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Analysing key relationships: digitalization, innovation and structural conditions in EU

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Analysing key relationships: digitalization, innovation and structural conditions in EU

Abstract

There is an intrinsic relationship between innovation and digitalization, marked by the specific and structural socioeconomic characteristics of our regions and countries. These characteristics explain the territory heterogeneity and determine in many cases specific paths for the next digital transformations in the EU.

The EU is answering this movement with an ambitious multimillion public investment, the NextGeneration Funds, and an ample set of policies to encourage its digital 2030 agenda: innovation is in front line, governing most of the decision for countries' digitalization under our specific set of European values (Hajighasemi et al., 2022)

But there are some tough questions countries cannot ignore: are all these economical efforts around innovation well addressed to foster digital transformation? To what extent a country offers a different behavior across this intimate relationship between digitalization and innovation? In which aspects higher degrees in innovation means a higher advantage for the economic and social digitalization in a country?

Innovation, as it is broadly defined in the European Innovation Scoreboard (EIS), published by European Commission, is a complex concept built by a multitude of interacting aspects that do not necessarily work synergistically: a framework of conditions, innovation activities, investment, and economics impacts. The consequential results of cross-cutting drivers, such as digitalization, is often difficult to assess, as the achievement of certain targets may also inadvertently hinder progress towards others. Although digitalization in economy implies positive relationship with technological innovation (Yuan et al., 2021), and digital transformation boosts companies' innovation and performance (Ferreira et al., 2019), other results show that besides improving the level of business digitalization, innovation has a direct influence on business performance, as well as acting as a moderating variable that should be aligned with strategy (Fernández-Portillo et al., 2022). However, other research shows that innovation activities do not necessarily imply technological improvements (Zabala-Iturriagagoitia et al., 2021). Our study describes a comprehensive and systematic European country-based analysis of statistical associations between both, digitalization and innovation indicators operating at several different levels to understand better these apparent contradictions.

We use for this study a regression and some graphical analyses, using open data coming from EIS and DESI (Digital Economy and Society Index), this last one used by the European Commission to measure countries' digitalization in Europe. Also, we have considered structural economic indicators which complement the EIS related to country's wealth, population and rule of law, business activity, innovation enterprise segmentation and environmental factors.

Relationships among indexes have been modelled initially using a linear bivariate regression. Also, we built and present a heatmap correlating all their second line subindices. The structure of this research follows a top-down approach, starting with the analysis of composite indexes, followed by second lower-level innovation and digitalization indexes and then, we will finish with a discussion for some specific aspects and countries.

Results showed at first a strong correlation between the European composite indices for digitalization (DESI) and Innovation (EIS). However, the analysis of second and third level indicators for both compound indexes shows that not all digitalization variables have high associations with all innovation variables, meaning that not all digitalization strategies will lead to a rise in the innovation scale. It appears that while synergies are generated in many aspects related to human resources, research systems and information technologies relevant trade-offs occur in areas related to sales impacts, and product and business innovation because to their negative associations with current economic development models. These structural obstacles need to be acknowledged and adequately managed guaranteeing harmonious and integral progress towards effective digital transformation, understanding regions and enterprise heterogeneity (Hervás-Oliver et al., 2021).

This research is another step forward trying to understand how digital policies for countries are well design in short and long term. And which capabilities must be developed or restructured (de Rojas et al., 2022).

Currently, there is still a lot of debate in this area, considering the constant geopolitical changes we are facing and how European Digital Agenda for 2030 is still under construction and debate. Overall, our research main ambition is to inspire scientist and the digital policy community to focus on the EU Digital Sector and analyze how it is reacting to the global challenges around it.

Highlights

- EIS shows a strong relationship with DESI in areas of Integration of *Digital Technologies*, especially for SMEs with at least a basic level of digital intensity, and with *Human Capital*, in terms of ICT specialists.
- DESI is strongly correlated with innovation variables specially with the *Human resources* area, an attractive research system, innovators using linkages or relations among public and private stakeholders and the proper intellectual assets developed around innovation, besides considering the high value of the employment further created.
- DESI and EIS share some common structural economic variables for European countries. We can describe Digitalization and Innovation in Europe likely based on a stable economy, with an advanced consumer behavior in the private and public sphere and where there exists an in-house strong product and process innovation with intensive employment in services. Enterprise births is negatively correlated with digitalization and innovation which means that the dynamism of entrepreneurship is unfortunately most focused in low value bird enterprises and could happen most commonly in the less sophisticated countries.
- Mobile connectivity and ICT specialists are highly correlated with GDP per capita in terms of digitalization (DESI). Attractiveness of the scientist system employed ICT specialists and also employment in “knowledge-intense activities” jointly with impacts from “Knowledge-intensive services exports” are highly correlated with GDP per capita in terms of innovation (EIS) in a country. *As a main conclusion we see a stunning growing place for GDP per capita driven both by digitalization and innovation with a strong and extensive specialized technical labor force.*
- GDP per capita per region and innovation in a region are also highly associated. “Employed ICT” and “Individuals with above overall skills” interpreted as a proxy for digitalization appears highly correlated with regional innovation and GDP, pointing out the most advanced regions. The more digitalized a country is, considering these indices, the more their different regions (even with their internal specific heterogeneity) are more sophisticated in term of innovation.
- Being an ample heterogeneity of innovation and digitalization in a country, many times the capital is heading the country in terms of Innovation and Digitalization
- A robust regional digital indicator is needed to further studies inside regions in UE to explore robust innovation/digitalization relationships.

1 Introduction

There is a doubtless intrinsic relationship between innovation and digitalization, both relevant engines to achieve social and economic progress as well as relevant competitiveness for modern countries.

Digitalization is a complex phenomenon where exponential technologies that come from a few core technological firms are enabled through data and high speed connectivity to be translated to the rest of society in a movement named *Digital Transformation where the entire organization of public sector and private organizations are involved*.

On the other hand, Innovation as appears in (OECD/Eurostat, 2018) is “a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)”.

How should we measure then the Digital Economy? There is a lot of effort regarding measuring digitalization because there has been a substantial increase in well-being that is missed by traditional metrics like GDP or productivity (Brynjolfsson & Collis, 2019): (OECD, 2020) has published guidelines (DETF, 2018) and European Union has been working for a long time with the DESI (Digital Economy and Society Index), even creating some specific benchmarks with other non-EU countries (named I-DESI). Others are updated by nonprofit organizations such as the World Economic Forum (WEF) in their Network readiness index (NRI) or their Global competitiveness Report, or keep track of digitalization from an entrepreneurial perspective, like the Global Entrepreneurship monitor (GEM).

Concerning innovation, we can find some relevant indices: GII (Global Innovation Index) maintained by (*World Intellectual Property Organization (WIPO)*, n.d.) and European Innovation Scoreboard (EIS), published by European Commission.

The reality is that year by year more fresh datasets can be found in Eurostat but also in international institutions such as OECD or Word Bank. Other regions are also working hard to understand the impact of digital technology usage and modulate their specific position: (Kirshin et al., 2015) for BRICs, (Myovella et al., 2020) for Subsahara and even sometimes mixing digitalization and innovation (Afonasova et al., 2019).

This last point is one of the most interesting for us because we need to answer some questions:

- (Question 1) Are all economical efforts around innovation well addressed to foster digital transformation?
- (Question 2) To what extent a country offers a different behavior across this intime relationship between digitalization and innovation?
- (Question 3) In which aspects, higher degrees in innovation means a higher advantage for the economic and social digitalization in a country?

This is why we need to understand how innovation and digitalization are associated and which underlying core variables could be quite pertinent to update those indexes. *Some research is found related to this, but only partly, specifically for innovation, intending to refine EIS to simplify it and so find it more reliable* (Bielińska-Dusza & Hamerska, 2021).

The novelty of this research compared with the current literature is then, the combination of a jointly understanding of digitalization and innovation as a whole and the cross-side study for discovering the most relevant indicators which measure both, taking as a modulator for both the structural economic variables in a country and in a region.

1.1 Distribution of the paper

In section 2.1 we describe the DESI and EIS as the key indices used for this research. In section 2.2 we explain the statistical methodology used in this paper.

In section 3 we made our analysis, first comparing the higher level scores, then comparing relations between second level from DESI with EIS main score in section 3.1.1, and finally, in section 3.1.2, second level EIS with DESI main score.

In section 3.2 we introduce background structural variables to understand as a whole the economic, social, and political characteristics of a country and how these variables affect digitalization. We correlated them to select the most relevant and then in section 3.2.2 we describe cross-side dependencies for innovation and digitalization. In section 3.2.3 we analyze deeper the GDP (Gross Domestic Product) per capita, which is widely mentioned in literature as a direct driver for innovation and digitalization. Section 3.3 takes in to account European regions and using RIS (Regional Innovation Scoreboard) to get some results correlating GDP per capita and digitalization. Section 3.3.1 provides a sample for two Spanish regions, Andalucía and Cataluña, spotting their similar behaviors and different options along their digitalization and innovation path.

In section 4 we resume and explain our main conclusions.

2 Methodology

2.1 Description and comparison of the different data sources

For our analysis we will use the last published DESI (*The Digital Economy and Society Index (DESI)*, 2022) and European Innovation Scoreboard (EIS).

DESI has been used to monitor EU Member States' digital progress since 2014 based in four strategical areas: Human capital, Connectivity, Integration of digital technology and Digital public services. Inside these first level areas appears 10 subdimensions with a total of 32 indicators.

- *Human capital area* captures digital skill sophistication for both, general population, and ICT specialists.
- *Connectivity* measure fixed and mobile broadband take-up, coverage, and prices.
- *Integration of digital technology* captures the penetration of fundamental digital technologies in business in all their commercial and productive processes.
- *Digital public services area* describes the overall e-Government deployment.

Data Sources come primarily from Eurostat and the European Commission who verifies and aggregates systematic national surveys and studies. Public services data is collected by Capgemini and verified by member state's ministries. Ipsos and iCite surveys the usage of digital technologies and it is reviewed by the Digital Single Market Strategic Group.

Also, DESI is considered the fundamental tool for guiding developments around the European Digital Decade program which includes the *Digital Compass*. So, it must be aligned to measure digital transformation across all sectors of economy: with every methodological change DESI's scores and ranks of previous years are recalculated attending changes of data and indicator choices. In this last update we highlight "At least basic digital skills", "ICT specialists", "Female ICT specialists" indicators (inside Human capital dimension), "Fixed VHCN and 5g coverage" indicators (inside Connectivity Dimension), "SMEs with a basic level of digital intensity" and "take-up of Big Data, Cloud and AI" indicators (inside Integration of digital technology dimension) and "Digital public services for citizens and business" indicators as relevant targets of the Digital Decade Compass.

