenez, and Pulina 2016). Finally, there is also evidence that social capital works as a catalyst for local and regional growth (Beugelsdijk & Smulders, 2009; Egeln et al., 2004; Rodríguez-Pose, 1999).

4 Data

4.1 RIs data

Data on the European RIs come from the MERIL[5] online platform. This platform is the outcome of a project that started in 2010 and was supported by the European Commission under the Framework Programme 7. It also receives funding from the European Union's Horizon 2020 research and innovation programme, and it is coordinated by the European Science Foundation (ESF)[6], which is also in charge of data collection, management, and project communication. The platform provides access to a database that stores information about openly accessible RIs in Europe, across all scientific domains, including the social sciences and humanities. The database includes a list of identified, eligible RIs, and a set of data for each individual RI, collected and displayed in a standardised way. Precisely, MERIL contains information on about 1,042 European RIs. These include research facilities that differ considerably one from the other. For instance, it includes large facilities with high

[5] https://portal.meril.eu/meril/

[6] https://www.esf.org/

technological content such as radio telescopes or particle accelerators as well as data archives and museums. This information is gathered in a standardised format through a questionnaire voluntarily completed by the coordinators and staff of the Research Infrastructures (RIs) who chose to participate in the portal and publish their details. The questionnaire is built on three main sections: the core data; the additional data; and the advanced data. The first module encompasses essential identification details pertaining to the RI and its hosting organization. It includes contact information, localization details, as well as a concise description of the scientific objectives and the range of services provided. The set of data within this section is compulsory, it needs to be complete for the RI entry to be published and thus visible on the public portal. The second module is non-compulsory and includes information on the networks, access, users, and ESFRI projects. Also, the third section is non-compulsory. The data collected within this module concern information that can be used for impact assessment and evaluation purposes such as employment, training, services, publications, patents, technological transfer, start-ups, and costs and funding. However, it is worth noting that the majority of RIs have provided limited information in the second and third sections, resulting in a lack of statistical representativeness in many cases. Consequently, a significant portion of the data utilized in our analysis primarily pertains to the core data section. The present analysis focuses on 667 RIs of which MERIL provides information on their localisation that allows retrieving the respective NUTS 2 region.

Table 1 provides a concise overview of the primary characteristics of RIs. Among the total of 667 RIs, 34 are recognized as ESFRI projects, denoting their pan-European significance in terms of scientific relevance and scale. Out of the 612 RIs for which information is available, they can be classified into four main types:

I. Single sited centres with a single location, comprising 396 RIs (59.4%);

II. Distributed centres with multiple sites, accounting for 126 RIs (18.9%);

III. Mobile research facilities that are not stationary, such as vessels or satellites, totalling 9 RIs (1.4%);

IV. Virtual research facilities with a virtual dimension, such as data archives, encompassing 81 RIs (12.2%).

These facilities conduct research activities in different scientific domains and often one RI operates in more fields. 645 RIs have provided information about the scientific fields of their research activities. According to the scientific domain stated as first by each RIs, three domains out of eight register the highest share. These are biological and medical sciences (23%); physics, astronomy, astrophysics, and mathematics (17.3%); earth and environmental sciences (14.4%). The rest of the shares range between 5% and 10%, chemistry and material sciences (10%), engineering and energy (9.8%); information science and technology (8%); humanities and arts (6.5%); and social sciences (8%). However, a large part of the sample (40.6%) is multidisciplinary in its research activities.

Table 1. RIs features

RI feature	Frequency	Percentage	Data availability
ESFRI projects	34	5.1%	complete
RI type:			on 612 RIs
Single-sited	396	59.4%	
Distributed	126	18.9%	
Mobile	9	1.4%	
Virtual	81	12.2%	
Scientific domain			on 645 RIs
Inf. sciences & Tech	53	8%	
Bio. & Med sciences	153	23%	
Earth & Environ. sciences	96	14.4%	
Phy., Astroph. & Math	115	17.3%	
Chem. & mat. sciences	67	10%	
Eng. & Energy	65	9.8%	
Social Sciences	53	8%	
Hum. & Arts	43	6.5%	
Multidisciplinary	271	40.6%	on 649 RIs

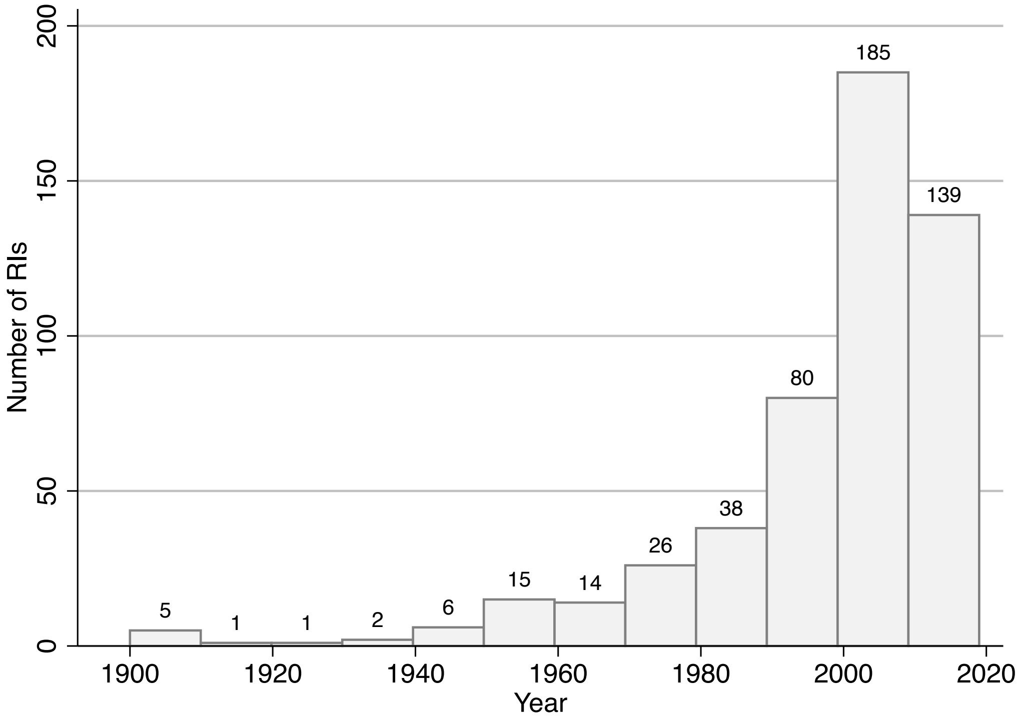
Source: authors' elaboration on MERIL's portal data

As Figure 2 shows, the majority started their operating phase during the second half of the twentieth century to date. Particularly, the last three decades registered an exponential increase in the number of operating RIs across Europe with 404 new centres being operative out of the 513 for which the operational phase status year is available.

