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ORIGINAL RESEARCH

Digitalisation in Italy: Evidence from a New Regional Index

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Abstract

The geographic digital divide has a relevant, though largely unexplored, within country dimension. This paper proposes an index of digital development for the Italian NUTS2 regions (rDESI) based on the European Commission's Digital Economy and Society Index (DESI). The rDESI monitors the regional digital divide along five dimensions: (i) the infrastructure and the network usage (connectivity), (ii) the population's digital skills, (iii) the use of internet services by households, (iv) the integration of ICT by firms, and (v) the level of digital services offered by the local government. According to our findings, southern regions tend to lag behind in most of these dimensions, even if infrastructures and the quality of connectivity appears rather homogeneous across the country. We also propose a methodological discussion of the DESI index, highlighting some limitations and possible solutions. The rDESI represents a useful policy instrument, providing a regional mapping of the shortfalls and strengths of digital development, which could be referred to as a guideline for policymakers when deciding about funds allocation and public investment, fostering a more inclusive diffusion of digital technologies all over the country.

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1 Introduction

Given the well-established transforming power of digital technologies for advanced economies, addressing deficits in the digital domain is at the heart of many current policy interventions.

At the European level, the Next Generation EU is a recovery package aimed at supporting European countries towards the digital transition, among other goals. As part of the next long-term EU budget (i.e. the Multi-annual Financial Framework 2021–2027), the Digital Europe Programme will provide strategic funding to projects in five key capacity areas: super-computing, artificial intelligence, cybersecurity, advanced digital skills, and Digital Innovation Hubs. With a planned overall budget of 7.5 billion euros,[1] the programme aims to shape the digital transformation of Europe, benefiting the entire economy and in particular small to medium enterprises (SMEs).

At the national level, the Italian Government has allocated 27% of the Recovery and Resilience Facility budget to the digital transition.[2] Developing an accurate mapping and monitoring tool for specific regions is beneficial to the design of public policies that promote investment in ultrafast broadband infrastructures, favour the accumulation of digital human capital, and foster ICT adoption by firms.

Since 2015, the European Commission monitors the level of digitalisation in the economy and society of EU Member States, by computing the Digital Economy and Society Index (DESI). This composite indicator summarises relevant aspects of Europe digital performance and tracks the developments in the EU27 along five main dimensions: connectivity, human capital, use of the internet, integration of digital technologies, digital public services.

According to the most recent edition of the DESI, as of 2022, Italy ranks 18th out of 27 countries, with an indicator value of 49.3 out of 100, quite close to the EU average (52.3%), but still lagging behind with respect to the top scorers, Finland, Denmark and the Netherlands, all displaying figures close to 70%. As in the past years, the poorest performance is recorded in the human capital sub-index, where our country ranks third last (with only Bulgaria and Romenia further behind), followed by digital public services, where it occupies the 19th position. On the other hand, Italy's ranking has been improving throughout the last years both regarding connectivity and the degree of integration of ICT technologies in firms.

Besides the general delay in digitalisation, which involves the whole country, heterogeneity across Italian territories represents a crucial factor, informing the Government's future action within the Italian digital agenda. Along this line, the prompt availability of disaggregated data, providing a mapping of the digital development within regions represents a fundamental tool to establish priorities of intervention and to efficiently guide

[1] The Digital Europe Programme will complement the funding available through other EU programmes, such as the Horizon Europe programme for research and innovation, the Connecting Europe Facility for digital infrastructure, the Recovery and Resilience Facility, and the Structural funds.

[2] See the detailed allocation in the PNRR document.

investment plans. The aim of this paper is to propose a NUTS2-level[3] index of digital development, called *rDESI* closely following the methodology of the 2020 DESI to analyse the different characteristics of the Italian territory.[4] Notice that we chose to follow the 2020 DESI methodology because of two main reasons: first, data at the NUTS2 level are generally released with delay (one to two years on average) compared to their national correspondent; second, as the DESI methodology has changed since 2021, we would have lost a fundamental term of comparison, if we had applied the new procedure to previous year data. Therefore, we decided to consider the 2020 DESI edition for the present analysis, leaving to the technical appendix, as a robustness check, the construction of an rDESI according to the new methodology, but based on 2019 data, so without the possibility of checking the correspondence with the national level DESI.

Our synthetic measure is built over a wide range of data and allows to identify the gaps across Italian regions in the same five fields included in the national composite indicator.

The scope of our study is twofold: first, we aim at providing a methodological description of the composite regional DESI, by presenting the data sources, the technical characteristics and shedding light on strengths and flaws of our metrics; second, we put our index at work, show our descriptive results and the consequent ranking for the 20 Italian regions (corresponding to 21 NUTS2 areas).

According to our findings, the sub-indices are highly correlated, the strongest relationship being retrieved between the components referred to human capital and to the use of internet services, confirming the low performance on both fronts at the country level. High correlation is also retrieved between internet usage and both integration of ICT by firms, and the level of digital services offered by local public administrations, mainly reflecting the dominance of the demand-side sub-indices within each composite measure.

As of geographical heterogeneity, we find a significant degree of cross-regions variability in all the sub-indices, with Lombardia, Emilia Romagna and Lazio outperforming the rest of the country and Northern and Central-Western regions showing—on average—better figures than Southern and Central-Eastern ones. Similarly to the 2020 DESI, the data we rely on to construct the regional indicator refer to 2019. Clearly, in 2020 many changes have occurred, in response to the extraordinary demand shock of digital applications that the Covid-19 pandemics and the associated Governments' prevention measures have brought about. These structural changes, together with the acceleration towards a digital transition impressed by the National Recovery and Resilience Plan, are not reflected in the current rDESI yet, but they have such a scale that we expect a strong boost in all its subcomponents as well as in the country-level DESI for years to come.

In our analysis we also discuss some methodological issues of the DESI index and propose some possible alternatives, aimed at better capturing key aspects of digitalisation while also tackling some of the current data limitations. Many of our proposals are in line with the ongoing revision of the general index by a Working Group of the European Commission, aiming at constructing an *enhanced* DESI. The 2021 edition of the indicator was already amended to account for some of the proposed corrections, and some are planned to be incorporated in the years to come, including further Key Performance Indicators (KPIs), to provide a more advanced and reliable monitoring tool for the Digital Decade.

[3] https://ec.europa.eu/eurostat/web/nuts/background.

[4] Alaimo and Maggino (2020) performed a similar exercise with respect to the UN sustainable development goals.

The topic considered in this article relates to and extends on two strands of the literature. First, it pertains to the field studying the effects of the digital divide. The latter refers to the gap between those able to benefit from digital technologies and those unable, and it is often measured in terms of availability of broadband infrastructure (i.e. spatially) or in terms of digital literacy (e.g. across genders or cohorts).[5] There is growing evidence that the lack of access to the internet can have consistent repercussions in the education attainments, social capital, and economic domain.[6]

In the European context, Szeles (2018) and Szeles and Simionescu (2020) analyse regional- and country-level determinants of the regional digital divide in the EU. According to their findings, a mix of regional and national measures (e.g. increasing the tertiary education attainments, boosting R &D expenditure, and discouraging early leaving from education) could successfully reduce the digital gap among EU regions. García et al. (2012) find that regional governments' policies on broadband expansion have partly bridged the digital divide within the EU; however, regional level interventions are crucial for the improvement of broadband access. Nucciarelli et al. (2013) examined three regional initiatives aimed to enhance broadband coverage in Italy and concluded that the major threats to local broadband projects success would source from the projects' wide geographical extension (leading to a misalignment between public interests and private business opportunities) and from having set up weak incentives to private investments.[7]

Though our paper is close to the aforementioned literature, insofar as regional heterogeneities are at stake, our current focus is mostly on the methodology. In fact, we first propose an indicator measuring the degree of digitalisation at the local level, discuss its features and statistical properties also in comparison with its national level correspondent, then we employ our regional DESI to provide insights on the Italian geographical distribution of the different components. Along these lines, we also contribute to the stream of literature studying different digitalisation metrics in the wake of the European Commission's work.