EIS is focused in systematically compared innovation performance across EU Members States but also for other non-EU Members searching for relative strengths and weakness of their research and innovation systems. Being first published in 2001, the latest mayor revision happened in 2011. Distinguishes four main classes of activities: *Framework conditions*, *Investments*, *Innovation activities* and *Impacts* which are finally subdivided in 12 dimensions with 32 indicators.

- *Framework conditions* captures external drivers for enterprises considering percentage of STEM, tertiary education and lifelong learning activities, attractiveness of the research system and digitalization.
- *Investments* measures both investment in public and private sectors in terms of private funding, R&D expenditures in university and government and reskilling or upskilling inside enterprises.
- *Innovation activities* measures product and business process innovation in SMEs, collaboration efforts between parts and intellectual assets formation.
- *Impacts* evaluates the results of enterprise innovation activities along employment, sales impact and environmental sustainability.

Data sources are slightly more heterogeneous, coming mainly from Eurostat, Scopus database (for co-publications), OECD (for patent data and development of environment-related technologies), European Union Intellectual Property Office (for design applications) and UN ComTrade for non-EU countries (for exports of medium and high technology)

It is important to highlight that EIS framework is also accompanied by some contextual and structural economic indicators to provide a better understanding and differences between countries. These indicators are related with:

- *Performance and structure of the economy*, planning to measure GDP and growth among employment sophistication and turnover in enterprises.
- *Business and entrepreneurship*. Entrepreneurship is measured by rating enterprise births and the total early-stage Entrepreneurial Activity; Business innovation capabilities are measured with top R&D spending enterprises (currently restricted to large companies are responsible for that) and also understanding demand customer sophistication to prioritize prices versus quality.
- *Innovation profiles*. Capabilities and behaviors for innovation are diverse and can be focused through product, or via marketing, process, or organizational changes. Besides, these innovations introduced can be developed in-house or even there is noninterest for these activities. In total there are six profiles.

- *Governance and policy framework*, in a sense that institutional and legal favorable environments can help to innovate; also, basic-school entrepreneurial, helping to create transformative skills; governments acquiring advanced technological products to foster innovation; finally, the trust inside the society as a way to get the “Rule of Law”.
- *Climate change*. Digital innovations are pivoting over the common interest in environment sustainability as a driver of social change: it is measured in global terms by circular use of materials within households, private and public sector, greenhouse effectiveness and eco-innovation activities.
- *Demography*, meaning population size and average annual growth rate of population as a symptom that increasing demand following an increasing population can foster finally innovation. Additionally, population density is considered interpreting that a densely populated city could provide easier government services, training, or jobs opportunities.

Data source as the rest of the indicators consider in the paper comes mainly from Eurostat and National Statistical Offices from European countries. Other sources include World Bank (Worldwide Governance, World Development and doing business indicators) and World Economic Forum.

2.2 Statistical analysis

First, a country-based cross-section approach was carried out to explore the Spearman and Pearson correlation for first level DESI and EIS aggregation to quantify their relationship. After that, we have navigated inside the different sublevels and indicators to discover which of them are more relevant, using for that case a Pearson analysis between all the variables.

Then, we compared DESI and EIS specifically with contextual and structural economic indicators to isolate which are the common points for both indicators.

For Pearson analysis used a regression analysis modelled initially using a linear bivariate regression.

The regression coefficients were calculated using the least squared approach to minimize the square sum of the error terms. From every linear regression, the correlation coefficient (R), the determination coefficient (R^2) and the sensitivity of one indicator against to the variations in the other were obtained. The p-values were calculated to determine the statistical significance of the associations, considering in the analyses only regressions with p-values below 0.05.

3 Results and further analysis

Table 1 Pearson and Spearman R for DESI and EIS

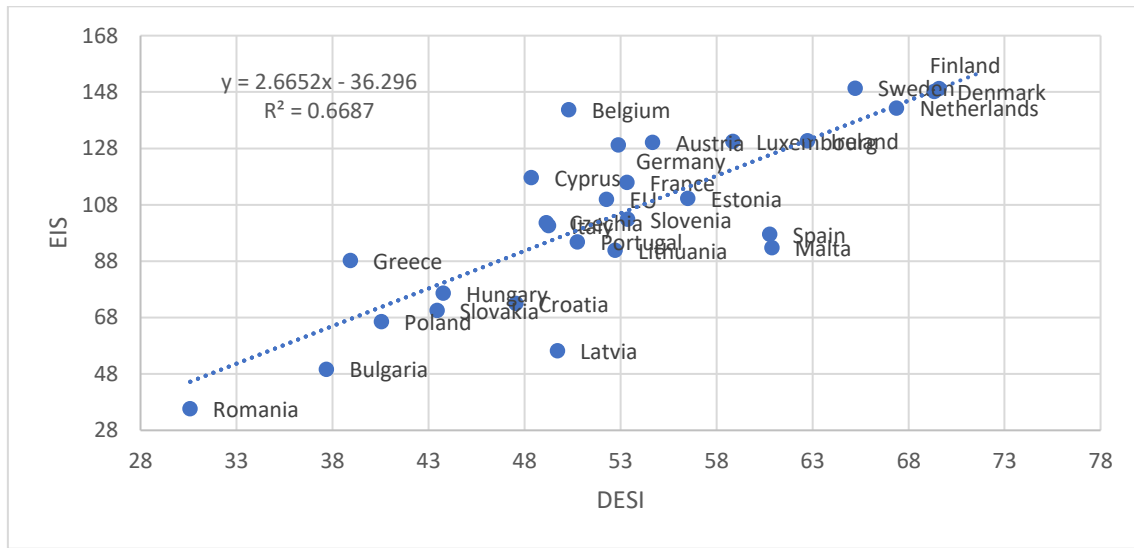
R	EIS (Spearman)	EIS (Pearson)
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DESI	0.79310345	0.81774079
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3.1 Associating digitalization and innovation

The results in Table 1 shows strong correlation (R) between DESI and EIS, both for Pearson and Spearman. In Figure 1 we have plot EIS and DESI global score with its linear regression.

Figure 1 Plot for EIS vs DESI, R^2 and linear regression for EIS vs DESI.



3.1.1 Associating second level DESI scores with EIS

At the first subdimension level we see in Table 2 that the incorporation and integration of digital technology and *Human Capital* are the most relevant areas which influence innovation, followed by *Digital Public Services*. *Connectivity* appears slightly lagged.

Table 2 Pearson correlation (R) between second level DESI an EIS. P value <0.05

Second DESI level indicators	R EIS
1. Human Capital	.765
2. Connectivity	.474
3. Integration of Digital Technology	.848
4. Digital Public Services	.633

In Table 3 we have dept in the *Integration of Digital Technology* variables and we highlight the importance of SMEs with at least basic digital levels and technologies such as Social Media, Cloud, Big Data and AI.

Related with *Human Capital*, ICT specialists appears as the most relevant indicator although others upskilling or reskilling enterprise activities are a close second. But in general, the total amount of basic global population digital skills is highly correlated.

And to remark *Public Sector indicators* appears not at very first positions specially referred to its access to the population and then because of its self-digitalization.

Additionally, and as outstanding observation connectivity only appears relevant in order to foster Mobile Broadband take-up. Fixed broadband is kept outside as relevant, even for faster configurations (1Gbps). 5G coverage has a very week correlation. For this case, the explanation is the contrary, because at this moment 5G deployment is at the beginning and with not a relevant influence at this moment.

Table 3 Pearson correlation (R^2) between third level DESI indicators and EIS. No data appear if $p > 0.05$. Broadband price index is correlate negatively.

Third level DESI indicators	R^2 EIS
1a Internet User Skills	.541
1b Advanced Skills and Development	.398
2a Fixed broadband take-up	-
2b Fixed broadband coverage	-
2c Mobile broadband	.261
2d Broadband price index	.183
3a Digital intensity	.760
3b Digital technologies for businesses	.671
3c e-Commerce	.347
4a e-Government	.40
1a1 At least Basic Digital Skills	.557
1a2 Above basic digital skills	.493
1a3 At least basic digital content creation skills	.481
1b1 ICT Specialists	.649
1b2 Female ICT specialists	-
1b3 Enterprises providing ICT training	.569
1b4 ICT graduates	-
2a1 Overall fixed BB take-up	.233
2a2 At least 100 Mbps fixed BB take-up	-
2a3 At least 1 Gbps take-up	-
2b1 Fast BB (NGA) coverage	-
2b2 Fixed Very High Capacity Network (VHCN) coverage	-
2c1 5G spectrum	-
2c2 5G coverage	.192
2c3 Mobile BB take-up	.577
2d1 Broadband price index	.183
3a1 SMEs with at least a basic level of digital intensity	.760
3b1 Electronic Information Sharing	.317
3b2 Social media	.651
3b3 Big data	.439
3b4 Cloud	.595
3b5 Artificial intelligence	.410
3b6 ICT for environmental sustainability	-
3b7 e-Invoices	-
3c1 SMEs selling online	.250
3c2 e-Commerce turnover	.259
3c3 Selling online cross-border	.324
4a1 e-Government Users	.462
4a2 Pre-filled Forms	.175
4a3 Digital public services for citizens	.273
4a4 Digital public services for businesses	.331
4a5 Open Data	-

3.1.2 Associating second level EIS scores with DESI

In this section we compare the DESI composite index with second level EIS variables.

Table 4 Pearson correlation (R) between second level EIS and DESI general score. P value < 0.05

Area	Second level EIS	R DESI
Framework conditions	1.1 Human resources	.882
	1.2 Attractive research systems	.778
	1.3 Digitalisation	.834
Investments	2.1 Finance and support	.532
	2.2 Firm investments	.444
	2.3 Use of information technologies	.851
Innovation activities	3.1 Innovators	.390
	3.2 Linkages	.713
	3.3 Intellectual assets	.694
Impacts	4.1 Employment impacts	.626
	4.2 Sales impacts	.420
	4.3 Environmental sustainability	.516

As appears described in Table 4, and discarding the obvious evident relation between digitalization and the use of information technologies, DESI is strongly correlated with innovation specially with the variables related to *Human resources*, “an attractive research system”, “innovators using linkages or relations among public and private stakeholders”, and the proper “intellectual assets” developed around innovation, besides mentioning the “employment impacts” associated.

Surprisingly “sales impacts” and “firm investment and finance” appears at second level of correlation. Environmental sustainability is not so appealing as at first position as we can supposed for innovation.

Going deeper into these relationships, in the following table we represent the correlation values between the DESI composite index and the EIS variables.