Table 2 shows how the allocation of RIs endowment varies across 26 different EU member states under analysis. A notable observation is that a significant 51.3% of these RIs are concentrated within just six countries. Specifically, these countries are Germany (17.1%), Netherlands (9.0%), Spain (8.2%), France[7] (7.0%), Belgium (5.3%), and Italy (4.7%). The shares of RIs hosted by the remaining 20 countries vary from 4% (Czechia, Finland, Ireland, and Portugal) to less than 1% (Poland and Bulgaria).

[7] 45 RIs operating in the Ile de France region are not considered since it is an outlier.

Figure 2. Operating RIs timespan distribution



Source: authors' elaboration on MERIL's portal data

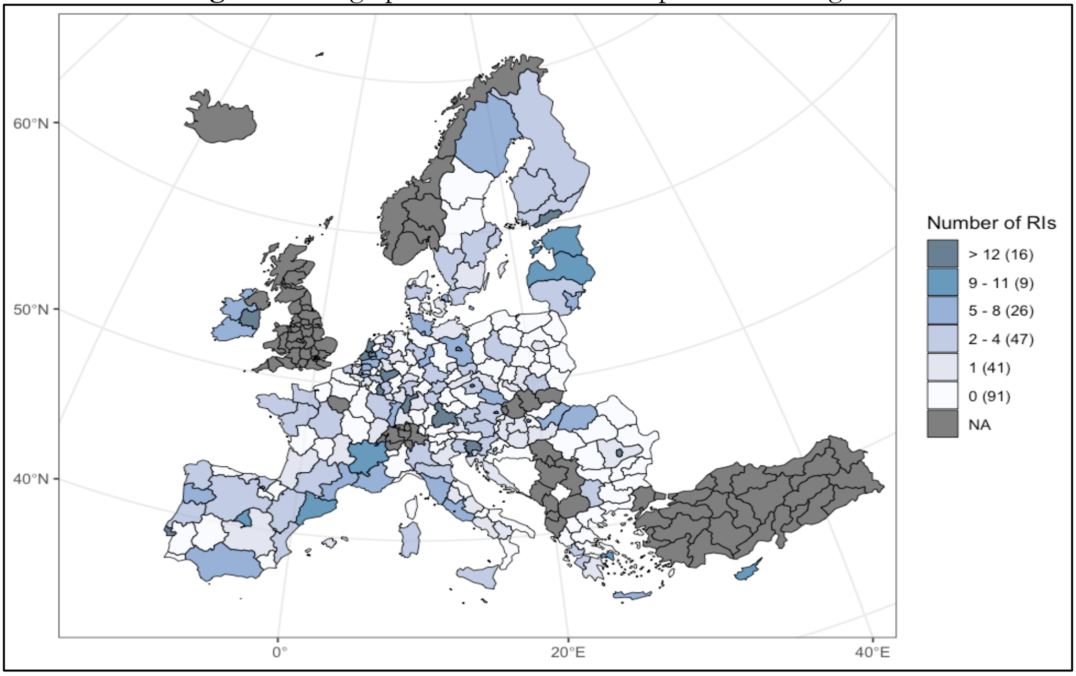
Table 2. RIs' distribution across EU countries

Country	Frequency	Percentage	Country	Frequency	Percentage
Austria	24	3.6	Ireland	35	4.1
Belgium	35	5.3	Italy	31	4.7
Bulgaria	4	0.6	Latvia	9	1.4
Croatia	7	1.0	Lithuania	9	1.4
Cyprus	12	1.8	Luxembourg	15	2.2
Czechia	28	4.2	Malta	1	0.2
Denmark	8	1.2	Netherlands	61	9.0
Estonia	9	1.3	Poland	6	0.9
Finland	27	4.0	Portugal	29	4.3
France	46	7.0	Romania	24	3.6
Germany	114	17.1	Slovenia	20	3.0
Greece	19	2.8	Spain	55	8.2
Hungary	22	3.3	Sweden	17	2.5
			Total	**667**	**100**

Source: authors' elaboration on MERIL's portal data

Figure 3 shows how the concentration of operating RIs varies across the NUTS 2 regions of the 26 EU countries. Out of 230 regions, 139 host the 667 RIs. The highest level of endowment is registered in 16 regions that host more than 12 and up to 21 RIs. 35 regions register a high level of endowment of between 5 and 11 RIs. Finally, more than half of the overall regions which host RIs have a low level of endowment (between one and 4 RIs). Precisely, 41 regions have only one RI and 47 have between 2 and 4 RIs.