In fact, the interest raised by the DESI brought about several reports, investigating national-level performance more in detail, and commenting specific aspects of its methodology and results (see e.g. Bánhidi et al. (2020) for a recent reviewed of this literature).[8] Other works have investigated the degree of digitalisation of the economy and society at the local level.

Some scholars and practitioners have replicated the DESI indicator for specific case studies. For instance, Russo (2020) provides an application for Abruzzo, while Ruiz-Rodríguez et al. (2018) built the Enterprise Digital Development Index (EDDI) for EU states and Spanish regions.[9] Focussing on the digital skills dimension, Bak (2020) has used the

[5] See e.g. Pereira (2016) for a more formal definition of digital divide.

[6] See, for instance, Guriev et al. (2021), Schaub and Morisi (2020), and Campante et al. (2018). Similar results are obtained by Mammadli and Klivak (2020).

[7] It is not just about broadband investments. Other works consider firms related policies. For example, Liberati et al. (2016) using difference-in-differences estimation argue that Italian science and technology parks have partly improved the economic performance and innovative capacity of firms located around them.

[8] For example, Bak (2020) recently tested the so-called Internet Skill Scale in Hungary to assess the level of digital knowledge. Nagy (2019) have compared the DESI of Hungary and Ukraine and concluded that Hungary is more developed with respect to key dimensions of digitalisation. Moroz (2017) exploits the DESI and the Networked Readiness Index (NRI), finding that Poland is less digitally developed than its peers.

[9] The key variables are identified with a factor analysis on series retrieved from the "Community survey on ICT usage and e-commerce in enterprises" of Eurostat.

Internet Skill Scale (ISS) to analyse the performance of Hungary.[10] Differently from our work, these examples are limited to a specific aspect, and do not offer a comprehensive portrait of the digital development.

Some studies are closer in spirit to the proposed rDESI, as they attempt to measure the digital performance in Italy at the regional level: Politecnico di Milano, Piedmont Region, a CENSIS-TIM partnership, and Traversa et al. (2022) have tried to replicate the DESI, while Unioncamere and Ernst and Young have created their own regional index to measure Italian firms' digital level.

The Politecnico di Milano produced a regional version of the DESI, employing 34 out of 44 DESI variables in the 2019 version and 35 out of 37 DESI variables in the 2020 version. In their latest work, the index measuring firms' integration of digital technologies exploits very limited regional variation as it is based on data at the NUTS1 level. Also, some series used for the connectivity index lack regional detail.

Compared to the Politecnico, we employ regional data for firms' integration of digital technologies (see Sect. 2 for details) and we resort to new data sources for connectivity and e-government.[11]

The regional centre for ICT of Piemonte has conducted an analysis in 2019 and in 2020 to describe the performance of Piemonte compared to the other Italian regions. In the 2019 edition, they accounted for all the five dimensions of the DESI and added three e-health variables to the e-government sub-component, Osservatorio Digitale Regione Piemonte (2019). However, their results are presented by sub-index, while the overall composite indicator is not available, making it difficult to compare it with the DESI.

In December 2020, Censis (Center for Social Investments Studies) jointly with TIM, issued a report, investigating the pandemic-induced developments in the use of the internet in the Italian society. Quoting the DESI, they computed a province-level composite indicator of digitalisation, resulting from the combination of 15 variables, Censis-Tim (2020). The main flaw of this index, compared to ours, is that it entirely neglects the connectivity and human capital dimensions.

In the same period, Ernst & Young released a report presenting its Digital Infrastructure Index, a composite indicator measuring the degree of digital infrastructure within a territory, distinguishing between the connectivity infrastructure and the diffusion of the IoT, Ernst & Young (2020).[12] Its main strength lies in providing a broader view of the technological factors enabling development.[13] Differently from other studies, they enriched the analysis providing some statistics at the NUTS 3 level. However, due to the close focus on infrastructure, their work neglects other aspects of digitalisation.

Focusing on the digital competence of firms, Unioncamere appraises the businesses' digital maturity though a self-assessment test. The regional average represents the maturity

[10] This skills measurement framework has been developed and validated by Van Deursen et al. (2016) and is based on 35 questions organised into 5 factors (operational, information navigation, creative, social and mobile).

[11] With respect to measuring the e-government services, it is hard to understand whether our methodology is more accurate compared to the Politecnico's as they do not explain how this is computed. However our sub-index is highly correlated to theirs.

[12] The connectivity infrastructure mainly refers to investments by TLC operators. The diffusion of Internet of Things (IoT) mainly depends on the degree of digitisation of the other types of infrastructures present in the territory: transport, energy, and environmental networks.

[13] More in detail, they considered fixed connectivity (from ADSL to FTTH), wi-fi and mobile connectivity (from LTE to 5 G), IoT technologies (networks and sensors), for a total of 30 combined indicators.

level of the area.[14] This said, no unbiased assessment can be drawn from their data, since the sample consists of respondents who are self-selected by accessing a specific section of the Unioncamere's website.

Lastly, Traversa et al. (2022) constructed a DESI at a regional level (NUTS2) to focus on the strong digital gap between the northern and the southern areas of the country, highlighting also the criticality of human capital and integration of digital technologies index.

On the whole, compared to previous attempts, to the best of our knowledge, our work provides the closest replica of 2020 DESI methodology at the regional level for Italy. In particular, we have improved the data sources used for the connectivity index and for the index of firms' digitalisation.

The rest of the paper unfolds as follows. Section 2 describes the methodology to construct the rDESI and its components, critically addressing its methodological limitations and proposing possible solutions; Sect. 3 illustrates the Italian regions' digital development according to our indicators; Sect. 4 investigates the main correlations among these indices and presents some robustness checks with respect to the aggregation weights. The final section offers some concluding remarks.

2 Building a Regional Index of Digital Development

Closely following the methodology of the index elaborated by the European Commission in the 2020 edition, the regional DESI (rDESI) is structured along five dimensions: connectivity, human capital, use of internet, integration of digital technology, and digital public services.[15] Each dimension is measured by a composite index, which summarises several indicators, as reported in Table 1.

All the indicators are normalised between 0 and 1 with the minimum-maximum method, where the lowest and highest value are taken from the Italian regional values. These indicators are in turn an aggregation of individual data series (appropriately normalised). Data, mostly referred to 2019, were collected for all 20 Italian regions (corresponding to 21 NUTS2 areas)[16]; whenever the information for 2019 was not available, we relied on earlier data, as indicated below. No other imputation techniques were adopted. Therefore, the indicator provides a snapshot of the pre-pandemic situation. We also underline all instances in which the NUTS2 breakdown of the original DESI variable was not available and had to be replaced with a close proxy, leading to minor discrepancies between the DESI and the rDESI.