Table 5 Pearson correlation (R) between EIS third level indicators and DESI. Not show correlations where $p > 0.05$

Third level indicator	R DESI
1.1.1 New doctorate graduates	.628
1.1.2 Population with tertiary education (Regional)	.548
1.1.3 Population involved in lifelong learning (Regional)	.881
1.2.1 International scientific co-publications (Regional)	.730
1.2.2 Scientific publications among the top 10% most cited (Regional)	.684
1.2.3 Foreign doctorate students as a % of all doctorate students	.703
1.3.1 Broadband penetration	.524
1.3.2 Individuals with above basic overall digital skills (Regional)	.887
2.1.1 R&D expenditure in the public sector (Regional)	.486
2.1.2 Venture capital expenditures	.544
2.1.3 Direct and indirect government support of business R&D	-
2.2.1 R&D expenditure in the business sector (Regional)	.475
2.2.2 Non-R&D innovation expenditures (Regional)	-
2.2.3 Innovation expenditures per person employed (Regional)	.480
2.3.1 Enterprises providing ICT training	.742
2.3.2 Employed ICT specialists (Regional)	.836
3.1.1 SMEs introducing product innovations (Regional)	-
3.1.2 SMEs introducing business process innovations (Regional)	.418
3.2.1 Innovative SMEs collaborating with others (Regional)	.447
3.2.2 Public-private co-publications (Regional)	.714
3.2.3 Job-to-job mobility of HRST	.461
3.3.1 PCT patent applications (Regional)	.712
3.3.2 Trademark applications (Regional)	-
3.3.3 Design applications (Regional)	.489
4.1 Employment impacts	.626
4.1.1 Employment in knowledge-intensive activities (Regional)	.707
4.1.2 Employment in innovative enterprises (Regional)	-
4.2.1 Exports of medium and high technology products	-
4.2.2 Knowledge-intensive services exports	.423
4.2.3 Sales of new-to-market and new-to-firm innovations (Regional)	-
4.3.1 Resource productivity	-
4.3.2 Air emissions by fine particulates (Regional)	.437
4.3.3 Environment-related technologies	.402

As main results from our variables analysis, it is worth mentioning that many human capital subindices appear with very high correlation: population with basic digital skills, but also population involved in lifelong learning and enterprise providing ICT training are the main relevant factors; even the indicator for new doctorate graduates. And specifically, for enterprises, ICT specialists appears as a very important variable in our analysis.

Surrounding an attractive research system, we can see other variables correlated with innovation: international scientist co-publications and its worldwide impact and foreign doctorate students as a % of all doctorate students which highlight international collaboration for a research system. And related with this area, public-private co-publications.

At a second level broadband penetration as a proxy for digitalization does not appear relevant.

But surprisingly R&D expenditure in the public and private sector and innovation expenditure per employed person does not present a relevant correlation with Digitalization. Neither does SMEs acting as a collaborative innovator stakeholder, for sample introducing business process innovation.

Lagged and with little relevance we discover knowledge-intensive services exports, which reflects the ability of an economy to export services with high levels of value added, and successfully take part in knowledge-intensive global value chains, and finally, environment-related technologies.

As a main conclusion, the relation between Digitalization and Innovation is fostered mainly by human capital and a competent international research system but lacks from a clear support from SMEs; and R&D business and private investments are not pushing digitalization with clear intensity.

3.2 Associating second level scores from DESI and EIS with structural variables

In this section we repeat later analysis for DESI and EIS but considering structural variables. In Table 6 we have presented Pearson correlation value (R²). The principal idea is to determine which structural indicator are more cross influential for Digitalization and Innovation, so after that we can proceed analyzing them.

Table 6 DESI and EIS R² values for structural variables (only structural index shown where for both DESI and EIS p>0.05. In red and not shown where for an specific value p>0.05)

Structural index	DESI correlation value	EIS correlation value
5.1.1 GDP per capita (thousands) (SD)	.310	.399
5.1.3 Employment share Manufacturing (SD)	.223	.228
5.1.5 Employment share Services (SD)	.176	.155
5.1.6 Employment share Knowledge-intensive services (SD)	.347	.449
5.2.1 Enterprise births (SD)	.350	.578
5.2.4 Top R&D spending enterprises (SD)	.232	.280
5.2.5 Buyer sophistication (SD)	.445	.705
5.3.1 In-house product innovators with market novelties (SD)	.315	.491
5.3.3 In-house business process innovators (SD)	.215	.449
5.3.4 Innovators that do not develop innovations themselves (SD)	-	.431
5.3.5 Innovation active non-innovators (SD)	-	.275
5.3.6 Non-innovators with potential to innovate (SD)	-	.205
5.3.7 Non-innovators without disposition to innovate (SD)	-	.291
5.4.1 Ease of starting a business (SD)	.221	.145
5.4.2 Basic-school entrepreneurial education and training (SD)	.534	.265
5.4.3 Government procurement of advanced technology products (SD)	.377	.460
5.4.4 Rule of law (SD)	.695	.722
5.5.3 Eco-Innovation Index (SD)	.468	.581
5.6.2 Average annual population growth (SD)	.310	.581

Digitization in Europe is related to countries with a *stable economy* (Rule of Law), within a *basic level of knowledge of entrepreneurship*, and an *advanced consumer behavior in the private and public sphere* (Buyer sophistication, Government procurement of advanced technology products, Eco-innovative) and where there exists an *in-house strong product innovation at the market* generated with *intensive employment in services*. However, there is a negative correlation with the *number of births of companies* (Enterprise births).

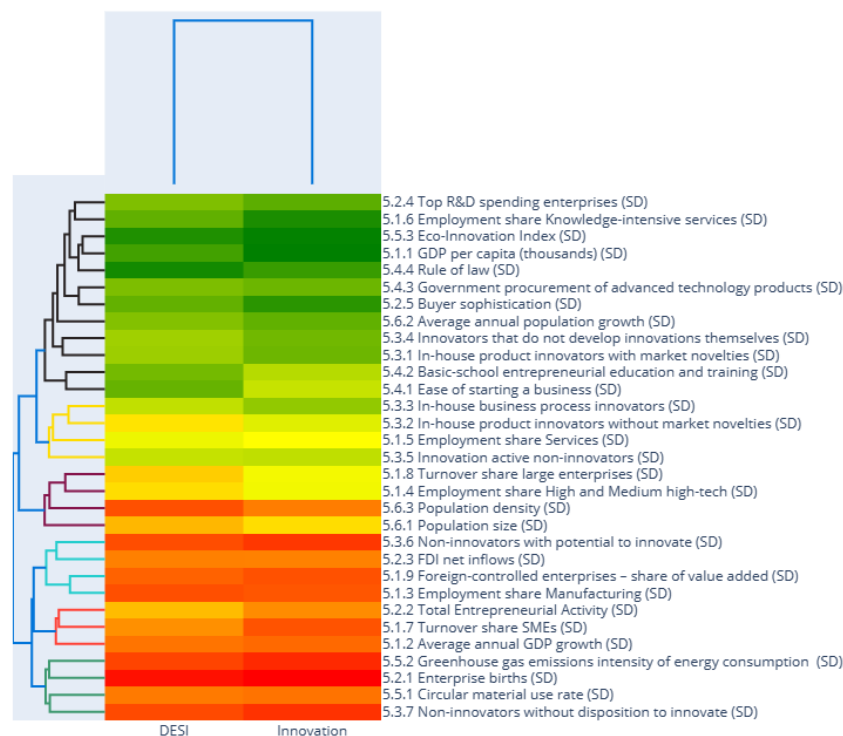
On the other hand, if we look through Innovation it is in some way similar but basic-school entrepreneurial education and training is much less relevant, buyer sophistication is much more relevant, and we must consider in-house product and process innovators and not only those with market novelties. Additionally, the (negative) enterprise birth indices relationship is increased.

3.2.1 Main structural factors explanation

In this section we continue using Pearson relationship (R) selecting main structural indicators from Table 6. In order to select the most relevant variables, we have made a dendrogram along with a heat map that shows the relationship between the structural variables and the DESI and EIS as we can see in Figure 2.

The dendrogram is created by calculating the Euclidean distance between the different structural variables. In order to build it we must reduce a nxn matrix and reduce it through iterations where we remove the smallest distances. The heat map is calculated using a variant of the Euclidean distance calculates as $dist(x, y) = \sqrt{dot(x, x) - 2 * dot(x, y) + dot(y, y)}$, where $dot()$ represents the scalar product between the two vectors. Therefore, the smaller distance will represent that the two variables are more correlated.

Figure 2 Dendrogram structural variables and heatmap for DESI and EIS main scores



The selected structural indicators finally to analyze are: “Rule of Law”, “Buyer sophistication”, “Eco-innovation”, “Enterprise births”, “Government procurement of advanced technology products”, “Employment share Knowledge-intensive services” and “In-house product innovators with market novelties.”

Trust is important for creating a business environment for carry out risky innovative activities. **Rule of law** captures differences in the extent to which people have confidence in and abide by the rules of society. **Rule of law** 37 measures differences in the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.

Demand factors shape innovation activity in two major ways: for the development of new products, as firms modify and differentiate products to increase sales and market share; and for the improvement of the production and supply processes reducing costs and lowering prices. But a robust indicator measuring the demand for innovation is not available. **Buyer sophistication** taken from Executive Opinion Survey of the World Economic Forum measure of the preferences of individual consumers for innovative products. The degree of **Buyer sophistication** indicates whether buyers focus more on price or quality of products and services.

The **Eco-Innovation** index is a composite indicator based on 16 sub-indicators in five thematic areas (eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency outcomes and socio-economic outcomes). It shows how well individual Member States perform in eco-innovation compared to the EU average. For the EIS results from the 2022 edition of the Eco-IS are used.

Entrepreneurship is important for introducing new innovations on the market. **Enterprise births** measures the share of new enterprise births in the economy in numbers of births of enterprises except activities of holding companies and with 10 employees or more.

Government procurement of advanced technology products measures the extent to which government procurement decisions in a country foster technological innovation based solely on price or on technical performance and innovativeness.

Employment share Knowledge-intensive services is the percentage of employment in knowledge-intensive services¹ versus total employment in services (NACE Rev. 2 G-N). There is an ample literature describing the benefits for these firms in terms of a region: For sample in (Kong et al., 2021) positively manifest that “The establishment of high-tech development zones can improve the innovation capability of knowledge-intensive service enterprises.” And “In terms of service type, if the knowledge-intensive service enterprises belong to the technology

¹ Water transport; Air transport (NACE Rev. 2 50-51); Publishing activities; Motion picture, video and television programme production, sound recording and music publishing activities; Programming and broadcasting activities; Telecommunications; computer programming, consultancy and related activities; Information service activities (NACE Rev. 2 58-63); Financial and insurance activities (NACE Rev. 2 64-66); Legal and accounting activities; Activities of head offices, management consultancy activities; Architectural and engineering activities, technical testing and analysis; Scientific research and development; Advertising and market research; Other professional, scientific and technical activities; Veterinary activities (NACE Rev. 2 69-75); Employment activities (NACE Rev. 2 78); Security and investigation activities (NACE Rev. 2 80)

service category, then the more obvious the positive impact of high-tech zone establishment on the innovation of knowledge-intensive service enterprises.”