Figure 3. Geographic distribution of RIs per NUTS 2 region



Source: authors' elaboration on MERIL's portal data

4.2 Other variables

As mentioned above, this work focuses on the economic growth effect driven by RIs in EU NUTS 2 regions for two different periods: 2001-2020 and 1981-2020. The first period analysed considers 230 NUTS 2 regions of 26[8] EU member states while the second examines 148 NUTS 2 regions of 10 states among the first EU-12[9] members states. This differentiation enables to take into account the enlargement process of the EU over the overall timespan considered (1981-2020) and thus test if the impact magnitude varies between the two groups of regions. It also facilitates testing the durability of the results over the 40-year term while capitalizing on the availability of data. Therefore, the analysis employs two cross-sectional

[8] See footnote 1 for the complete list of these countries.
[9] See footnote 2 for the complete list of these countries.

datasets whose variables are summarised in Tables 3 and 4. The information on the regions RIs endowment is combined with regional socio-economic statistics available on Eurostat and OECD databases. The dependent variable, which measures the regional economic growth, is the growth in GDP per capita in purchasing power standard (PPS). For the EU26 regions, the measurement covers the period from 2001 to 2020, while for the EU-12 regions, it spans from 1981 to 2020. In addition to the dependent variable, two relevant explanatory variables are taken into consideration: the endowment of RIs and their age. The first one refers to the number of operating RIs in the region and the second one it is the average age of the operating RIs in a same region. Regions are then compared in terms of their socio-economic and innovative structure at the base year of the two periods analysed, respectively 2000 and 1980. Population proxies the size of the region and its economy. Regions' innovation capacity is proxied by the stock of patents filed[10]. GDP per capita in PPS is a measure of the initial level of development. Physical capital measures the extent of physical capital endowment and the corresponding investments made.[11] Finally, the level and quality of human capital is proxied by the share of labour force with tertiary education. Note that, in the analysis, we consider the natural logarithm of the independent variables.

Table 3. Variables descriptive statistics. EU26 regions

Variable	Obs	Mean	Std. Dev.	Min	Max
GDP growth 2001-20	230	0.03	0.02	-0.01	0.07
Log RIs endowment	230	0.89	0.91	0.00	3.09
Log RIs endow. avg. age	230	1.85	1.55	0.00	4.56
Log population	230	14.10	0.82	10.15	16.00
Log innovativeness	230	0.0007	0.0009	2.90e-6	0.005
Log GDP per capita	230	9.67	0.51	8.12	10.77
Log of physical capital	230	0.03	0.014	0.004	0.13
Log human capital	230	0.15	0.06	0.05	0.36

Source: authors' elaboration

[10] The stock of patents is estimated using the Perpetual Inventory Method with 1977 as base year.
[11] The physical capital stock is estimated using the Perpetual Inventory Method with 1980 as base year.

Table 4. Variables descriptive statistics. EU-12 regions

Variable	Obs	Mean	Std. Dev.	Min	Max
GDP growth 1981-20	148	0.04	0.18	-0.01	0.07
Log RIs endowment	148	0.92	0.90	0.00	3.09
Log RIs endow. avg. age	148	1.95	1.56	0.00	4.22
Log population	148	14.07	0.89	11.63	16.00
Log innovativeness	148	0.00006	0.001	8.73e-07	0.0005
Log GDP per capita	148	8.63	0.60	7.38	10.08
Log of physical capital	148	0.02	0.017	0.004	0.13
Log human capital	148	0.15	0.06	0.05	0.36

Source: authors' elaboration on MERIL's portal data

5 Empirical Strategy

To verify the role of regions RIs endowment and its age on regional economic growth and the extent of the direct and indirect effects across regions, we employ a Spatial Durbin Model as in other contributions on regional economic growth (see Ertur and Koch, 2007). Using such a model rather than another spatial specification, is supported by some theoretical motivations. It produces unbiased coefficient estimates even if the true spatial data-generating process is a spatial lag or spatial error model. Moreover, in the SDM specification, no restrictions are imposed on the ratio between indirect and direct effects. The direct effect is the impact of a change in an explanatory variable in a particular region on the dependent variable of the same region. The indirect, or spillover effect, is the impact of a change in an explanatory variable in a particular region on the dependent variable of another region (Elhorst, 2010, 2014; LeSage and Fischer, 2008). Hence, we specify the model as follows:

$$Y_i = \beta_0 + \sum_{k=1}^{p} \beta_k x_{ik} + \rho \sum_{j=1}^{n} w_{ij} Y_j + \sum_{k=1}^{p} \sum_{j=1}^{n} \theta_k w_{ij} x_{jk} + \varepsilon_i \qquad (1)$$

where $i = 1, \dots, n$ denotes the 230 regions of the 26 Member States of the European Union at NUTS 2 level or the 148 regions of the 12 Member States of the European Union at NUTS 2 level; Y is the dependent variable defined as the average GDP per capita growth of the i^{th} region over the period 2001-2020 for EU26 regions and over the period 1981-2020 for EU-12 regions; W is the row-standardised k-nearest neighbours spatial weights matrix (with $k = 10$)[12]; ρ is the spatial autocorrelation parameter, which measures the intensity of spatial dependence; X is a vector of covariates for region i including:

[12] We set k=10 as in Postiglione, Andreano, and Benedetti. 2013 and Le Gallo and Dell'Erba 2006 to allow regions that are islands being connected to other regions which would not be possible only with simple binary contiguity.

I. The relevant variables:

$RIs\ endowment$ is the logarithm of the number of operating RIs in the region

$RIs\ endowment\ age$ is the logarithm of the average age of the number of operating RIs in the region

II. The control variables:

- The logarithm of the population of region i at the base year of the two periods (2000 and 1980)
- The logarithm of the stock patents filed in region i at the base year of the two periods (2000 and 1980)
- The logarithm of the GDP per capita of region i at the base year of the two periods (2000 and 1980)
- The logarithm of the stock physical capital of region i at the base year of the two periods (2000 and 1980)
- The logarithm of the share of the labour force with tertiary education of region i at the base year of the two periods (2000 and 1980).

Such specification draws on the regional growth and β-convergence growth models employed by the main literature (Díaz Dapena, Rubiera-Morollon, and Paredes 2019; Ertur and Koch 2007; Panzera and Postiglione 2022; Postiglione, Andreano, and Benedetti 2013) to which the two relevant variables described above are added to test the hypothesis of the work. Two different estimations of the model are computed. The first one considers the impact on economic growth over 2001-2020 of the 230 NUTS 2 regions of 26 EU member states. The second estimation is computed on a longer period, from 1981-2020, considering only the 148 regions of 10 countries out of the first 12 that became part of the EU. To verify that the Spatial Durbin Model is the most appropriate specification for our purpose, we also estimate the Spatial Autoregressive Model and the Spatial Error Model. We compare the estimations results for each model and choose the best specification.