The rDESI index is computed weighting the five mentioned components; weights strictly follow the Commission methodology, which reflects the EU's digital policy priorities:

[14] In their last report, Trentino Alto Adige ranked first for the digitalisation of small to medium enterprises (SMEs), while Molise ranked last.

[15] See the 2020 methodological note.

[16] The 20 administrative Italian regions correspond to 21 NUTS2 regions, because the autonomous provinces of Trento and Bolzano in Trentino Alto Adige are accounted for separately. When data were unavailable at the province-level, we attributed to the provinces of Trento and Bolzano the regional value of Trentino Alto Adige.

$$rDESI = 0.25\ \text{Connectivity} + 0.25\ \text{Human Capital} + 0.15\ \text{Use of Internet services} + 0.20\ \text{Int. of digital technology} + 0.15\ \text{E-government}. \quad (1)$$

In the following paragraphs, we present and describe the data series employed to construct each dimension of our metrics, we address some critical issues regarding both the methodology and the data sourcing, and propose some possible alternatives.

Our suggestions aim to contribute to the debate on what might be revised of the current DESI index in order to continue building up an *enhanced* version.

In fact, in light of the EU's goal of digital transformation for 2030, the Commission proposed the Policy Programme "Path to the Digital Decade", which relies on an improved version of the DESI, serving as the analytical basis for the Report on the state of the Digital Decade (RSDD). The EU's goal is to be digitally sovereign in an open and interconnected world, and to pursue digital policies that empower people and businesses to seize a human centred, inclusive, sustainable and more prosperous digital future. This includes addressing vulnerabilities and dependencies as well as accelerating investment.[17]

In this regard, Member States expressed strong support for enhancing DESI as a monitoring tool for the Digital Decade, with consistent but adaptable indicators to facilitate comparisons across time and space. When selecting targets, the Commission looked at existing Key Performance Indicators (KPIs), having in mind that targets need to be measurable in order to be monitored. The choice of lead KPIs was guided by existing indicators, currently in the DESI, appropriately modified and improved upon, which will be enriched with new potential KPIs, should studies (ongoing or future) or other sources be needed, methodologies still be developed or relevant data still be acquired to measure progress towards the 2030 targets.

To better present the five dimension we will refer to them in the text as: DESI 1 (Connectivity), DESI 2 (Human Capital), DESI 3 (Use of Internet services), DESI 4 (Integration of digital technologies), DESI 5 (E-government).

2.1 DESI 1—Connectivity

The connectivity dimension accounts for coverage and usage of the essential infrastructure of a digital economy. In fact, it is well-known that in those rural areas, characterised by low population density and high deployment costs, private investments are often discouraged, creating a vicious circle of limited capacity, high prices, and low service demand (so called "white clusters" or "market failure areas"). Table 2 lists the variables that compose this indicator.

The first two sets of sub-components in the connectivity index relate to fixed broadband take-up and coverage. They are measured as of 2019 and made available by the Authority for Communications Guarantees, henceforth AGCOM. With respect to the take-up, we employ the percentage of households subscribing to any fixed broadband (1a1) and fixed broadband of at least 100 Mbps (1a2). As of the fixed broadband coverage, we consider the percentage of households for whom a fixed broadband of at least 30 Mbps in download is available (1b1) and the percentage of households having any fixed very high capacity

[17] The Commission's Communication "2030 Digital Compass: the European way for the Digital Decade" of 9 March 2021 laid out the vision for a successful digital transformation of the European Union by 2030.

Table 1 Components of the DESI index

DESI dimension	Main sub-component
1 Connectivity	1a Fixed broadband take-up
	1b Fixed broadband coverage
	1c Mobile broadband
	1d Broadband price index
2 Human capital	2a Internet user skills
	2b Advanced skills and development
3 Use of internet services	3a Internet use
	3b Activities online
	3c Transactions
4 Integration of digital technology	4a Business digitisation
	4b E-commerce
5 E-government	5a E-government users
	5b Pre-filled forms
	5c Online service completion
	5d Digital public services for businesses
	5e Open data

network (VHCN, at a minimum speed of 1 Gbps) available (1b2). The next three sub-components pertain to mobile connections: the percentage of populated areas with 4 G coverage—measured as the average coverage of telecommunication operators in a given area (1c1), the number of mobile data subscriptions per 100 people (1c2), and the amount of spectrum assigned and ready for 5 G use by the end of 2020 within the so-called 5 G pioneer bands (1c3)—this indicator is available only nation-wide, as tenders for allotment of spectrum parcels were launched on a national basis.

The last sub-component is the broadband price index, which measures the prices of representative baskets of fixed, mobile and converged broadband offers (1d1). We use the national indicator as we are unaware of any regional difference in broadband prices, nor local price discrimination policies.

2.1.1 Methodological Gaps of DESI 1

DESI 1 indicators measuring connectivity do not properly take into account the actual speed, nor the quality of connections. While we do have information on the maximum theoretical speed provided by a given technology, it would be more appropriate to base the indicator on estimates of the actual performance. These data are available for Italy and could be sourced from AGCOM, but many countries do not have equivalent disaggregated high quality information, making the transition towards more accurate indicators quite unfeasible.[18]

[18] The theoretical speed approach penalises countries that adopt alternative technologies to address local challenges (e.g. geographical ones) with cost-effective solutions, such as internet dongles, fixed wireless access, or consumer-grade satellite Internet service.

Table 2 Components of the connectivity index

Id	Basic sub-component	Weight	Level	Source
1a1	Overall fixed broadband take-up	0.125	NUTS 2	Istat
1a2	At least 100 Mbps fixed broadband take-up	0.125	NUTS 2	AGCOM
1b1	Fast broadband (NGA) coverage	0.125	NUTS 2	AGCOM
1b2	Fixed very high capacity network (VHCN) coverage	0.125	NUTS 2	AGCOM
1c1	4 G coverage	0.117	NUTS 2	AGCOM
1c2	Mobile broadband take-up	0.117	NUTS 2	Istat
1c3	5 G readiness	0.117	NUTS 0	Commission
1d1	Broadband price index	0.150	NUTS 0	Commission

Sources between take-up (Eurostat) and coverage (i.e. supply, sourced by AGCOM) should be coherent, using either a single source or at least the same definitions of technology or connection speed. This would ensure a more consistent comparison between demand and supply, both within and across countries. Finally, the broadband (2 Mbps) take-up and the 4 G coverage, still accounted for in the DESI 2020 edition, are now clearly outdated and consequently replaced in the current edition, by the 5 G coverage and the at least 1 Gbps take-up indices.

2.2 DESI 2—Human Capital

The endowment of human capital is key to foster digitalisation, as it sustains both the demand and the supply of ICT tools. Interestingly, in the labour market, despite an increasing demand for ICT related skills and the soaring unemployment, firms suffer from a shortage of digital skills (Mahida & Ramadas, 2013; Jackman et al., 2021).

Fully adhering to the DESI methodology, our regional composite indicator is based on the rich set of variables listed in Table 3.[19]

The first sub-set of the human capital index consists of indicators of individual digital competences and skills. The component is calculated as the weighted average (with equal weights) of the following three normalised indicators: (i) at least basic digital skills, (ii) above basic digital skills, and (iii) at least basic software skills.