In-house product innovators with market novelties includes all enterprises that introduced a product innovation that was developed by the enterprise and that was not previously offered by competitors. This is the most advanced profile for innovation of the seven ones profiles described in EIS.

3.2.2 Second DESI and EIS levels relationships for more influence structural variables

Navigating along these second and third level DESI and EIS variables we are trying to identify which indicators are more shared correlated with the key structural variables previously identified.

Rule of Law

As a better transversal and general digital skilled population and SMEs with a relevant percentage of ICT specialist support, a better Rule of Law appear in terms of digitalization. Also, these countries exhibit a robust mobile broadband take-up and an enhanced digital public service explained because of there have been digitalized time before. Besides, Innovation is fostered with an attractive and international scientist system, where ICT specialist also accompanies, but where innovation is neither entering via SMEs nor having direct impacting in sales. These relationships describe most of the western digitalized stable societies; but besides we can agree, for instance according to (Adams & Akobeng, 2021), that ICT and the inequality link (including threats to civic harmony and democratic legitimacy) can be strengthened by governance measures. And, according to World Bank (World Development Report 2016: Digital Dividends - World Bank Group - Google Libros, n.d.), digital technologies to benefit the whole population requires countries to work on the “analogue complements”, strengthening regulations that ensure competition among businesses and ensuring that public institutions are accountable.

Correlation with DESI variables:

Highly influenced by first level variables, especially those of *Human Capital* (and significantly for “ICT Specialists”), but not for any connectivity indicator (except for a very high correlation with “mobile broadband take-up”)

In terms of integration of Digital Technology “SMEs with at least a basic level of digitalization” appears at first; then, followed by the specific indicators of technologies, lagging, all the references to ecommerce technology. Understanding Eurostat reports (*How Digitalised Are the EU’s Enterprises? - Products Eurostat News - Eurostat*, n.d.) and its Digital Intensity Index (DII) a basic level of digitalization for a company means the use of at least four of twenty selected digital technologies. in 2021 only 55% reach basic level of basic level of digital intensity compared with 88% of large enterprises. Also, there are a huge heterogeneity between European high digitalized countries (Denmark with the 75% of at least a basic level of digitalization) and poor ones (Greece with only a 40% figure). According to one of the targets of the Digital Compass more than 90% of EU SME should reach at least a basic level of digital intensity of 2030, with is according to our findings in this research (because of his high correlation) it is a quite a reasonable objective: the better the best.

For Digital Public Services, all “Rule of Law” appears quite relevant except for “Pre-filled Forms”.

Correlation with EIS variables:

It has a very high correlation with many EIS area level indicators but not for SME introducing innovation indicators (*Innovators area*), *sales impacts* area (because of a low value in knowledge-intensive services exports) and environmental sustainability indicators (*Impacts area*).

Slightly underscored appear someone specific indices distributed across those high ranked areas and specifically related with tertiary education, broadband penetration, innovative SME collaborating and finally, "Job-to-job mobility of Human Resources in Science and Technology" indicator.

Buyer sophistication

Also, Buyer sophistication is addressed by a digital-educated consumer and governments which appreciate innovation, with also a small digital-enabled business and where ICT specialists' presence is relevant in the whole ecosystem. Innovation is aligned with digitalization because is responsible for creating differential knowledge (for sample with PCTs) and being able to channelize it throw employment and finally to sales with a global impact. But it is notorious that ICT specialist and intensiveness in private innovation investment are key to describe societies beginning its digitalization some time ago and therefor, with a solid path after them.

Correlation with DESI variables:

As for other structural indicators connectivity appears lower than the rest, although "Mobile BB take-up" remain as the most correlated variable for this area and in a very high important position.

For Human Capital, "ICT Specialists" is the highest correlated variable although the rest categories for Advanced Skills and Development appear close by. Social media, Big Data and slightly lagged Cloud are the main Digital Technologies indicators, all of them strongly focused on businesses. But again, SMEs with at least a basic level of digitalization also appears in the first position.

Government indicators are not highly correlated; however, we would like to remark the "e-Government" indicator, which explains how the government is digitalized.

Correlation with EIS variables:

The overall behavior is similar to the previous variable analyzed. Main areas in *Framework conditions* rank quite high, although tertiary education is located marginally lower. Attractiveness for the research systems also appears on top positions. Digitalization can be found high but more in a second stage. At the same second level appear *investments area* but there is a remarkable exception for these two specific indicators: "innovation expenditures per person employed", "Employ ICT specialists" which remains quite high.

Innovations activities area rank high but exhibit fragility for specific innovators indices in SMEs and Trademark and Design applications.

Related with *impacts area*, correlations figures offer some decreasing level compared with the rest of areas (for sample for sustainability) except for employments and sales directed related with knowledge-intensive activities and knowledge-intensive services exports.

Eco-Innovation

Quite aligned with Buyer sophistication, Eco-innovation means also a sophisticated digital driven society using advanced technologies for its businesses. Considering innovation, this

factor is also supported by a strong research system able to create differentiation throw knowledge but for this case with the help coming differentially from the public sector.

Correlation with DESI variables:

All first level DESI categories appear with similar relevance than prior structural indices, apart from mobile broad band with shows up because many of eco-innovation process needs for mobile technologies based on IOT. (BUSCAR MENCIÓN)

For Human Capital highlights “ICT specialists” and also business Digital Technologies appear relevant, especially those related with SMEs and AI technologies.

Correlation with EIS variables:

With similarities to prior structural indices, the main correlations are retained in *Framework conditions area* with some weaker value around Digitalization but remaining in a relative middle level.

Investments area follow them in importance outstanding “R&D expenditure in public sector” but lagging “Entreprises providing ICT training”. Innovations activities rank similar than in preceding structural indices (with a very high level in public-private co-publication) repeating weakness in SMEs collaboration and Design Applications intellectual assets.

Impacts area at the bottom in term of correlation only with a middle figure in Environment-related technologies and a modest relative figure in “Employment impacts” second level indicator.

Enterprise births

Apparently, because of its general negative correlation, this indicator is quantifying a lack of dynamism coming from digitalization and innovation creating SMEs in Europe. Countries or regions with low innovation or poor digitalization are creating relatively more new companies but not so knowledge intensive o innovative relevant than the ones created in high developed countries. This is in our opinion a relevant weakness of the innovation-digitalization European system.

Correlation with DESI variables:

It is negative correlated with all DESI areas approximately in the same medium level but stands out from these indicator as “ICT Specialists”, “Mobile BB take-up”, “SMEs with at least a basic level of digital intensity”, “e-Government users” and Cloud technology.

Correlation with EIS variables:

It is also negatively correlated with *Human resources area*, especially with “New doctorate graduates” or the proper research system, with is associate in the same way with innovation activities in term of linkages and patents. Also is affected negatively by a well-financed ecosystem, the R&D investment from public administration and the employment of ICT specialists, or even the use of information technologies (from *Investments area*). It is finally remarkable from *impacts*, the proper negative consequences in less employment in knowledge-based companies.

Government procurement of advanced technology products

As mentioned in prior sections public administration can facilitate digitalization in a country introducing pioneering technologies as Big Data inside their processes and being intensive in ICT specialist human resources; of course, they will need some support from a skilled population able to intensively use their e-government services. Innovative providers and employment pushed by these public expenditures developed those new services and will create additional knowledge potentially exportable.

Correlation with DESI variables:

Connectivity and Integration of Digital Technologies are the less correlated pillars with this structural indicator, but for the last one area, the Big Data sub indicator appears as the highest correlated variable. Regarding connectivity, we see a similar behavior as in other sections, “Mobile BB Take-up” scales up until being first correlated indicator.

Taking into consideration Human Capital, “ICT Specialists” and “Advanced Skills and Development” sub indicators are remarkable.

All sub indicators related with Digital Public Services obtained high correlations scores except “Pre-filled Forms” and “e-Government Users”, explaining than sophisticated digital services for citizens and businesses are the key drivers.

Correlation with EIS variables:

Decreasing the general correlation from *Framework conditions area* Human resources remain high specially for the attractiveness of the research system and percentage of foreign doctorate students. But tertiary education is by far the less relevant (even with low score). Digitalization exhibits a medium behavior.

Investments area maintain a middle level relationship and only it is found good records for ICT specialists. *Innovations activities area* relationship is not good performer though exhibit quite high marks with intellectual assets indices.

Related with *Impacts area*, employment ranks with some good figures in knowledge-intensive activities but are quite poor for sales and environmental indices.

Employment share Knowledge-intensive services

Evidently, ICT Specialists act as a driver for a complex digital society enhancing knowledge-intensive services. But the complete Human Capital ecosystem also is getting benefits from this, not forbidding SMEs with basic digital development presumably playing some relevant consumer role. Mobile connectivity is the favorite technology to grow over it all these digital services. In terms of innovation a direct impact is also associated with the creation of ICT expert employment in these industries, fostered by an international scientist system able to attract doctorate worldwide.

Values specifically for DESI:

Human Capital is the most relevant DESI pillar for this structural indicator, due to “ICT Specialists”.

After *Human Capital*, we have *Integration of Digital Technologies* and *Digital Public Services*. Technologies such as Social Media, Big Data, Cloud and AI appear as relevant; but apparently there is a low correlation (and p-value over 0.05) for those technologies related with environment and e-

commerce. For Digital Public Services the sub indicator for business services ranks the highest correlated, being the others not so far except for “Pre-filled Forms” which rates low with a high p value.

For connectivity, “Mobile BB Take-up” appears as the main variable.

Correlation with EIS variables:

Tractor area here is *Framework conditions* area, especially for those measuring an attractiveness research system. Digitalization appears even with some representativeness.

Investments area is far lagged with a clear exception coming from the use of information technologies indicator and led by a very high score from “Employed ICT specialists”.

Also, *Innovation activities* area exhibit medium-low relation with some specific exception (with somewhat high marks) related with public-private co-publications. *Impacts area* behavior is somehow dual: a very high for employment (of course, in knowledge-intensive activities), little lower for export in knowledge-intensive services and with middle relationship for resource productivity.