6 Results

Table 5 and table 6 present the results of the estimates for the regions sample of the EU 26 member states over the period 2001-2020. More precisely, Table 5 reports the estimates of the three spatial specifications and table 6 the impact estimates of the Spatial Durbin Model.

As shown in Table 5 the results are quite similar in the three different specifications: SDM, SAR, and SEM. RIs endowment has a positive effect and is highly significant in all three cases, thus suggesting that RIs affect the economic growth of their hosting regions. The coefficient of the RIs endowment mean age appears to be negative, potentially suggesting a detrimental impact on economic growth. However, it is not significant in all models. The estimates of most control variables' coefficients align with the literature. The negative and significant coefficients of the initial level of GDP per capita signal conditional convergence (LeSage & Fischer, 2008; Postiglione, Andreano and Benedetti, 2013). The estimates of the human capital coefficients, both non-spatially and spatially lagged, result opposite compared to Postiglione, Andreano and Benedetti (2013). The first has a positive sign and it is significant and the second is negative but not significant. The most relevant aspect in these results is the lowest AIC statistic which serves as indicator of the most suitable model specification. The AIC statistics for the SDM is the lowest compared to the other two specifications SAR and SEM. This suggests that the SDM is the most appropriate specification.

Table 5. Estimations results. Period 2001-2020. 230 NUTS 2 regions

Dependent variable: GDP growth 2001-20	SDM	SAR	SEM
RIs endowment	0.003***	0.002**	0.003***
	(0.001)	(0.001)	(0.001)
RIs endow. avg. age	-0.0001	-0.0003	-0.004
	(0.0005)	(0.0005)	(0.0005)
Physical capital	0.030	0.049	0.051
	(0.054)	(0.050)	(0.055)
GDP per capita	-0.014***	-0.012***	-0.017***
	(0.003)	(0.002)	(0.003)
Innovativeness	-0.658	1.136*	0.048
	(0.852)	(0.621)	(0.864)
Human capital	0.038***	0.023***	0.041***
	(0.012)	(0.009)	(0.012)
Population	0.0004	0.001	-0.0001
	(0.001)	(0.001)	(0.001)
lag. RIs endowment	0.0002		
	(0.003)		
lag. RIs endow. avg. age	-0.0005		
	(0.002)		
lag. Physical capital	-0.040		
	(0.138)		
lag. GDP per capita	0.001		
	(0.005)		
lag. Innovativeness	4.320*		
	(1.352)		
lag. Human capital	-0.039		
	(0.020)		
lag. Population	0.004**		
	(0.002)		

Observations	230	230	230
sigma2	0.00005	0.0001	0.0001
AIC	-1,592.759	-1,584.719	-1,576.694
Wald Test (df = 1)	97.565***	215.298***	476.123***
LR Test (df = 1)	64.020***	114.113***	106.088***

Standard error in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As mentioned in Section 5, the interpretation of the SDM should be based on the estimated impacts rather than the estimated coefficients. Because of the spatial dependence effect that is incorporated in the model, a change in an explanatory variable for a single spatial unit has a direct impact on the dependent variable at the same unit as well as an indirect effect on the dependent variable of neighbouring units. LeSage and Pace (2009) proposed scalar summary measures for these impacts. The average direct impact, averaged over all regions, provides a summary measure of the impact arising from changes in the $i - th$ observation of a covariate r on the dependent variable of the $i - th$ region and also includes feedback influences that arise as a result of impacts that, starting out from a spatial unit, pass through neighbouring units and come back to the unit itself. The average indirect impact reflects spatial spillovers and precisely how a change in an explanatory variable in all regions influences the economic growth of a particular region i (LeSage and Pace 2009). The sum of the average direct and indirect impacts measures the average total impact (LeSage and Pace 2009). Table 6 shows the average direct, indirect, and total impacts that would arise from changing each explanatory variable of the SDM specified in section 5 for the 230 regions of EU 26 member states economic growth over the period 2001-2020. A set of 1,000 draws is used to produce the impact estimates and inferences regarding their statistical significance.

The RIs endowment impacts – direct, indirect and total - are positive. However, only the direct impact is significant. Such results allow only saying that RIs endowment is positively correlated with economic growth only for the RIs hosting regions. The negative and statistically insignificant impact estimates of the RIs endowment age, as shown in Table 5, do not provide evidence to conclude that the RIs' average age significantly influences the impact. The negative sign of the direct, indirect and total impact of the initial level of the GDP confirms the conditional β-convergence hypothesis as in LeSage and Fischer (2008) and Postiglione, Andreando, and Benedetti (2013). The average direct impact of human capital is significant and positive, as in LeSage and Fischer (2008), while the corresponding indirect is negative but not significant. Such a result gives evidence of the contribution of the quality of human capital to economic growth (LeSage & Fischer, 2008).

Table 6. Spatial Durbin Model impact estimates on economic growth between 2001-2020

Impact measures:	Direct	Indirect	Total
RIs endowment	0.0034***	0.0130	0.0165
RIs endow. avg. age	-0.0002	-0.0017	-0.0019
Physical capital	0.0277	-0.0622	-0.0345
GDP per capita	-0.0152***	-0.0279***	-0.0431***
Innovativeness	-0.2429	12.2102***	11.9673***
Human capital	0.0362***	-0.0410	-0.0048
Population	0.0009	0.0145***	0.0153***

Note: *p<0.1 **p<0.05 ***p<0.01

Table 7 and Table 8 present the results of the estimates for the region sample of the EU 12 member states over the period 1981-2020. Table 7 reports the estimates of the three spatial specifications, and Table 8 the impact estimates of the Spatial Durbin Model.
Also, in this case, results are similar across the three different specifications: SDM, SAR, and SEM. The results presented in Table 7 are largely consistent with those in Table 5, except for the negative and significant coefficient of the average mean age of RIs in all three specification implying that older endowments have a lower effect on economic growth. The RIs endowment coefficient is again positive and significant. It is worth noting that the SDM exhibits the lowest AIC statistic among the three models also in this case, suggesting that it represents the most suitable model specification.