According to the Eurostat definition, the measurement of skills is based on selected activities related to internet or software use, performed by individuals aged 16–74 in four specific areas, i.e. information, communication, problem solving, and software skills.

It is assumed that individuals having performed certain activities have the corresponding abilities. According to the variety or complexity of activities performed, two levels of skills (basic and above basic) are constructed for each of the four dimensions. The source used by the European Commission for the international comparison is the *Community survey on ICT usage in Households and by Individuals* made available by Eurostat. The respective Italian survey is called *Multipurpose survey on households: aspects of daily life*.[20] We rely on the indicators aggregated and disclosed at NUTS2 level by Istat.

[19] Out of six indicators, five have been confirmed in the most recent revision of the DESI indicator.

[20] All activities listed in the methodological manual of Eurostat are present in the corresponding Istat survey starting from 2019.

The second component of human capital refers to advanced skills and development. Also in this case, three variables are combined averaging over equal weights. The reference statistics are: (i) share of ICT specialists, (ii) share of female ICT specialists, and (iii) share of ICT graduates.

The source of information for these variables is the 2019 ISTAT *Labour Force Survey*. ICT specialists are identified through the categories of the International Standard Classification of Occupations (ISCO-08) by the International Labour Organisation (ILO), which groups jobs according to the tasks and duties undertaken. The categories of workers considered as ICT specialists are the following: ICT Service managers, Software and multimedia developers and analysts, Database specialists and systems administrators, ICT operations and user support technicians, Communications technicians, and Electronics, Telecommunications Installers and Repairers.[21]

The variable on graduates in ICT degrees is computed from the data made available each year by the Ministry of Education, University and Research (MIUR). The indicator is the share of ICT graduates over the total number of graduates, based on the region of students' residence.

2.2.1 Methodological Gaps of DESI 2

With respect to the human capital dimension, two alternative definitions could be used for the proxy based on the share of ICT graduates. The index employs the share of the population graduating in ICT subjects over the total number of students graduating in a given solar year in a region (i.e. the annual flow of graduates). The region of attribution could either be the region of origin of the student or the region where the university granting the degree is located. The DESI index is computed according to the latter definition. However, we point out that student mobility is particularly important across the Italian regions and therefore this methodological choice might have substantial implications in the computation of the rDESI for Italy, but also in the national DESI.

Apart from the issue of whether it is best to measure the stock or the flow of graduates, the current methodology also misses human capital relocation, i.e. the very fact that an increasing share of graduates moves to a different country to work.[22] As a starting point, the methodology should explicitly handle incoming foreign students and/or people moving abroad to study.[23]

When accounting for the digital skills, one may question whether the DESI is effectively capturing the relevant "soft skills".[24] As a matter of fact, it is not clear whether nowadays browsing on the internet for various purposes corresponds to an actual communication and/or information skill. In parallel, mastery of digital skills should include the ability to verify the truthfulness of web content. This information is hard to measure given the current

[21] It should be noted that the European Commission's DESI is based on 4-digit ISCO codes, and therefore it includes also Electronic engineers (2152), Telecommunication engineers (2153), Graphic and multimedia designers (2166), Information technology trainers (2356), ICT sales professionals (2434), Electronics engineering technicians (3114).

[22] This is the so-called *brain drain* or *brain gain* phenomenon that has grown drastically as the tertiary education markets have become global (see, for example, the work of Giousmpasoglou and Koniordos, 2017).

[23] Consider that the European Commission in 2021 has almost doubled the budget of the European student mobility programme (Erasmus).

[24] Before the introduction of DESI, these important concepts of digital competence and literacy were defined by Ferrari (2012).

Table 3 Components of the human capital index

Id	Basic sub-component	Weight	Level	Source
2a1	At least basic digital skills	0.166	NUTS 2	Istat
2a2	Above basic digital skills	0.166	NUTS 2	Istat
2a3	At least basic software skills	0.166	NUTS 2	Istat
2b1	ICT specialists	0.166	NUTS 2	Istat
2b2	Female ICT specialists	0.166	NUTS 2	Istat
2b3	ICT graduates	0.166	NUTS 2	MIUR

data availability, nevertheless it could be worthy to collect survey data about number of frauds incurred while browsing the internet. Next, we point out that lacks in software skills (2a3)[25] accrue three times in the overall formula; indeed, according to the definitions, having at least basic digital skills (2a1) amounts to scoring "above basic" in all four domains, including software skills. Similarly, having above basic digital skills (2a2) implies having at least one "basic" but no "no skills" in all four domains. In the 2022 DESI methodology, this indicator has been replaced with a similar one on the fraction of individuals mastering at least basic digital content creation skills. Abstracting from considerations on the relevance of digital content creation vis-á-vis software skills, the issue of redundancy is still open to dispute.

2.3 DESI 3—Use of Internet Services

The index focuses on three different dimensions: (a) general internet usage; (b) basic online activities; (c) online transactions (banking, buying and selling goods or services). Consistently with the DESI, all data refer to 2019.

Table 4 shows the list of variables and their weights. Several data sources are employed: for 3a1, 3a2, 3b5, 3c1, 3c2 and 3c3 we retrieved regional data from Eurostat, the same source employed by the European Commission. For all the other series, we resort to Istat; in particular, for 3b1, 3b2, 3b3 and 3b4, data are sourced from the survey *Cittadini e ICT*, while for 3b6 from *Multipurpose survey on households: aspects of daily life—general part*. The main difference is represented by the age group each statistic refers to: Eurostat data refer to 16–74 years old people, whereas *Cittadini e ICT* considers the 14–74 years old range and the *Multipurpose survey of households* includes individuals aged 6 and over. All indices are referred to the share of individuals who used Internet in the last 3 months, excluding 3c2, which relates to individuals who used Internet in the last year, and 3a1 and 3a2, which consider all individuals.

[25] The activities to be performed to be considered skilled are the following: using word processing software; using spreadsheet software; used software to edit photos, video or audio files; creating presentation or document integrating text, pictures, tables or charts; using advanced functions of spreadsheet to organise and analyse data (sorting, filtering, using formulas, creating charts); have written a code in a programming language.

2.3.1 Methodological Gaps of DESI 3

Regarding the use of internet, we have observed a strong correlation of this index with the human capital one. Although it is not surprising that skills and internet usage are strongly associated, we argue that methodologically this is also due to an overlap of some sub-indicators. As a matter of fact, within the DESI 3, we measure the proportion of citizens who have recently performed a given set of online activities. Some of these activities coincide with those used to measure the digital skills in one indicator of the DESI 2, e.g. the percentage of individuals who used the internet to make telephone or video calls (3b4). These redundancies have been addressed by the Commission, which resolved to entirely drop the third index from the new edition of the DESI. Yet, for the sake of consistency with the DESI 2020, which represents our national benchmark for this study, we decided to construct the DESI 3 at the regional level.

2.4 DESI 4—Integration of Digital Technology

The digital transformation is also a fundamental pillar for industrial growth, as the economy is increasingly digitalised. This subsection presents the source of data used to monitor the adoption of digital technologies by Italian firms. In particular, the indicator looks at the use of big data, cloud services, and e-commerce, while overlooking other technologies.

In order to construct our indicator, we rely on data collected by Istat in the context on the *Survey on the Use of ICT by Businesses*, for the time range 2018–2020.[26] Firms are located according to their legal headquarters.