In-house product innovators with market novelties

We see that this high profile of innovators is driven by Human Capital considering the demand side sophistication, but not the research system per se. Digitalization is not so relevant except for online technologies that act as pushers of the novelty, especially with social media and SME that are focused to sell locally. But this high-profile innovation occupies a relevant position creating employment, especially for SMEs which are introducing product and process differentiation and collaborating with each other and with the necessary support of R&D expenditures from the public sector. But there is some lack of impact in sales on even in sustainability which is aligned with some findings in (Denicolai et al., 2021) which explains that there even existing a relationship between internationalization, digitalization, and sustainability finally SMEs (rightnow) struggle in pursuing those multiple growth paths at the same time.

Correlation with DESI variables:

The main areas for DESI remain with the same tendency. *Human Capital* and *Integration of Digital Technology* are the most relevant, followed by *Digital Public Services* and with the *Connectivity* at the end.

But for Human Capital the main relationships are focused on more general skills associated with citizens (“Internet User Skills”, “At least Basic Digital Skills”, “Above basic digital skills”, “At least basic digital content creation skills”) with less representation coming from the business skills as “ICT specialists”.

The highest correlated technologies are Social media, Electronic Information sharing and others related with e-commerce (excluding SMEs selling online *internationally*)

Related with Digital Public Services the principal key driver is repeated, coming from users side e-government indicator which is also the most relevant. Connectivity is mere represented by broadband fixed and mobile although not in a very front place.

Correlation with EIS variables:

With not so strong general correlation than prior indices although highlight “linkages” and “innovators” second levels, especially for SMEs performance.

Framework area ranks are still middle-relevant but tertiary education and those measuring internationally competitiveness for the research system appear little lower. *Investments area* ranks in the middle upper position likely explained for R&D expenditure in public sector.

Besides, for *Impacts area*, “Employments impact” second level correlation is remarkable for innovative enterprises but does not appear any relationship with any sales or environmental sustainability indices.

Table 7 Pearson Heatmap (R^2) for selected structural indicators and DESI (in red with no value where $p>0.05$)

	Rule of law	Buyer sophistication	Ecoinnovation	Enterprise births	Government procurement of advanced technology products	Employment share Knowledge-intensive services	In-house product innovators with market novelties
DESI	.695	.445	.468	.350	.377	.347	.315
1. Human Capital	.662	.415	.407	.180	.358	.370	.345
1a Internet User Skills	.549	.297	.373	.153	.235	.292	.368
1a1 At least Basic Digital Skills	.549	.285	.373	.173	.227	.282	.398
1a2 Above basic digital skills	.513	.307	.307	-	.218	.232	.324
1a3 At least basic digital content creation skills	.499	.261	.387	-	.229	.330	.307
1b Advanced Skills and Development	.540	.414	.282	.142	.396	.323	-
1b1 ICT Specialists	.688	.627	.417	.405	.552	.546	.221
1b2 Female ICT specialists	-	-	-	-	-	-	-
1b3 Enterprises providing ICT training	.446	.326	.214	.248	.188	.319	-
1b4 ICT graduates	-	-	-	-	-	-	-
2. Connectivity	.203	.160	.289	.241	-	-	-
2a Fixed broadband take-up	-	-	-	-	.148	.209	-
2a1 Overall fixed BB take-up	-	-	-	-	.161	.236	-
2a2 At least 100 Mbps fixed BB take-up	-	-	-	-	-	-	-
2a3 At least 1 Gbps take-up	-	-	-	-	-	-	-
2b Fixed broadband coverage	-	-	-	-	-	-	.206
2b1 Fast BB (NGA) coverage	-	-	-	-	-	-	-
2b2 VHCN coverage	-	-	-	-	.155	-	-
2c Mobile broadband	-	-	.295	.157	-	-	.213
2c1 5G spectrum	-	-	.233	-	-	-	-
2c2 5G coverage	-	-	-	-	-	-	-
2c3 Mobile BB take-up	.699	.420	.427	.375	.306	.407	-
2d Broadband price index	-	-	-	-	-	-	-
2d1 Broadband price index	-	-	-	-	-	-	-
3. Integration of Digital Technology	.547	.389	.393	.290	.220	.271	.305
3a Digital intensity	.548	.436	.396	.329	.268	.320	.266
3a1 SMEs with at least a basic level of digital intensity	.548	.436	.396	.329	.268	.320	.266
3b Digital technologies for businesses	.523	.427	.418	.257	.254	.311	.287
3b1 Electronic Information Sharing	.336	.187	.229	.168	.141	-	.294
3b2 Social media	.466	.480	.317	.171	.244	.337	.299
3b3 Big data	.388	.438	.148	-	.379	.269	.188
3b4 Cloud	.385	.316	.275	.315	.174	.272	-
3b5 Artificial intelligence	.441	.275	.374	.156	.232	.184	.195
3b6 ICT for environmental sustainability	-	-	-	-	-	-	-
3b7 e-Invoices	-	-	.196	-	-	-	-
3c e-Commerce	.265	-	-	.156	-	-	.222
3c1 SMEs selling online	.164	-	-	-	-	-	-
3c2 e-Commerce turnover	.214	-	-	.256	-	-	.281
3c3 Selling online cross-border	.265	-	-	-	-	-	.182
4. Digital Public Services	.532	.297	.266	.262	.328	.243	.222
4a e-Government	.532	.297	.266	.262	.328	.243	.222
4a1 e-Government Users	.524	.215	.270	.318	.157	.20	.452
4a2 Pre-filled Forms	.299	.145	-	-	.141	-	-
4a3 Digital public services for citizens	.475	.226	.256	-	.363	.233	-
4a4 Digital public services for businesses	.377	.286	.157	.296	.327	.298	-
4a5 Open Data	-	-	-	-	-	-	-

Table 8 Pearson Heatmap (R^2) for selected structural indicators and EIS (in red and no value where $p > 0.05$)

	Rule of law	Buyer sophistication	Ecoinnovation	Enterprise births	Government procurement of advanced technology products	Employment share Knowledge-intensive services	In-house product innovators with market novelties
EIS	.722	.705	.581	.578	.460	.449	.491
1.1 Human resources	.761	.604	.523	.497	.395	.458	.428
1.1.1 New doctorate graduates	.566	.430	.584	.532	.334	.203	.312
1.1.2 Population with tertiary education (Regional)	.262	.285	-	.165	.150	.289	.208
1.1.3 Population involved in lifelong learning (Regional)	.655	.438	.489	.337	.295	.352	.281
1.2 Attractive research systems	.688	.718	.548	.430	.487	.621	.404
1.2.1 International scientific co-publications (Regional)	.559	.519	.477	.381	.284	.520	.422
1.2.2 Scientific publications among the top 10% most cited (Regional)	.548	.704	.570	.369	.401	.410	.260
1.2.3 Foreign doctorate students as a % of all doctorate students	.60	.583	.334	.318	.560	.613	.242
1.3 Digitalisation	.575	.40	.288	.186	.317	.257	-
1.3.1 Broadband penetration	.313	.259	-	.140	.231	-	-
1.3.2 Individuals with above basic overall digital skills (Regional)	.518	.308	.325	-	.217	.240	.322
2.1 Finance and support	.463	.328	.370	.529	.192	-	.398
2.1.1 R&D expenditure in the public sector (Regional)	.404	.193	.466	.281	.164	-	.407
2.1.2 Venture capital expenditures	.327	.270	.269	.333	.198	-	-
2.1.3 Direct and indirect government support of business R&D	-	-	-	.222	-	-	-
2.2 Firm investments	.342	.338	.286	.450	.261	-	.257
2.2.1 R&D expenditure in the business sector (Regional)	.445	.330	.343	.462	.208	-	.310
2.2.2 Non-R&D innovation expenditures (Regional)	-	-	-	-	-	-	-
2.2.3 Innovation expenditures per person employed (Regional)	.336	.538	.279	.353	.338	.211	.242
2.3 Use of information technologies	.668	.551	.362	.380	.420	.494	.233
2.3.1 Enterprises providing ICT training	.452	.323	.213	.251	.187	.309	-
2.3.2 Employed ICT specialists (Regional)	.704	.637	.418	.407	.566	.549	.242
3.1 Innovators	.163	.229	.229	.209	-	-	.514
3.1.1 SMEs introducing product innovations (Regional)	-	.173	.20	.184	-	-	.461
3.1.2 SMEs introducing business process innovations (Regional)	.206	.262	.238	.215	-	.140	.524
3.2 Linkages	.518	.474	.40	.369	.223	.327	.681
3.2.1 Innovative SMEs collaborating with others (Regional)	.20	.314	.155	.259	-	.162	.704
3.2.2 Public-private co-publications (Regional)	.606	.479	.622	.346	.251	.444	.454
3.2.3 Job-to-job mobility of HRST	.20	-	-	-	-	-	.211
3.3 Intellectual assets	.480	.472	.463	.262	.460	.237	.235
3.3.1 PCT patent applications (Regional)	.615	.525	.583	.427	.415	.183	.320
3.3.2 Trademark applications (Regional)	-	-	-	-	.156	.180	-
3.3.3 Design applications (Regional)	.240	.218	.271	-	.251	-	-
4.1 Employment impacts	.394	.572	.297	.343	.323	.413	.541
4.1.1 Employment in knowledge-intensive activities (Regional)	.401	.616	.219	.282	.395	.756	.302
4.1.2 Employment in innovative enterprises (Regional)	.180	.243	.192	.20	-	-	.490
4.2 Sales impacts	.188	.290	.177	.299	-	.187	-
4.2.1 Exports of medium and high technology products	-	-	-	.20	-	-	-
4.2.2 Knowledge-intensive services exports	.222	.584	.218	.201	.360	.404	-
4.2.3 Sales of new-to-market and new-to-firm innovations (Regional)	-	-	-	-	-	-	-
4.3 Environmental sustainability	.228	.292	.293	.256	.258	.273	-
4.3.1 Resource productivity	-	.259	-	-	.170	.30	-
4.3.2 Air emissions by fine particulates (Regional)	.155	.145	.165	.193	-	.162	-
4.3.3 Environment-related technologies	.225	-	.340	.275	.183	-	-

3.2.3 GDP per capita

Table 9 Pearson R for GDP per capita with main components from DESI and EIS (components with $p > 0.05$ not shown except for second level variables that appears in red and not value)