Table 7. Estimations results. Period 1981-2020. 148 NUTS 2 regions.

Dependent variable: GDP growth 1981-20	SDM	SAR	SEM
RIs endowment	0.003***	0.002***	0.003***
	(0.001)	(0.001)	(0.001)
RIs endow. avg. age	-0.001***	-0.001*	-0.001***
	(0.0004)	(0.0004)	(0.0003)
Physical capital	0.040	0.013	0.045*
	(0.027)	(0.030)	(0.027)
GDP per capita	-0.024**	-0.020***	-0.026***
	(0.001)	(0.001)	(0.001)
Innovativeness	11.153**	15.718***	11.264**
	(5.005)	(5.551)	(5.103)
Human capital	0.040***	0.031***	0.039***
	(0.011)	(0.009)	(0.011)
Population	-0.0004	0.0002	-0.0001
	(0.0005)	(0.001)	(0.001)

lag. RIs endowment	0.0002		
	(0.002)		
lag. RIs endow. avg. age	-0.0005		
	(0.001)		
lag. Physical capital	-0.120*		
	(0.069)		
lag. GDP per capita	0.018***		
	(0.003)		
lag. Innovativeness	17.618*		
	(10.075)		
lag. Human capital	-0.023		
	(0.019)		
lag. Population	0.003***		
	(0.001)		
Observations	148	148	148
sigma2	0.00002	0.00003	0.00002
AIC	-1,155.056	-1,113.030	-1,152.139
Wald Test (df = 1)	87.249***	67.737***	305.7577***
LR Test (df = 1)	41.936***	53.994***	93.103***

Standard error in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8 reports the average direct, indirect, and total impacts arising from changing each explanatory variable of the SDM specified in section 5 for the 148 regions of EU 12 member states economic growth over the 40-year period 1981-2020. As in the case of the EU 26 regions, we also employ a set of 1,000 draws to generate impact estimates and to make statistical inferences about their significance. With respect to the impacts of the RIs endowment, the estimates confirm the positive sign of those reported in Table 6 for regions the 26 EU member states considered. Their magnitude is slightly higher compared to those in Table 6. The impacts estimate for the RIs endowment age of the EU-12 regions sample differ from those of the EU 26 member states. The magnitude of the three impacts is higher by one decimal in this case; their sign is always negative, and the direct effect results are significant at 10%. Such a result suggests that the age of RIs in a region negatively affects its economic growth in the long run. The negative and significant GDP per capita estimates in Table 8 confirm for the EU-12 sample over the 40-year period 1981-2020, the conditional β-convergence hypothesis as in LeSage and Fischer (2008) and Postiglione, Andreano and Benedetti (2013) also proven in Table 6.

The estimates of Innovativeness are all positive and highly significant. Their magnitude is considerably higher than those in Table 6 because of the longer timespan that affects the estimation of the patent stock with the Perpetual Inventory Method, whose base year is 1977 (See footnote 11). Finally, the human capital estimation results suggest, as in the case of the EU 26 sample, the positive impact on economic growth (LeSage & Fischer, 2008).

Table 8. Spatial Durbin Model impact estimates on economic growth between 1981-2020

Impact measures:	Direct	Indirect	Total
RIs endowment	0.0035***	0.0022	0.0057
RIs endow. avg. age	-0.0012*	-0.0042	-0.0053
Physical capital	0.0290	-0.3144	-0.2854
GDP per capita	-0.0242***	-0.0030	-0.0212***
Innovativeness	14.2023***	87.9874***	102.1896***
Human capital	0.0402***	0.0198	0.0600
Population	-0.0001	0.0107*	0.0106

Note: *p<0.1 **p<0.05 ***p<0.01

7 Conclusion

RIs are special capital-intensive projects whose site-location choice is quasi-exogenous since it is the result of a political bargaining process which often leads to build them in different regional socio-economic contexts and can be considered as an exogenous policy change. They generate multiple socio-economic impacts over different geographical levels, including local, regional, national and international. These impacts are all drivers of regional economic growth well-studied by the literature. However, so far, very little is known about RIs' contribution to the economic performance of their hosting regions. Yet, most contributions study the impact of one single RI case or, when multiple cases are considered, the focus is on one of the drivers only. This paper addresses this gap by examining the overall impact on the economic growth of EU NUTS 2 regions resulting from the activities of all RIs entities operating within European regions. It is among the limited number of studies in the literature on RIs' socio-economic impact assessment that consider the entire landscape of European RIs, enabling the generalisation of the findings. It also offers a first attempt to examine how such RIs impact regional growth and generate spillover effects on the economic performance of neighbour regions. To this end, a Spatial Durbin Model is applied on a β-convergence growth model augmented with two relevant variables: the regional RIs endowment and the average age of the RIs endowment. Two original cross-sectional datasets, with information on all the EU RIs, are used for this purpose. Each dataset considers two different periods and samples of regions. First, the sample of 230 NUTS 2 regions of 26 European Union member states over the 20-year period 2001-2020. Secondly, for a longer period of 40 years, from 1981 to 2020, only for the 148 NUTS 2 regions of 10 EU-12 member states. Dividing the analysis into these two periods offers several advantages. It allows for the examination of the EU enlargement process, testing the robustness of the results over a 40-year timeframe, assessing potential