Table 5 shows the list of variables and their weights. More in detail, the digital integration component is the average of the percentage of firms with Enterprise resource planning and electronic information sharing in 2019 (4a1); the percentage of firms present on at least two social media in 2019 (4a2); the percentage of firms analysing big data in 2018 (4a3); the share of businesses purchasing cloud computing services in 2020 (e.g.: hosting of the enterprise's database, accounting software applications, CRM software, computing power) (4a4); the share of SMEs selling online at least 1% of their turnover (4b1); the ratio of e-commerce turnover over total turnover in 2020 (4b2); and the percentage of firms selling online cross-border in 2019 (4b3). Differently from Eurostat, which refers to companies with 10 to 249 employees, our data also include larger firms (i.e. with 10 or more employees).[27]

2.4.1 Methodological Gaps of DESI 4

The range of applications of ICT technology is very broad and multifaceted. In some business contexts, the corporate use of cloud infrastructure or administrative software is extremely common. Nevertheless, it does not necessarily correspond to innovative technologies. Additionally, the DESI 4 methodology is likely to penalise economies with low services weight: the e-commerce and the social network indicators are lower in manufacturing

[26] The statistics have been published in the *Rapporto sul territorio 2020. Ambiente, economia e societá*.

[27] Notice that the inclusion of larger firms induces a trade-off between sample size and actual sample representativeness at the regional level. In fact, on the one side, by including also higher size classes, we increase our sample, on the other side, if larger firms are also multi-plants, the regional assignment based on the location of their legal headquarter may be not realistic.

Table 4 Components of the use of internet services index

Id	Basic sub-component	Weight	Level	Source
3a1	Individuals who never used the internet	0.125	NUTS 2	Eurostat
3a2	Internet users (at least once a week)	0.125	NUTS 2	Eurostat
3b1	Reading online news sites, newspapers or news magazines	0.083	NUTS 2	Istat
3b2	Playing online or download games, images, films or music	0.083	NUTS 2	Istat
3b3	Using online video on demand services	0.083	NUTS 2	Istat
3b4	Making telephone or video calls (e.g. Skype)	0.083	NUTS 2	Istat
3b5	Participating in social networks	0.083	NUTS 2	Eurostat
3b6	Doing an online course (on any subject)	0.083	NUTS 2	Istat
3c1	Using online banking	0.083	NUTS 2	Eurostat
3c2	Ordering goods or services online	0.083	NUTS 2	Eurostat
3c3	Selling goods or services online	0.083	NUTS 2	Eurostat

(as suggested by the negative correlation between the share of workforce in the industry sector and the e-commerce performance of the region presented in Table 10).

This concern results attenuated in the new DESI methodology since it includes the adoption of other digital technologies i.e. artificial intelligence, e-invoices. Finally, DESI 4 indicators measure the integration of digital technologies, but there is no evaluation of the ability to create new digital technologies. Some possible indicators could be the number of ICT patents or the share of innovative SMEs.[28]

2.5 DESI 5—E-Government

E-government refers to the digital provision of public and administrative services, which requires a joined-up technology to run both front-end and back-end operations in a cohesive fashion. For example, the virtual ID, in Italy called SPID, is intended to make easier to fulfil basic administrative tasks online, such as registering a new residency, compiling income statements, registering a car, or applying for public child-care. To fulfil these requests, official databases need to be integrated and accessible to the national or local authority the citizen is interacting with. Similar infrastructures are required to develop e-health services based on electronic patient databases, such as the European Union's "digital green certificate", whose functioning depended on Covid-19 vaccine data being digitised and collated.

As mentioned earlier, our methodology for the e-government index diverges substantially from the European Commission's, due to a lack of comparable data at the regional level. At this level, it is necessary to consider the quality of digital services offered by local authorities such as municipalities (the Commission uses a sample of few large cities).[29] For this reason we propose several proxies to replicate the dimensions that compose the original index.

[28] The paragraph 25 of the Italian law 221/2012 contains the Italian definition of innovative SMEs. The Italian Ministry of Economic Development collects quarterly the number of innovative firms by region.

[29] The cities sampled by the European Commission are: Bari, Bologna, Brescia, Catania, Firenze, Genova, Messina, Milano, Modena, Napoli, Padova, Palermo, Prato, Reggio-Calabria, Roma, Taranto, Torino, Trieste, Venezia, and Verona.

Table 5 Components of the integration of digital technology index

Id	Basic sub-component	Weight	Level	Source
4a1	Electronic information sharing	0.10	NUTS 2	Istat
4a2	Social media	0.10	NUTS 2	Istat
4a3	Big data	0.20	NUTS 2	Istat
4a4	Cloud	0.20	NUTS 2	Istat
4b1	SMEs selling online	0.13	NUTS 2	Istat
4b2	e-Commerce turnover	0.13	NUTS 2	Istat
4b3	Selling online cross-border	0.13	NUTS 2	Istat

Table 6 shows the five main components of the e-government index. For all indices but the first, we employ several proxies to avoid relying on a single source.[30] In this context, data are collected at a lower frequency, so we combine data for 2018 and 2020.

The first item (e-government users, 5a) is defined as the share of individuals aged 14 and above who have submitted completed forms to any public authority in the last 12 months. Every year, Istat reports this figure at the regional level.

The second indicator of e-government (5b) is meant to measure the amount of data which is pre-filled in public service online forms. An essential step to this purpose is the creation of authentic sources, i.e. base registries used by governments to automatically validate or fetch data on citizens or businesses. Since we do not know the exact amount of data actually pre-filled for e-government users at the regional level, we employ three proxies, measuring the development and usage of authentic sources at the local authority level. In particular, we compute a simple average of the following five statistics: (i) the share of population living in municipalities which have joined the national registry (Anagrafe nazionale)[31]; (ii) the average number of management systems that are integrated within a local authority (2020 survey managed by the Bank of Italy)[32]; (iii) the average number of datasets used by local authorities (2019 survey commissioned by the "Corte dei Conti")[33]; (iv) the share of local authorities which allow authentication to online services via SPID (2019 survey commissioned by the "Corte dei Conti"); (v) the share of municipalities that have received payments through pagoPA in 2020.[34]

[30] In Appendix 4, we verify that our index is robust to selecting only a subset of proxy variables as well as to aggregating the series using weights based on their correlation with the first principal component (the one with the largest eigenvalue).

[31] A main purpose of the Anagrafe nazionale is to allow e-government users to be more easily identified without asking them for official certificates, e.g. residence certificate.

[32] The management systems considered are: accounting; register of suppliers; HR management; procurement; secretariat, document protocol; treasury (with SIOPE+); registry office (for municipalities only); local taxes record.

[33] The dataset included in the list are: (1) national registry of territorial data; (2) registry office (ANPR); (3) criminal record; (4) business record; (5) immigration and asylum seekers record; (6) agricultural business record; (7) motor vehicles registry (PRA); (8) federated national information system of infrastructures (SINFI); (9) national archive of house numbers of urban streets (ANNCSU); (10) land registry.

[34] pagoPa is a new payment method, introduced by the Italian Code for Digital Administration and by the Decree-law 179/2012 with the aim of guaranteeing safe and reliable electronic payments to the public administration. It is managed by PagoPA S.p.A., a public company owned by the Italian Ministry of Economy and Finance.