	EIS indicator	R EIS	DESI indicator	R DESI
Framework conditions	1.1 Human resources	.663	1. Human Capital	.585
	1.1.1 New doctorate graduates	.507	1a Internet User Skills	.515
	1.1.2 Population with tertiary education	.592	1a1 At least Basic Digital Skills	.503
	1.1.3 Population involved in lifelong learning	.478	1a2 Above basic digital skills	.474
	1.2 Attractive research systems	.758	1a3 At least basic digital content creation skills	.538
	1.2.1 International scientific co-publications	.637	1b Advanced Skills and Development	.554
	1.2.2 Scientific publications among the top 10% most cited	.683	1b1 ICT Specialists	.640
	1.2.3 Foreign doctorate students as a % of all doctorate students	.753	1b3 Enterprises providing ICT training	.394
	1.3 Digitalisation	.495	1b4 ICT graduates	.378
	1.3.2 Individuals with above basic overall digital skills	.483	2. Connectivity	-
Investments	2.1 Finance and support	-	2a Fixed broadband take-up	.387
	2.1.2 Venture capital expenditures	.376	2a1 Overall fixed BB take-up	.401
	2.2 Firm investments	-	2c3 Mobile BB take-up	.702
	2.2.3 Innovation expenditures per person employed	.475	3. Integration of Digital Technology	.415
	2.3 Use of information technologies	.571	3a Digital intensity	.439
	2.3.1 Enterprises providing ICT training	.389	3a1 SMEs with at least a basic level of digital intensity	.439
Innovation activities	2.3.2 Employed ICT specialists	.657	3b Digital technologies for businesses	.413
	3.1 Innovators	-	3b2 Social media	.421
	3.2 Linkages	.570	3b3 Big data	.534
	3.2.2 Public-private co-publications	.639	3b5 Artificial intelligence	.429
	3.3 Intellectual assets	.394	4. Digital Public Services	.482
Impacts	4.1 Employment impacts	.552	4a e-Government	.482
	4.1.1 Employment in knowledge-intensive activities	.791	4a1 e-Government Users	.428
	4.2 Sales impacts	.468	4a3 Digital public services for citizens	.467
	4.2.2 Knowledge-intensive services exports	.621	4a4 Digital public services for businesses	.509
	4.3 Environmental sustainability	.579		
	4.3.1 Resource productivity	.575		
	4.3.2 Air emissions by fine particulates (Regional)	.469		

In this section we make a further analysis specifically for GDP per capita, as a relevant economic indicator as we prior appreciated in Table 6. For this latest analysis, we take into account Table 9.

Considering DESI, the most important relationship with GDP per capita come up from the whole are of *Human Capital area* indicators, especially for the variable “ICT Specialists”. In this area, the weakest relationship could be associated with lifelong learning inside enterprises and also “ICT graduates” which depict some kind of weakness with societies not been able to leverage in these factors to foster digitalization.

For the rest of areas exists a notable correlation with “Mobile BB take-up” despite the overall low correlation between connectivity and GDP per capita. *Integration of Digital Technologies* in business and government act as a secondary driver, except for the case of Big Data.

Mobile connectivity it’s been for long time a source of economic progress and Mobile Broad Band (4G) take-up maybe represents its main indicator. But lately high degree of penetration in Europe and in other advanced countries (most of the time superior to 100%) are giving passed to new ways of creating value and wealth with implied mobile technologies such as IOT or 5G. In the first case there is not such direct indicator in DESI so we couldn’t correlate. In the second one, the correlation for 5G is still poor, because of roll-out of 5G are now under deployment specifically for industrial user cases.

Considering EIS and second and third level indicators stands out from *Framework conditions* area referred with the attractiveness of the scientist system are quite high, but also and specially “Employment in knowledge-intensive activities” and “Knowledge-intensive services exports” from *impacts*.

Finally, “Employed ICT specialists” it is from *Investment areas* the unique relevant indicator in a whole quite weak complete area.

As a main conclusion we see a stunning growing place for GDP per capita driven both by digitalization and innovation with an extensive specialized technical labor force. Here, looking at the digital compass we see a target for Europe of 20 million employed ICT specialists by 2030, which it is a substantial challenge to reach (Needs Analysis, Europe’s Most Needed Software Roles and Skills – ESSA, n.d.), in terms of a necessity of creation of plus 12.5 million of ICT Specialists during this decade. Besides, this problematic is reaffirmed in our studied with the low correlation detected with lifelong learning inside enterprises and “ICT graduates” with show up a real deficit even to create or reskill enough talent to get these 20 million figures.

3.3 Analyzing regions (NUTS2) for DESI and RIS

Analyzing relationships between digitalization and innovation throw all European regions (or in terms of NUTS2) could provide us some additional clarification.

Unfortunately, there is not an equivalent for DESI index in European regions despite some efforts made for understanding how policies and investment are alienated with the local needs (Reggi & Gil-Garcia, 2020). For innovation EIS is declined with a specific index named RIS (Regional innovation scoreboard) (EUROPEAN COMMISSION, 2021) revised in 2021 and which is provided for 240 regions across Europe with 21 of the 32 indicators used in the EIS 2021. Alas, structural regional info (NUTS2) which accompanies RIS is not as completed as EIS structural data. So, for this study we will focus on GDP per capita (value taken from 2019, attending its methodology report).

In Table 10, we present correlations between RIS score, GDP per capita with its inside variables. The proper Pearson correlation (R) between RIS score and GDP per capita is 0.7451, with it is quite relevant.

For RIS and its inside variables, those refereed which *Linkages assets*, Attractiveness of the international research systems, R&D in business sector and employment in innovative enterprises are the strongest correlated and describe in a quite comprehensible manner which are the key drivers for success in an innovative region.

For GDP per capita, main correlation highlights is for Use of information technologies, in concrete for Employed ICT specialists.

But if we look through most relevant cross-correlations shared of GDP per capita with RIS we see at first position innovation activities as “Public-private co-publications” and then “PCT Patents applications”, results of knowledge-asset creation; After that, some close, appears “R&D expenditure in the business sector” and “Employed ICT specialists” responsible for activating this innovative-knowledge inside the enterprise; and after that, most of the

Framework Conditions (except “Population related with tertiary education”) and employment impacts.

On the other hand, is highlighted that neither RIS nor GDP per capita are high related with “Sales of new-to-market and new-to-firm innovations”. Understanding this indicator, we see that was built exclusively with SMEs unlike its EIS similar indicator in which all enterprise were incorporated. The same happened with other RIS firm indicators, identified with (*) in Table 10. So, this current RIS methodology, eliminating those large multi-establishment companies from their variables (that presumably aggregate innovation activities in head-offices not in the place where they really occur), additionally shows us that SMEs innovative performance could be not enough to foster a region as an innovative place.

Table 10 Pearson R for RIS global score and structural value GDP per capita versus RIS main variable components

RIS indicator			RIS global score R	GDP per capita R
Framework Conditions	1.1 Human Resources	1.1.2 Population with tertiary education	.495	.485
		1.1.3 Population involved in lifelong learning	.694	.488
	1.2 Attractive research systems	1.2.1 International scientific co-publications	.761	.605
		1.2.2 Scientific publications among the top 10% most cited	.752	.473
	1.3 Digitalisation	1.3.2 Individuals with above basic overall digital skills	.782	.527
Investments	2.1 Finance and support	2.1.1 R&D expenditure in the public sector	.701	.451
		2.2.1 R&D expenditure in the business sector	.787	.634
	2.2 Firm investments	2.2.2 Non-R&D innovation expenditures (*)	.212	.129
		2.2.3 Innovation expenditures per person employed (*)	.673	.464
	2.3 Use of information technologies	2.3.2 Employed ICT specialists	.654	.711
Innovation activities	3.1 Innovators	3.1.1 SMEs introducing product innovations (*)	.663	.365
		3.1.2 SMEs introducing business process innovations (*)	.612	.408
	3.2 Linkages	3.2.1 Innovative SMEs collaborating with others (*)	.687	.459
		3.2.2 Public-private co-publications	.836	.673
	3.3 Intellectual assets	3.3.1 PCT patent applications	.855	.595
		3.3.2 Trademark applications	.590	.547
		3.3.3 Design applications	.412	.354
Impacts	4.1 Employment impacts	4.1.1 Employment in knowledge-intensive activities	.578	.605
		4.1.2 Employment in innovative enterprises (*)	.749	.439
	4.2 Sales impacts	4.2.3 Sales of new-to-market and new-to-firm innovations (*)	.360	.216
	4.3 Environmental sustainability	4.3.2 Air emissions by fine particulates	.546	.397

How could we build up some kind of regional DESI? This question is not solved at this moment, but in this study, we tried to briefly approximate setting some proxy variables from RIS; so, we have looked throw RIS variables and then finding which third level digitalization variables from DESI are most correlated. As we have seen in Table 3 comparing DESI third levels indicator with general score EIS and Pearson correlation the results are consistent.

In Table 11 we present the results.

Table 11 Spearman correlation (R^2) for most related DESI and RIS variables

		RIS third level variables	
		1.3.2	2.3.2
		Individuals with above basic overall digital skills (Regional)	Employed ICT specialists (Regional)
DESI third level variables	1b1 ICT Specialists		.994
	1a2 Above basic digital skills	.996	

- In “Individuals with above overall digital skills” and “Employed ICT”, our proxies for digitalization in a region act as a relative modulator of innovation. The more digitalized a country is considering these indices, the more their different regions (even with their inside specific heterogeneity) are more sophisticated in term of innovation.
- Being an ample heterogeneity of innovation and digitalization in a country, many times the capital is heading the country in these aspects.

Figure 3 we have additionally depicted across 240 regions, RIS, GDP per capita (per region) and DESI in a continuous representation from most digitalized (left side) to least digitalized (right side). We also have added those prior selected RIS third level variables represented in a secondary axis as a proxy indicator of regional digitalization.

In Figure 4 we represent in a scatter plot every European region, using y coordinate for the RIS variable and x coordinate for GDP per capita, this last one in logarithmic scale. The size of every ball is the media for our digital proxy variables taken from RIS.

Also, we have included two linear tendencies for Poland and Sweden as a sample of the variation between regions for these two different models of countries which describe the heterogeneity in a country but also the intimal dependency between GDP per capita and innovation for a region. We had remarked its capitals and in Figure 6 we had compared them with two Spanish regions, described in the next chapter.

For both representations we can conclude:

- Reaffirmed that GDP per capita per region and innovation in a region are highly associated.
- “Employed ICT” interpreted as a proxy for digitalization appears highly correlated with regional innovation and GDP, pointing the most advanced regions.
- “Individuals with above overall skills” showed less variation inside a country.
- “Individuals with above overall digital skills” and “Employed ICT”, our proxies for digitalization in a region act as a relative modulator of innovation. The more digitalized a country is considering these indices, the more their different regions (even with their inside specific heterogeneity) are more sophisticated in term of innovation.
- Being an ample heterogeneity of innovation and digitalization in a country, many times the capital is heading the country in these aspects.