variations in the impact magnitude between the two samples, and making the most of the data availability for EU-12 regions compared to the EU 26 sample.
Overall, the results align with the main contributions to regional β-convergence growth. In addition to this literature, it emerges that EU RIs impact the economic growth of the region where they operate, thus confirming the hypothesis of this work. Such impact decreases with a higher average age of the regional RIs endowment, but this is significant only in the long term and only for the EU-12 sample of regions. The magnitude of the impacts is slightly greater when solely focusing on EU-12 regions compared to the entire sample of 26 EU member states. Economic growth spillovers from RIs to neighbouring regions yield positive results in both sample sets. Nevertheless, it is worth noting that these results are not statistically significant.
While this study confirms the main hypothesis and makes an original contribution to the existing literature, it is important to acknowledge its limitations, which could serve as potential areas for further research and development. One limitation lies in the lack of statistical significance in spillovers. This result could indicate two possibilities: either spillovers do not occur, or they might be more localised, potentially taking place at a smaller geographical level, such as the NUTS 3 regional level, for instance. Another limitation is its inability to capture variations in the impact across diverse types of regional economies, such as those categorised by Cohesion policy development levels or less developed regions. Additionally, it does not explore the influence of different geographical contexts, which could provide valuable insights into whether the marginal effect varies in various socio-economic settings. Finally, the cross-sectional structure of the datasets does not allow us to account for dynamic changes over time and draw causal inferences. This would be a fruitful area for further work. Future studies should try to distinguish the impacts according to different regional contexts and exploit the panel data structure to account for time-variant changes in the variables.
Finally, given the rising trend of establishing RIs across Europe (like the Einstein Telescope and the ACTRIS)[13] this work has some relevant policy implications related to the effectiveness of the allocation of public resource on RIs projects. For instance, findings can support the site selection process by informing decision-takers about the potential impacts – in terms of marginal effect – on economic growth on the competing hosting regions for a RI project. Ceteris paribus – scientific requirements are met by competing sites, political and financial support is sufficient – investing in less developed regions or lagging regions could have higher return than investing in a more developed region. Moreover, since RIs project require certain type of environment and geographical context (for example a low population density and a low industrial activity is required for the Einstein Telescope to operate[14]) that are common to less developed regions, investments in RIs can be strategically used to help less developed regions exit their development trap.

[13] For a complete list of new RIs projects see the ESFRI Roadmap 2021: https://roadmap2021.esfri.eu/
[14] See Atzeni et al. 2020.

References

Abel, J. R., & Deitz, R. (2012). Do colleges and universities increase their region's human capital? *Journal of Economic Geography*, *12*(3), 667–691.

Atzeni, G., Biagi, B., Deidda, L., & Vargiu, L. (2020). *Einstein Telescope: An assessment of its economic, social and environmental impact in Sardinia*.

Autio, E. (2014). *Innovation from big science: Enhancing big science impact agenda*.

Autio, E., Hameri, A. P., & Vuola, O. (2004). A framework of industrial knowledge spillovers in big-science centers. *Research Policy*, *33*(1), 107–126. https://doi.org/10.1016/S0048-7333(03)00105-7

Basile, R. (2008). Regional economic growth in Europe: A semiparametric spatial dependence approach. *Papers in Regional Science*, *87*(4), 527–544. https://doi.org/10.1111/j.1435-5957.2008.00175.x

Battistoni, G., Genco, M., Marsilio, M., Pancotti, C., Rossi, S., & Vignetti, S. (2016). Cost–benefit analysis of applied research infrastructure. Evidence from health care. *Technological Forecasting and Social Change*, *112*, 79–91. https://doi.org/10.1016/j.techfore.2016.04.001

Beck, H. P., & Charitos, P. (2021). *The Economics of Big Science: Essays by Leading Scientists and Policymakers*. Springer Nature.

Beugelsdijk, S., & Smulders, S. (2009). *Bonding and bridging social capital and economic growth*. Tilburg University Tilburg.

Brida, J. G., Cortes-Jimenez, I., & Pulina, M. (2016). Has the tourism-led growth hypothesis been validated? A literature review. *Current Issues in Tourism*, *19*(5), 394–430. https://doi.org/10.1080/13683500.2013.868414

Castelnovo, P., & Dal Molin, M. (2020). The learning mechanisms through public procurement for innovation: The case of government-funded basic research organizations. *Annals of Public and Cooperative Economics*, 1–36. https://doi.org/10.1111/apce.12311

Castelnovo, P., Florio, M., Forte, S., Rossi, L., & Sirtori, E. (2018). The economic impact of technological procurement for large-scale research infrastructures: Evidence from the Large Hadron Collider at CERN. *Research Policy*, *47*(9), 1853–1867. https://doi.org/10.1016/j.respol.2018.06.018

Cebr. (2019). *The Importance of Physics to the Economies of Europe A study by Cebr for the period 2011-2016. September*.

Clarke, S., Mawhinney, M., Swerdlow, R., & Teichmann, D. (2013). *Staff Working Papers Project Preparation and CBA of RDI Infrastructure Projects* (Issue April).

COST. (2010). *Benefits of Research Infrastructures beyond Science* (Issue March).

Cramer, K. C., Hallonsten, O., Bolliger, I. K., & Griffiths, A. (2020). Big Science and Research Infrastructures in Europe: History and current trends. In *Big Science and Research Infrastructures in Europe*. Edward Elgar Publishing.

Crescenzi, R., & Rodríguez-Pose, A. (2011). *Innovation and regional growth in the European Union*. Springer Science & Business Media.

Dal Molin, M., & Previtali, E. (2019). Basic research public procurement: the impact on supplier companies. *Journal of Public Procurement*, *19*(3), 224–251. https://doi.org/10.1108/JOPP-07-2018-0027

Dal Molin, M., Scarrà, D., Piccaluga, A., & Valsecchi, V. (2023). Technology transfer from procurement relationships in big science contexts. *Industry and Higher Education*, *37*(4), 537–550.

Del Bo, C. F. (2016). The rate of return to investment in R&D: The case of research infrastructures. *Technological Forecasting and Social Change*, *112*, 26–37. https://doi.org/10.1016/j.techfore.2016.02.018

Del Bo, C. F., Florio, M., & Forte, S. (2016). The social impact of research infrastructures at the frontier of science and technology: The case of particle accelerators: Editorial introduction. *Technological Forecasting and Social Change*, *112*, 1–3. https://doi.org/10.1016/j.techfore.2016.09.001

Díaz Dapena, A., Rubiera-Morollon, F., & Paredes, D. (2019). New Approach to Economic Convergence in the EU: A Multilevel Analysis from the Spatial Effects Perspective. *International Regional Science Review*, *42*(3–4), 335–367. https://doi.org/10.1177/0160017618804010

Drooge, L. van, & Elzakker, I. Van. (2019). *General societal impact protocol (final draft) A light on societal impact of ERICs and RIs*. *January 2019*.