Table 6 E-government index components

Id	Main sub-component	Weight	Level	Source
5a	E-government users	0.20	NUTS 2	Istat
5b	Pre-filled forms	0.20	NUTS 2	Proxies
5c	Online service completion	0.20	NUTS 2	Proxies
5d	Digital public services for businesses	0.20	NUTS 2	Proxies
5e	Open data	0.20	NUTS 2	Proxies

To proxy each variable, we use several indicators that are available at the regional level and have been produced by Istat, the Bank of Italy or the "Corte dei Conti"

As a third element, the European Commission produced the online service completion indicator (5c). This measures the share of administrative steps that can be carried out online in several situations, such as changing job or moving to a new city. We substitute this indicator with the simple mean of three indices: (i) index of online service availability for services offered by municipalities in 2018 (computed by Istat); (ii) completeness of online services by local authorities (2020 survey run by the Bank of Italy); (iii) share of local authorities offering at least one online service (2019 survey commissioned by the "Corte dei Conti").

The fourth index (5d) broadly reflects the share of public services needed to open a business and conduct regular business operations that can be performed online by domestic as well as foreign users. This dimension is hard to capture at the regional level; in order to do so, we resort to two data-sets: (i) the share of municipalities offering online services of the "Sportello Unico Attività Produttive" (SUAP), and of the "Sportello Unico Edilizia" (SUE; 2020 survey run by the Bank of Italy)[35]; (ii) the share of municipalities offering online services for SUAP and SCIA-VIA (2019 survey commissioned by the "Corte dei Conti").[36] In both cases, we assign one point if the municipality offers both services online, half point if it offers only one service and zero if neither are offered.

The European Commission's open data index (5e) measures to what extent countries have an open data policy in place (including the transposition of the revised PSI Directive), the estimated political, social and economic impact of open data and the characteristics (functionalities, data availability and usage) of the national data portal. Our proposed regional version of this metrics relies on data regarding specific results achieved by local public authorities. In particular, we consider three indices: (i) the regional open data index released by the government and based on a basket of datasets selected for their relevance; (ii) the share of municipalities that provided open data online in 2018 (survey run by Istat); (iii) the share of local authorities providing online free-access open data in 2020 (survey run by the Bank of Italy).

[35] The SUAP is an office that every Italian municipality must run since all companies and entrepreneurs need to interact with their local SUAP to open, transfer, change or close a business. The SUE is another office that can be found in every Italian municipality and it is in charge of monitoring all requests of construction works.

[36] The SCIA ("Segnalazione certificata di inizio attività") and the VIA ("Valutazione impatto ambientale") are two formal protocols that are required to start construction works.

2.5.1 Methodological Gaps of DESI 5

The e-government index also presents some worrying issues. First, the supply-side indicators are fed from a small-size survey; second, even though the digital level of a country depends on both national- and regional-level digital services, the latter dimension is highly overlooked. A more robust methodology should distinguish between the set of online services provided by the local governments and those provided by the national Government (possibly through its agencies) all over the country. So far, the DESI is unable to capture the heterogeneity in the quality of digital services for local administrations, as the component related to local administrations is based on a non-representative sample data (few of the largest cities of a Country), and thus it neglects territorial disparities between more populated (core) and less populated areas (periphery).

This appears even more problematic for those services supplied by regional public administrations, such as the management of the healthcare system in Italy, which represents a major responsibility for regional governments. To provide a more complete picture, it would be desirable to enrich the index with variables describing the level of e-health. Indeed, in the 2022 edition of the DESI, rescheduling an appointment at a hospital is one of the many services evaluated by the European Commission to build the e-government indicator. Yet, the structure of the index is unchanged, thus this aspect is diluted among the services provided to citizens (and has limited impact on the overall index).[37]

2.6 General Methodological Gaps of DESI

The DESI is thought as an instrument to conduct policy evaluation in a standardised way across European countries and regions. To have an effective policy tool, it is fundamental to make several improvements in terms of data harmonisation across EU countries, and in terms of time consistency of the data, even within the same country.

Digital competences and technical solutions are rapidly evolving as new technologies are spread, contributing to the obsolescence of some indicators. In this sense, we face a tradeoff between the relevance of the variables and the continuity of time series, particularly relevant in monitoring digital progress. Furthermore, requiring the national and European statistical offices to add new survey questions might result into an excessive burden to the agencies and to the respondents.

In general, greater attention should be given to avoid conceptual ambiguity. At the moment, there might be a measurement issue stemming from the lack of clarity in some survey questions. For example, concerning ICT adoption by firms, cloud services have evolved over time into a variety of sophisticated applications, to the point that the most basic online storage systems might be omitted by the respondents when listing the adopted cloud services. With respect to this matter, the new edition of the DESI has introduced some improvements and the Commission Working Group is devising further developments of the questionnaire in this direction.

Finally, to calculate the rDESI we followed the aggregative-compensative approach employed by the European Commission, which entails using a weighted average of a

[37] Even in this case, it would be best to distinguish national e-health services from regional ones (not feasible with the Commission's data. A valid support to provide a more in-depth analysis, also with qualitative data on e-health at the regional level, will be the new survey on the digitalisation of local administrations (including Italian local health authorities) that Bank of Italy is planning to run in 2023 (as first wave).

number of different indicators. This approach, whilst used extensively by policymakers and researchers alike, has been subjected to severe criticism. The aggregative approach has been criticized as inappropriate and inconsistent (Freudenberg, 2003), concerning the difficulty in conveying complex phenomena into unidimensional measures. The aggregating technique might introduce implicitly meaningless compensations and trade-offs among often heterogeneous indicators; the combination of ordinal variables and numerical weights is not free from issues (Maggino, 2017; Alaimo, 2022b). In particular, the current methodology allows low values in some indicators to be compensated by high values in other indicators (Mazziotta & Pareto, 2013, 2017), but many digitalisation indicators are not substitutable (consider for example the supply versus the demand indicators). On the other side, this method allows a simpler and more direct comparison than the non-aggregative approach. Furthermore, for the sake of aggregation, the European Commission employs a mix of equal weights and expert opinion-based weights, according to Alaimo (2022a) a more appropriate method of weighting. Even though we observed a robustness of the rDESI rankings to the use of PCA weights, this does not exclude the possibility that some combination of weights may over- or under-estimates differences across regions or countries. Moreover, equal weighting entails that indicators have the same importance but this is seldom the case (see e.g. Alaimo, 2022a).

To conclude, it is important, at the policy level, to further discuss advantages and disadvantages of aggregating into a single indicator the heterogeneous dimensions of digitalisation, and to be more transparent about the *rationale* behind the choice of weights.

3 Analysis of the rDESI

The regional DESI is plotted in Fig. 1, where regions are sorted from the highest to the lowest score, and the green line represents the national average.

The leading regions in the rDESI index are Lombardia, Emilia-Romagna, and Lazio, while Calabria, Basilicata, and Molise are the least digitalised areas. More generally, the index confirms the gap among Northern and Southern Italian regions that we observe for a large range of statistics (e.g. GDP per capita, activity rate, etc.). With respect to the rDESI, almost all Northern regions score above the Italian average,[38] while the Southern ones are all below the national mean. Figure 2 presents a set of regional maps of Italy where each indicator is displayed through a colour map of the regional values.[39]

The connectivity index rDESI 1 (Fig. 2b) has the lowest variance among all five sub-indicators and does not show the North-South gap described before, displaying a more homogeneous distribution across all the Italian regions. This result can be at least in part ascribed to the national Government's policies[40] that have financed the construction of a fixed broadband infrastructure mostly in those areas where undertaking the investment was regarded as unprofitable for private operators (so called white areas or market failure zones). Moreover, both the fact that the mobile 4 G connection is nowadays

[38] Valle d'Aosta is the only exception, which can be partly explained by the poor results in the connectivity index, since it is a small mountain region.