Figure 3 Plot including RIS, DESI, GDP per capita and most correlated RIS third values with digitalization. Capital Regions appear remarked.

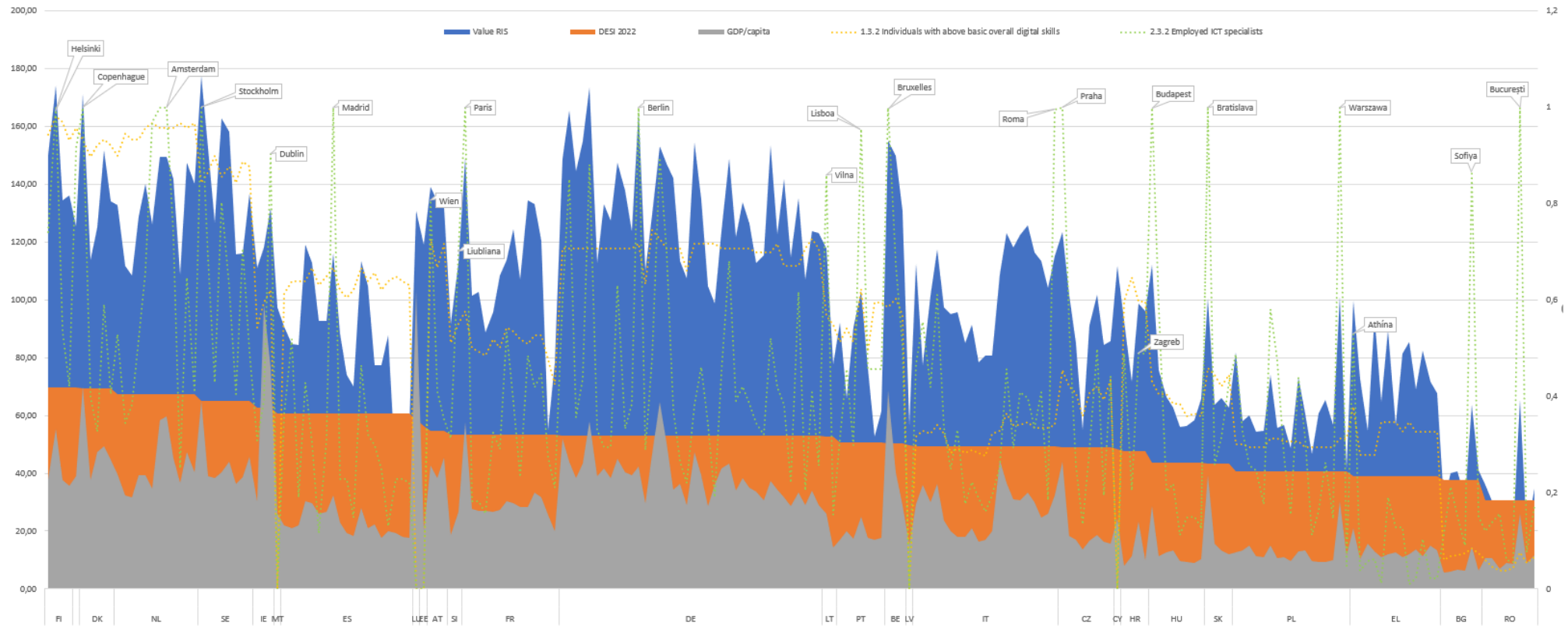
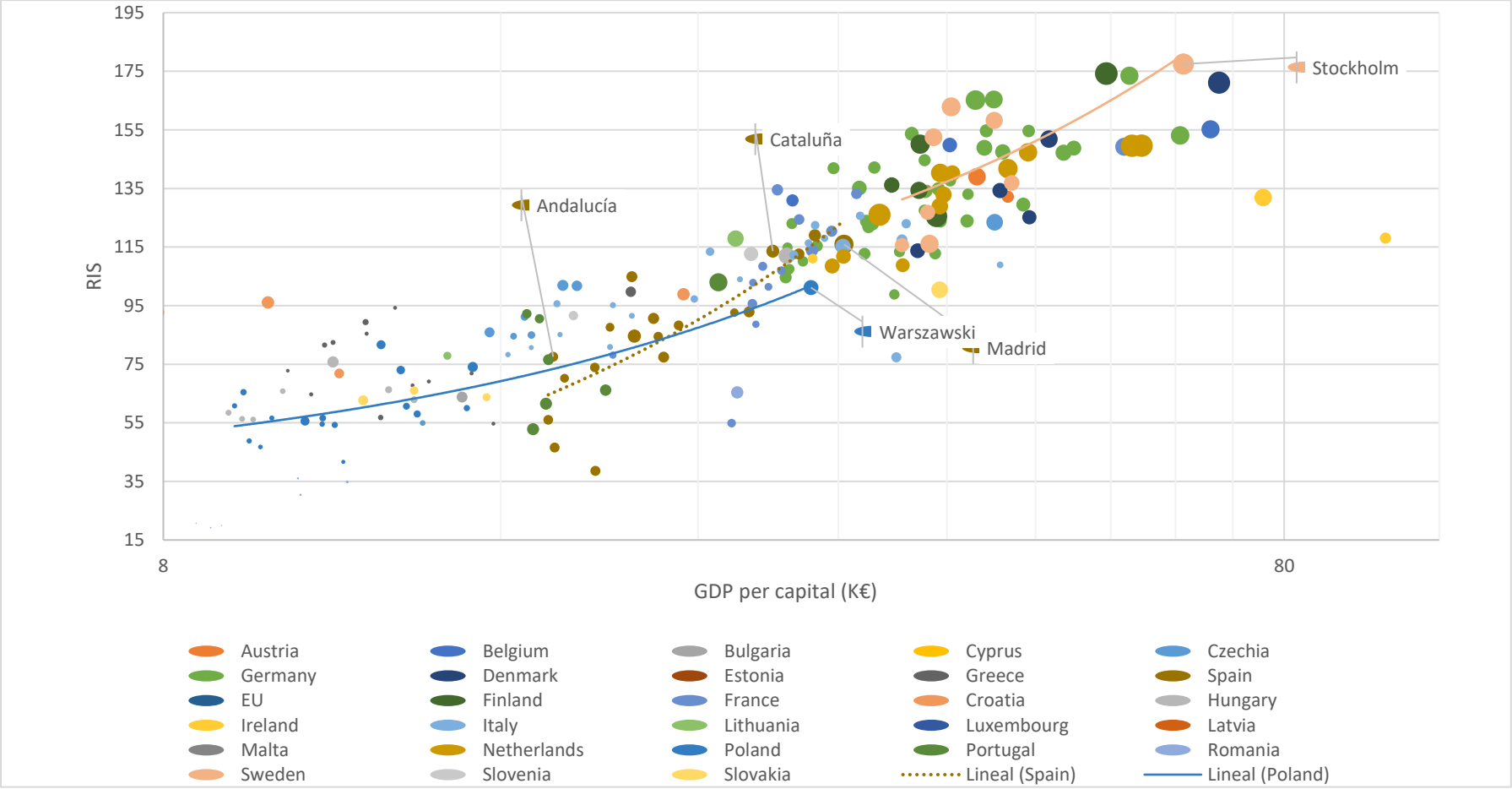


Figure 4 Another plot, including RIS, GDP per capita and most correlated RIS third values with digitalization with a different representation. Poland, Sweden and Spain lineal correlation for each country is included.



3.3.1 Analysis for some regions in Spain

For our study we present two Spanish regions.

We have chosen them because of its specific digitalization index built by regional governments in Spain using similar DESI methodology: Andalucía (*Portal de Digitalización y Sociedad Digital - DESI | Instituto de Estadística y Cartografía de Andalucía*, n.d.) for year 2022 and Catalunya (*Portada | Economía y Sociedad Digitales de Catalunya 2021*, n.d.) for year 2021.

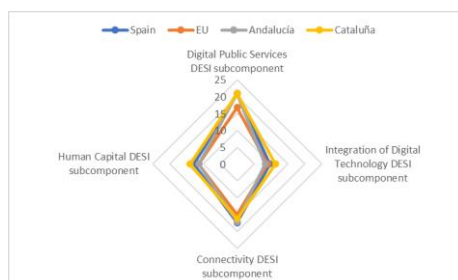
Andalucía based on Eurostat, and according to its GDP per capita in 2020 (in PPS, expressed as index EU27=100), is 63.23, ranked 189 in Europe.

Andalucía is slightly above the UE27 overall digitalization media with a 57.5 figure, compared with the European value of 52.3. Its digitalization is mainly pushed by Public Services Digitalization, so it is ranking very firstly in Europe in this area; Connectivity, and more specifically fixed broadband connectivity is another key driver, both for take-up and coverage also ranking at the very first positions. Those similar characteristic pattern appears globally for Spain (which is in sixth position for Public Services Digitalization, seventh in fixed broadband take-up and first in fixed broadband coverage). On the other side, considering integration of Digital Technology its position is much weaker even lower than the UE media.

Considering our selected proxy digitalization indexes taken from RIS 2021 “individuals with above basic overall digital skills” and “Employed ICT specialists” Andalucía is ranked in 117th and 172th positions respectively. We must underline the first indicator as a seed of success in digitalization and innovation but as we will see in the next paragraphs there are other trade offs values which create hard interferences.

According with RIS Andalucía ranks 177 as an “Emerging Innovation+” which means it is between 52.1% and 70% of EU average, lagged in Spain, which as a country with a moderate level of innovation. Underscore positively for Andalucía its position as a Top moderate performer in International scientific co-publications and even as a bottom strong performer in R&D expenditure in the public sector. But, unfortunately, the lack of R&D expenditure in the business sector (ranked 192th) and innovation expenditures per person employed in SMEs (rank 198th) ballast his ultimate innovation performance. The results are that there are a low number of SMEs introducing product innovation (ranked 222th) and process innovation (ranked 178th). *The lack of enough digital business sophistication could explain this.*

Figure 5 Andalucía, Cataluña, Spain and UE DESI main indicators. Cataluña for 2021, the rest for 2022.



Cataluña based on Eurostat, and according to its GDP per capita in 2020 (in PPS, expressed as index EU27=100), is 99.08, ranked 91th in Europe.