Egeln, J., Gottschalk, S., & Rammer, C. (2004). Location decisions of spin-offs from public research institutions. *Industry and Innovation*, *11*(3), 207–223. https://doi.org/10.1080/1366271042000265384

Elhorst, J. P. (2010). Applied spatial econometrics: raising the bar. *Spatial Economic Analysis*, *5*(1), 9–28.

Elhorst, J. P. (2014). *Spatial econometrics: from cross-sectional data to spatial panels* (Vol. 479). Springer.

Ertur, C., & Koch, W. (2007). Growth, technological interdependence and spatial externalities: theory and evidence. *Journal of Applied Econometrics*, *22*(6), 1033–1062.

Faggian, A., Modrego, F., & Mccann, P. (2019). Human capital and regional development. *Handbook of Regional Growth and Development Theories: Revised and Extended Second Edition*, 149–171. https://doi.org/10.4337/9781788970020.00015

Florio, M. (2019). *Investing in science: Social cost-benefit analysis of research infrastructures*. MIT Press.

Florio, M., Forte, S., Pancotti, C., Sirtori, E., & Vignetti, S. (n.d.). *EXPLORING COST-BENEFIT ANALYSIS OF RESEARCH, DEVELOPMENT AND INNOVATION INFRASTRUCTURES: AN EVALUATION FRAMEWORK*.

Florio, M., Forte, S., & Sirtori, E. (2015). *Cost-Benefit Analysis of the Large Hadron Collider to 2025 and beyond*. 1–17. http://arxiv.org/abs/1507.05638

Florio, M., Giffoni, F., Giunta, A., & Sirtori, E. (2018). Big science, learning, and innovation: Evidence from CERN procurement. *Industrial and Corporate Change*, *27*(5), 915–936. https://doi.org/10.1093/icc/dty029

Florio, M., & Pancotti, C. (2020). The Economics of Physics: The Social Cost-Benefit Analysis of Large Research Infrastructures. *Oxford Research Encyclopedia of Physics*, *August*, 1–21. https://doi.org/10.1093/acrefore/9780190871994.013.23

Florio, M., & Sirtori, E. (2016a). Social benefits and costs of large scale research infrastructures. *Technological Forecasting and Social Change*, *112*, 65–78. https://doi.org/10.1016/j.techfore.2015.11.024

Florio, M., & Sirtori, E. (2016b). Social benefits and costs of large scale research infrastructures. *Technological Forecasting and Social Change*, *112*, 65–78. https://doi.org/10.1016/j.techfore.2015.11.024

Florio, M., & Sirtori, E. (2016c). The Evaluation of Research Infrastructures: A Cost-Benefit Analysis Framework. *SSRN Electronic Journal*, *January 2016*. https://doi.org/10.2139/ssrn.2722500

Hallonsten, O. (2020). Research Infrastructures in Europe: The Hype and the Field. *European Review*, *28*(4), 617–635. https://doi.org/10.1017/S1062798720000095

Helmers, C., & Overman, H. G. (2017). My Precious! The Location and Diffusion of Scientific Research: Evidence from the Synchrotron Diamond Light Source. *Economic Journal*, *127*(604), 2006–2040. https://doi.org/10.1111/ecoj.12387

Horlings, E., Gurney, T., Somers, A., & Besselaar, P. van den. (2012). *The societal footprint of big science*. 1–29.

Huggins, R., & Johnston, A. (2009). The economic and innovation contribution of universities: a regional perspective. *Environment and Planning C: Government and Policy*, *27*(6), 1088–1106.

Huggins, R., & Kitagawa, F. (2009). Devolution and knowledge transfer from universities: Perspectives from Scotland and Wales. *University of Wales*.

Leonardi, R., Nanetti, R. Y., & Putnam, R. D. (2001). *Making democracy work: Civic traditions in modern Italy*. Princeton university press Princeton, NJ.

LeSage, J. P., & Fischer, M. M. (2008). Spatial growth regressions: model specification, estimation and interpretation. *Spatial Economic Analysis*, *3*(3), 275–304.

Llanos-Paredes, P. (2023). The effect of applied research institutes on invention: Evidence from the Fraunhofer centres in Europe. *Research Evaluation*, *July 2021*, 1–11. https://doi.org/10.1093/reseval/rvad028

Malecki, E. J. (2018). Technological innovation and paths to regional economic growth. *Growth Policy in the Age of High Technology*, 97–126.

Moretti, E. (2004). Workers' education, spillovers, and productivity: evidence from plant-level production functions. *American Economic Review*, *94*(3), 656–690.

North, D. C. (1955). Location theory and regional economic growth. *Journal of Political Economy*, *63*(3), 243–258.

OECD. (2019). *Reference Framework For Aassessing The Sscientific and Socio-Eeconomic Impactof Research Infrastructures*.

OECD. (2014). The impacts of large research infrastructures on economic innovation and on society: Case studies at CERN. *The Impacts of Large Research Infrastructures on Economic Innovation and on Society*, 79. www.oecd.org/sti/gsf.

Pancotti, C., Battistoni, G., Genco, M., Lavigra, M. V., Mella, P., Rossi, S., & Vignetti, S. (2015). *The Socio-Economic Impact of the National Hadrontherapy Centre for*