[39] Darker shades of blue refer to higher values of the indicator. In Appendix 1, Fig. 3 reports for each region the values of the rDESI and of its main sub-components for a more detailed comparison.

[40] Since 2009, the government launched the Piano Nazionale Banda Larga and Progetto Strategico Banda Ultralarga.

highly widespread over the whole nation and the lack of a regional dimension in the price index and 5 g spectrum allocation sub-indices contributes to curb the variance of the connectivity metrics as a whole. Within this index, Lazio, Liguria ad Emilia-Romagna are the top three regions, while Valle d'Aosta, Basilicata and Molise lie at the bottom of the distribution.

The human capital index rDESI 2 (Fig. 2c) displays the highest variance among all five sub-indicators, showing a large gap between Northern and Southern regions, both in the basic individual digital competences and with respect to ICT specialists and graduates. Recall that in the nationwide metrics, Italy was ranked among the last European countries over the years, gaining only two positions between 2020 and 2022, and therefore the country faces difficult challenges with respect to the educational domain. In the regional ranking, Lazio, Lombardia and Provincia Autonoma di Trento are at the top, while Basilicata, Calabria and Sicilia show the lowest scores.

The use of internet index rDESI 3 (Fig. 2d) follows a similar pattern as the previous indicator (see Sect. 4 for further insights). The top/last three regions ranking is almost confirmed: Lombardia, Emilia-Romagna and Tuscana are the top performers, while Basilicata, Calabria and Sicilia score poorest in the ranking.

The integration of digital technology by firms, indicator rDESI 4, (Fig. 2e) shows the North–South gap for the first component (digital integration), which disappears for the e-commerce one. As discussed in Sect. 2.4, this evidence is in line with the broadly accepted stylised fact that the *e-commerce* component tends to relatively favour economies with higher weight of the service sector. In particular, both *e-commerce* sub-components (number of SMEs that have sold their products online and share of turnover from online sales) are more than double in private services than in industry.[41] The top three regions in this case are Provincia Autonoma di Bolzano, Umbria and Piemonte, while Sicilia, Marche and Molise occupy the bottom of the distribution.

Lastly, the e-government index rDESI 5 (Fig. 2f) shows a better performance for Northern regions compared to the South-Center area, mostly driven by the supply of online services provided by local authorities. The top three regions in the ranking are Veneto, Lombardia and Emilia-Romagna, while Campania, Molise and Calabria score in the last three.

As anticipated, our rDESI, mainly due to the current data availability at the local level, has been constructed according to the 2020 Commission edition. Nevertheless, as robustness check, and in view to update it in the future, we also computed our regional indicator according to the DESI 2022 methodology (see Appendix 2 for further details). The main results is that the ranking is quite stable, with a 96% correlation with the 2020 methodology. Overall, nine regions keep the same position and six shift up or down by one place.[42]

[41] See for instance the data from Istat (2020) Survey on the Use of ICT by Businesses.

[42] The major shift concerns the Veneto region, which gains 5 positions, despite a small change in the overall indicator computed with the newest methodology. Nonetheless, the shift is not worrying, as it is motivated by the pre-existing small gap with respect to the regions immediately above it in the ranking.

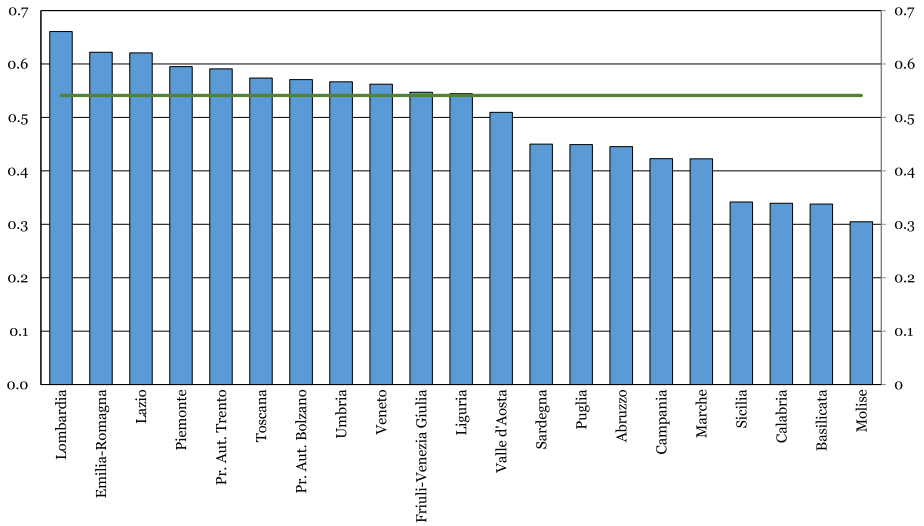


Fig. 1 Regional DESI

4 Statistical Properties of the rDESI

The different dimensions of a digital economy and society are interconnected and, as such, only concerted improvements in all of them would have a significant impact on people's life. In this section, we analyse the correlations among the rDESI components to highlight possible interplay and enabling roles.[43]

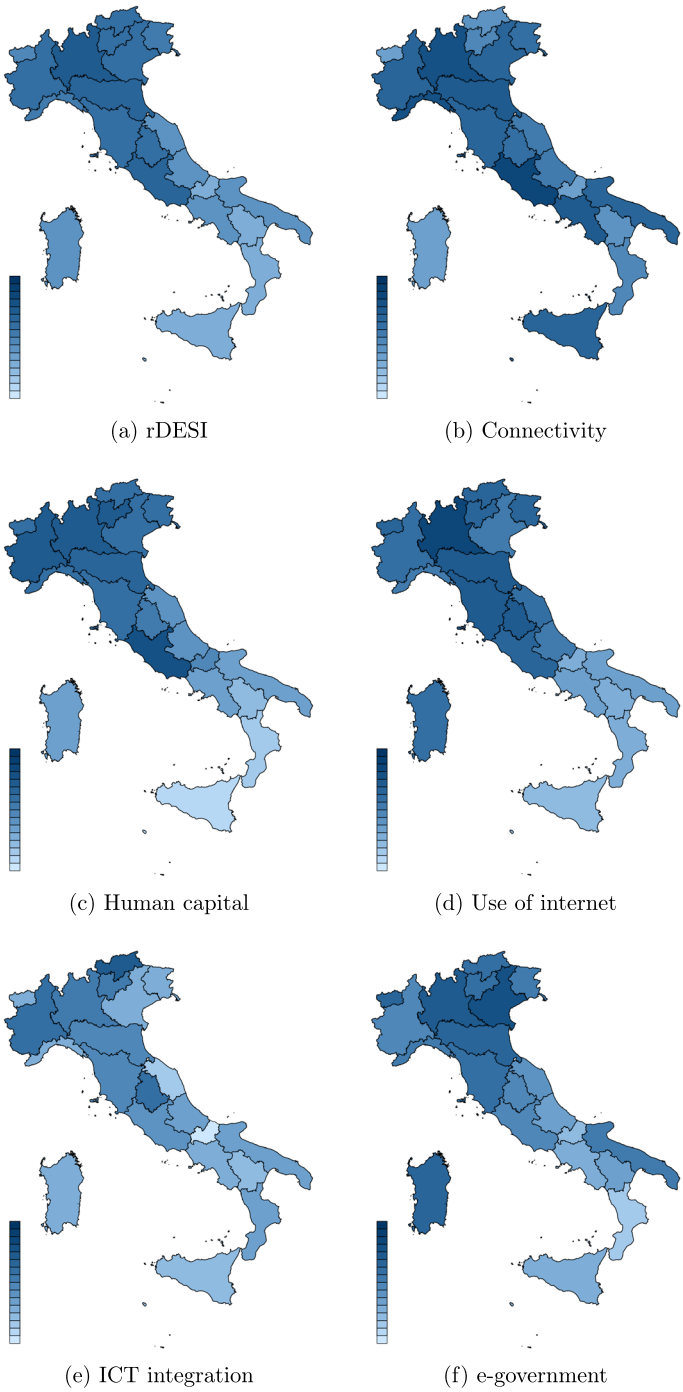
Table 7 shows the correlation matrix of the five aggregate indicators. Correlations are strong and larger than 0.49, except for the connectivity index, due to its supply components (as shown below). The strongest relationship is observed between the human capital index and the use of internet services and might suggest that skills are essential to the widespread use of digital services.[44] Interestingly though, it is the use of internet that more strongly correlates with the other two indices (integration of digital technology and e-government), pointing to the importance of the demand side in the development of a digital society. At the same time, this evidence confirms that the third indicator is redundant and as such it has been dropped from the new DESI.