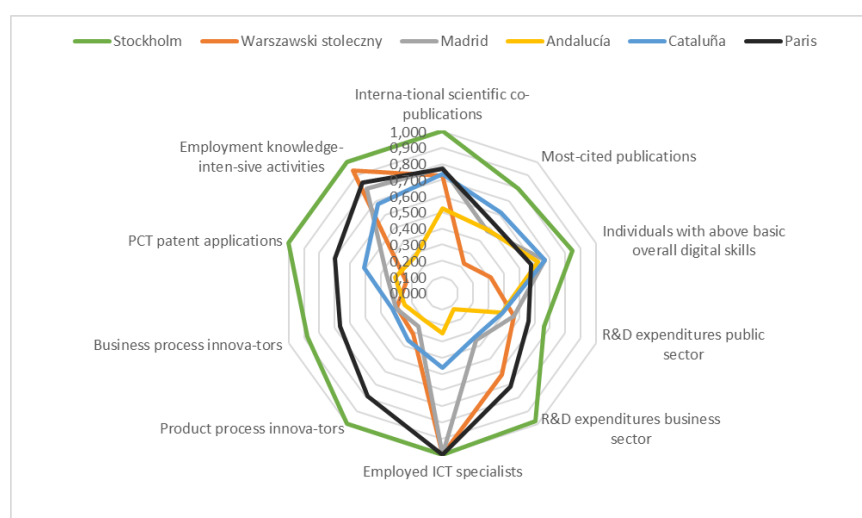
Cataluña in 2021 is above the UE media in terms of Digitalization with a 62.4 score and, with an upper figure, compared with the Spain media (57.5) that year. As similar as to Andalucía very important overscores come from Public Services digitalization and Connectivity (specifically because of an advanced fixed broadband infrastructure). But additionally, it is relevant their support from Human Capital and Integration of Technology (ranking 7th and 8th in EU respectively being compared with national DESI indicator)

Considering our selected proxy digitalization indexes taken from RIS 2021 “Individuals with above basic overall digital skills” and “Employed ICT specialists” Catalunya is ranked in 97th and 83th positions respectively. Both values are high and represent one developed region, only surpassed by Madrid and Asturias for ICT specialists (ranking at the top positions and 67th respectively for these regions in EU) and for Madrid in “individuals with above basic overall digital skills” (ranked 96th) in Spain.

According with RIS data Cataluña ranks 108th as an “Moderate Innovator+” which means it is between 90% and 100% of EU average, heading together with País Vasco and Madrid (ranked 93 and 100 respectively) the most innovative regions in Spain. Its strong position is exhibited as top strong performer in international co-publications and even as a better Top strong performer in Scientific publications among the top-10% cited publications (ranked 77th). R&D expenditure in both public and business sector perform in an advanced group (Middle strong performers) ranks 108th and 102th respectively. Also remarkably is the Employment in knowledge-intensive activities (ranking 65th) accompanied by a top strong performance in PCT patents applications (ranked 100th) and leading this variable in Spain.

But repeating the behavior we saw in Andalucía (just only slightly improved) there is in Cataluña an adverse performance for innovations in SMEs introducing product innovation (ranking 183th) and process innovation (ranking 166th) acting as a barrier to scale on the most innovative European regions.

Figure 6 Comparative for Andalucía and Cataluña versus others European Regions: Warszawski (Poland) and Stockholm (Sweden). Also included Paris and Madrid (NUTS2 Region) for comparison.



4 Conclusions and some answers

In this Section we try to answer questions made at the beginning of the paper understanding how different variables along indexes as DESI and EIS/RIS fit for digitalization and innovation.

To begin, we will recapitulate our main observations along this research.

(Borowiecki et al., 2021) argues that analyzing the “DESI synthetic index and its components, there is generally an increase in convergence between the EU-28 countries” and “The Integration of Digital Technology area was the only one where increasing polarization of results was observed”. As first conclusion, taken from Section 3.1.1, we saw the relevance of integration of digital technologies (especially for SMEs with at least some digital intensity) and human capital (considering ICTs specialists) for a healthy digitalization associated with innovation. So, we can agree in terms of a providing to the Integration of Digital Technologies such as first point attention in European Union strategy and policies.

On the other hand, from Section 3.1.1 and other sections (for sample Section 3.2) we have highlighted that Broadband connectivity (apart from Mobile Broad Band Connectivity) is not highly associated with innovation, maybe because right now has evolved from providing clear differentiation to be right now a key infrastructural builder, indispensable to develop Digital Technologies upon, and then to deploy further innovation.

From Section 3.1.2 as a second conclusion, the relation between Digitalization and Innovation is fostered mainly by human capital and a competent international research system but unfortunately is shorted from a clear support from SMEs; and R&D business and private investments are not pushing digitalization with clear intensity. Later (Figure 6), we have seen that those variables are responsible to create differentiate high performance Regions.

From Section 3.2.2, observing structural variables, we can describe Digitalization and Innovation in Europe likely based on a stable economy, with an advanced consumer behavior in the private and public sphere and where there exists an in-house strong product and process innovation with intensive employment in services. However, there is a negative correlation with the number of births of companies. In (Huarng & Yu, 2022) is described and analyzed the whole relation inside the Global Innovation Index (GII) and conclude that when all antecedents, but Market Sophistication are Positive, The GII tends to be positive and on the other hand, when all antecedents but market sophistication are Negative, the GII tends to be positive. We can confirm this asseveration partially understanding how market sophistication describe an advanced consumer behavior and European innovation.

In Section 3.2.3 we saw a growing place for GDP per capita driven both by digitalization, confirming (Fernández-Portillo et al., 2020) who explores positives relationship between GDP and ICT, and innovation, considering an extensive specialized technical labor force as a common driver for both. So, specialize ICT labor force will be one of the key challenges for this decade in terms of European strategy.

In Section 3.3 we navigated inside regions, showing a deficit for a specific digitalization index which could state heterogeneity. Then, using RIS we described such a strong relationship between GDP per capita and innovation; also we found “Individuals with above overall digital skills” and “Employed ICT” as proxies for digitalization in a region acting apparently as a relative modulator of innovation: the more digitalized a country is considering these indices,

the more their different regions (even with their inside specific heterogeneity) are more sophisticated in term of innovation.

In Section 3.3.1 we explored two Spanish regions, Andalucía and Cataluña, with different sophistication degrees but sharing advanced positions in terms of connectivity and public digital services. But we see, compared with other regions, as Warszawski (Poland) and Stockholm (Sweden), the importance of Employed ICT specialists to push forward digitalization in the close future. And in terms of innovation that, not only the knowledge creation part (based on research and PCTs) is relevant but it is crucial the incorporation of these capabilities inside firms, creating real knowledge driven companies.

Specifically for SMEs we have detected a generalize lack of performance (for innovation and digitalization) and finally a lack of sales impact. Related with innovations around SME and its drivers we found literature arguing (Hervás-Oliver et al., 2021) that “SME innovation ... is profoundly influence by location and context ... innovation policies fundamentally based on a place-blind increase of R&D investment may not deliver the best outcomes in regions where the capacity of SMEs is to benefit from R&D is limited. We posit that collaboration and regional specificities can play a greater role in determining SME innovation, beyond just R&D activities.”. We can confirm and so, understand how important local but sophisticated SMEs for regional innovation and digital transformation are.

Trying to answer our first question: **Are all economical efforts around innovation well addressed to foster digital transformation?**

As we have seen in Section 3.1 there is an intimate relationship between them. Considering correlations of DESI secondary areas versus EIS there are a relevance of Integration of Digital Technologies as Cloud, AI and Big Data (with sophisticated SMEs as front-door from innovation) and human capital (ICT Specialist). On the other side, considering second level of EIS score with DESI, also human capital and a competent international research system are key drivers for Digitalization.

Moreover, some shadows appear: as we have observed, there is a general lack of support from SMEs acting as a collaborative innovator stakeholder and besides, R&D business and private investments are not pushing digitalization with clear intensity in all territories.

Taking in consideration Section 3.2 and those structural variables both affecting Digitalization and Innovation in UE we can understand that Rule of Law (political and social stability), Buyer sophistication (for public and private sector able to incorporate differentiation), and the ability to create Employment in Knowledge-intensive services with Top R&D spending enterprises would describe our general scenario in Europe as a developed continent. Innovation aligned with these premises will drive Digitalization as a medium to accelerate those innovative products and services and create wealth and prosperity (Hajighasemi et al., 2022).

Secondly, **to what extent a country offers a different behavior across this intime relationship between digitalization and innovation?**

In Section 3.2.3 we revealed that GDP per capita is a main structural factor determining digitalization performance with a very high relationship with ICT specialists and Mobile BB take-up. Also, Employed ICT specialists appear as a core and intime relationship shared with innovation.

Analyzing in Section 3.3 what is happening inside Regions and using RIS score correlations, we see as most influential factors activities as “Public-private co-publications” and then “PCT Patents applications”, responsible of knowledge-asset creation; After that, appears “R&D expenditure in the business sector” and “Employed ICT specialists” responsible for activating this innovative-knowledge inside the enterprise.

Not having a specific digital indicator per regions, we have proxied most correlated RIS second level indexes, and then ICT Specialists and Advanced digital skills along population scores appear as significant. In Figure 3 and Figure 4 we have visualized how this ecosystem is working: high GDP per capita will mean high innovation and it will be related many times with a high level of ICT specialist and a population advanced in digital skills.

But there are quite heterogeneities in the same country (Figure 4), there are lagged Regions and others with much better performance. Countries that sharing similarities across connectivity levels and digital government initiatives can differs internally in terms of variables described in those last paragraphs (and plotted in Figure 6).

Here the Capital phenomena could be very relevant. Because IT talent is most of the times concentrated in those cities when they act as “innovation hubs” and because of the most top firms and theirs headquarter are located there, related with their digital transformation they will consume most of those specialized workers. So, in these areas, innovation and digitalization can work healthy together. As a second derivate and as former hypothesis to study this Capital phenomena could also happen in other vast regions, apparently lagged, but where their most populated cities could exhibit the same behavior and where they could act as digital/innovative pushers for these areas (Barcelona for Cataluña, Sevilla, or Málaga for Andalucía). Perhaps, digital agenda 2030 could accelerate digitalization taking into consideration those capital regions capabilities and possibilities.

And finally, in which aspects, higher degrees in innovation means a higher advantage for the economic and social digitalization in a country?

Partially this question has been answered in the past paragraphs and last questions.

To conclude, a new DESI would be needed, incorporating the NUTS2 sensibility for the Regions, to work jointly with RIS and provide a robust answer to describe intimate relationships between Innovation and Digitalization.

We have described along this study imbalances across European regions that make difficult to set a single policy for them and we presume can even shorten innovation. Maybe could be much better to incorporate in Digital Compass a flexible framework of policies considering those geographical innovation hubs not only located in populated National Capitals; and then, facilitating a much more opportunity for a distributed value chain across regions for knowledge creation (related for innovation), able to create sophisticated services (and fostering digital transformation in Regions), integrating local but sophisticated SMEs and able to attract and create enough IT talent to succeed in our European 2030 challenge.

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