Cancer Treatment (CNAO): Applying a CBA Aanalytical Framework. The C Chiara. *21501*(21522), 22–23. http://www.economia.unimi.it
Panzera, D., & Postiglione, P. (2022). The impact of regional inequality on economic growth: a spatial econometric approach. *Regional Studies*, *56*(5), 687–702.
Park, M. (101 C.E.). *Public_Guide_V1* (Vol. 1).
Postiglione, P., Andreano, M. S., & Benedetti, R. (2013). Using Constrained Optimization for the Identification of Convergence Clubs. *Computational Economics*, *42*(2), 151–174. https://doi.org/10.1007/s10614-012-9325-z
Putnam, R. D. (2000). Bowling alone: America's declining social capital. In *Culture and politics* (pp. 223–234). Springer.
Robbiano, S. (2022). The innovative impact of public research institutes: Evidence from Italy. *Research Policy*, *51*(10), 104567. https://doi.org/10.1016/j.respol.2022.104567
Rodríguez-Pose, A. (1999). Innovation prone and innovation averse societies: Economic performance in Europe. *Growth and Change*, *30*(1), 75–105. https://doi.org/10.1111/0017-4815.00105
Rodríguez-Pose, A., & Crescenzi, R. (2008). Research and development, spillovers, innovation systems, and the genesis of regional growth in Europe. *Regional Studies*, *42*(1), 51–67. https://doi.org/10.1080/00343400701654186
Rodríguez-Pose, A., & Villarreal Peralta, E. M. (2015). Innovation and regional growth in Mexico: 2000-2010. *Growth and Change*, *46*(2), 172–195. https://doi.org/10.1111/grow.12102
Scaringella, L., & Chanaron, J. J. (2016). Grenoble–GIANT Territorial Innovation Models: Are investments in research infrastructures worthwhile? *Technological Forecasting and Social Change*, *112*, 92–101. https://doi.org/10.1016/j.techfore.2016.05.026
Simmonds, P., Kraemer-Mbula, E., Horvath, A., Stroyan, J., & Zuijdam, F. (2013). Big Science and Innovation. In *Science and Innovation* (Issue July). https://doi.org/10.4337/9781781950241
Veugelers, R., & Del Rey, E. (2014). *European Network on Economics of Education*.
Vuola, O., & Hameri, A. P. (2006). Mutually benefiting joint innovation process between industry and big-science. *Technovation*, *26*(1), 3–12. https://doi.org/10.1016/j.technovation.2005.03.003
Zuijdam, F., Boekholt, P., Deuten, J., Meijer, I., & Vermeulen, N. (2011). *The role and added value of large-scale research facilities*. *February*, 1–57. http://www.technopolis-group.com/resources/downloads/reports/1379_Report_Large-scale_Research_Facilities_EN.pdf
Zuniga, P. C. and P. (2013). Public Policies to Foster Knowledge Transfer from Public Research Organizations. *Innovation, Technology and Entrepreneurship Global Practice*, *March*.

Ultimi Contributi di Ricerca CRENoS

I Paper sono disponibili in: http://www.crenos.unica.it

23/13 *Alberto Tidu,* "Dissecting inequality: conceptual problems, trends and drivers"

23/12 *Luciano Mauro, Francesco Pigliaru,* "Italy's National Recovery and Resilient Plan: Will it Narrow the North-South Productivity Gap?"

23/11 *Fabrizio Antolini, Samuele Cesarini, Giorgio Garau,* "The economic impact of the tourism sector on the overall Italian economy: An Input-Output Approach"

23/10 *Giorgio Garau, Andrea Karim El Meligi,* "The Impact of the Pandemic and War on Surplus Redistribution Mechanisms: A Sectoral Analysis of France and Italy"

23/09 *Maria Giovanna Brandano, Alessandra Faggian, Adriana C. Pinate,* "The impact of COVID-19 on the tourism sector in Italy: a regional spatial perspective"

23/08 *Fabrizio Cipollini, Giampiero M. Gallo, Alessandro Palandri,* "Modeling and evaluating conditional quantile dynamics in VaR forecasts"

23/07 *Ugo M. Gragnolati, Luigi Moretti, Roberto Ricciuti,* "Early railways and industrial development: Local evidence from Sardinia in 1871–1911"

23/06 *Giampiero M. Gallo, Demetrio Lacava, Edoardo Otranto* "Volatility jumps and the classification of monetary policy announcements"

23/05 *Diego Dessì, Raffaele Paci,* "The impact of Global Value Chains participation on countries' productivity"

23/04 *Edoardo Otranto, Luca Scaffidi Domianello,* "On the relationship between Markov Switching inference and Fuzzy Clustering: A Monte Carlo evidence"

23/03 *Mario Agostino Maggioni, Emanuela Marrocu, Teodora Erika Uberti, Stefano Usai,* "The role of localised, recombinant and exogenous technological change in European regions"

23/02 *Bianca Biagi, Laura Ciucci, Claudio Detotto, Manuela Pulina,* "University study programmes and students dynamics"

23/01 *Giovanni B. Concu, Claudio Detotto, Marco Vannini,* "Drivers of intentions and drivers of actions: willingness to participate versus actual participation in fire management in Sardinia, Italy"

22/06 *Alberto Tidu, Stefano Usai, Frederick Guy,* Measuring spatial dispersion: an experimental test on the M-index

22/05 *Luca Scaffidi Domianello, Giampiero M. Gallo, Edoardo Otranto,* "Smooth and Abrupt Dynamics in Financial Volatility: the MS-MEM-MIDAS"

22/04 *Claudio Detotto, Riccardo Marselli, Bryan C. McCannon, Marco Vannini,* "Experts and Arbitration Outcomes: Insights from Public Procurement Contract Disputes"

22/03 *Gerardo Marletto, Cécile Sillig,* "Global influence and national diversity in socio-technical transitions: a sectoral taxonomy"

22/02 *Federico Aresu, Emanuela Marrocu, Raffaele Paci,* "Public capital and institutions' quality in the Italian regions"

22/01 *Gabriele Cardullo, Maurizio Conti, Andrea Ricci, Sergio Scicchitano, Giovanni Sulis,* "On the Emergence of Cooperative Industrial and Labor Relations"

21/11 *Gianfranco Atzeni, Luca G. Deidda, Marco Delogu, Dimitri Paolini,* "Effects of migration with endogenous labor supply and heterogeneous skills"

21/10 *Alberto Tidu, Stefano Usai, Frederick Guy,* "Agglomeration in manufacturing and services: an experimental application of a distance-based measure to Sardinia"

21/09 *Andrea Caria, Fabio Cerina, Marco Nieddu,* "Political Selection and Monetary Incentives in Local Parliamentary Systems" www.crenos.unica.it

ISBN 9788868514907

9 788868 514907 >