Table 8 suggests that the low correlation of connectivity with the rest of the rDESI components is mainly driven by the low correlation of supply of fixed broadband (1b) despite it has a 0.5 correlation with broadband take-up.[45] Mobile connectivity is not considered here because some components are available only at the national level and because the 4 G indicators display very little variation (likely produced by sheer geographical factors—see Sect. 2.2).

[43] In the literature, Bánhidi et al. (2020) have proposed a similar multivariate statistical analysis of the original DESI across European countries.

[44] In this regard, it is worth remembering that Italy's human capital index is far below the EU average.

[45] As we discuss later on, there is an issue of consistency between these two indicators due to the use of different data sources (AGCOM and Istat).



(a) rDESI (b) Connectivity

(c) Human capital (d) Use of internet

(e) ICT integration (f) e-government

Fig. 2 Regional digitalisation levels

Table 7 Correlation matrix of DESI components

	(1)	(2)	(3)	(4)	(5)
(1) Connectivity	1.00	0.25	0.22	0.31	0.22
(2) Human capital	0.25	1.00	0.82	0.52	0.64
(3) Use of internet services	0.22	0.82	1.00	0.62	0.77
(4) Integration of digital technologies	0.31	0.52	0.62	1.00	0.49
(5) E-government	0.22	0.64	0.77	0.49	1.00

Given the sample size (n=21), correlations above 0.43 have a two sided p value of 0.05 while correlations above 0.55 have a two sided p value of 0.01

Table 8 Correlation of connectivity sub-components

	(1a) Fixed broadband take-up	(1b) Fixed broadband coverage
(2) Human capital	0.64	0.04
(3) Use of internet services	0.68	− 0.02
(4) Integration of digital tech	0,52	0.10
(5) E-government	0.47	− 0.03

Note: given the sample size (n=21), correlations above 0.43 have a two sided p-value of 0.05 while correlations above 0.55 have a two sided p-value of 0.01

Table 9 Correlation of use of internet services

	(3a) Internet use	(3b) Activities online	(3c) Transactions
(2a) Internet user skills	0.72	− 0.05	0.94
(2b) Advanced skills	0.52	0.11	0.33
(4a) Business digitisation	0.49	0.41	0.31
(4b) E-commerce	0.49	− 0.16	0.45
(5a) E-government users	0.65	− 0.02	0.80
(5b-d) E-government offer	0.53	0.02	0.63

Given the sample size (n=21), correlations above 0.43 have a two sided p-value of 0.05 while correlations above 0.55 have a two sided p-value of 0.01

Table 9 shows the correlation of the components of the use of internet services with components of the other indices. In particular, it can be noticed that internet use (3a) and transactions (3c) strongly correlate with other indicators, while online activities (3b) does not. Furthermore, basic skills of internet users tend to be much more correlated both with the use of internet and the internet transactions, compared to the endowment of advanced skills.

Table 10 reports correlation and partial correlation coefficients for the two components of the integration of digital technology index (4a and 4b) with respect to the skills and to

Table 10 Correlation of integration of digital technology

	(4a) Business digitisation		(4b) E-commerce	
	correlation	partial correlation	correlation	partial correlation
(2a) Basic digital skills	0.28	0.13	0.44	0.42
(2b) Advanced skills	0.42	0.33	0.27	0.19
Share of industry	0.33	0.23	− 0.05	− 0.22

The partial correlation between y and x1 is an attempt to estimate the correlation that would be observed between y and x1 if the other x's did not vary. This squared correlation can also be interpreted as the decrease in the model's R2 value that results from removing x1 from the full model

Industry includes: (B) mining, (C) manufacture, (D) utilities and (E) waste collection and water supply The source of the industry share is Istat, ASIA for 2018

Table 11 Correlation of integration of e-government

	(5a) E-government users		(5b–5e) E-government services	
	correlation	partial correlation	correlation	partial correlation
(2a) Basic digital skills	0.82	0.83	0.50	0.45
(2b) Advanced skills	0.28	0.12	0.12	0.01
Share of old age residents	0.20	− 0.40	0.31	0.09

The partial correlation between y and x1 is an attempt to estimate the correlation that would be observed between y and x1 if the other x's did not vary, This squared correlation can also be interpreted as the decrease in the model's R2 value that results from removing x1 from the full model

The share of old age residents is defined as the ratio between residents at January,1st 2020 older than 64 and those older than 14; the source is Demoistat.it

the share of employees in the Industry sector at the regional level.[46] We observe a negative correlation between e-commerce and the industry share, supporting the idea that this sub-index favours service-based economies. On the other hand, the share of industry is positively associated to the business digitalisation index, confirming the idea that digital innovations, such as cloud or big data are more likely to be adopted by manufacturing firms. In either case, we do not observe a strong relationship. Moreover, advanced skills seem to be more correlated with business digitalisation than with e-commerce, whereas the opposite holds true for basic digital skills, suggesting that different kinds of skills can trigger different digital transitions.

Finally, Table 11 displays the correlation and partial correlation coefficients for the demand and for the supply indicators of e-government services with respect to skills and share of senior residents (defined as share of 65 and older over the population aged 15 or

[46] We use only partial correlation as an exploration of the data because the limited number of observations prevent robust estimations of e.g. OLS coefficients.

Table 12 Correlation between e-government sub-indices

	(5a)	(5b)	(5c)	(5d)	(5e)
correlation with (5a) e-gov. users	–	0.11	0.57	0.26	0.43
coefficient of variation	0.50	0.26	0.40	0.43	0.33

The coefficient of variation is the ratio of the standard deviation to the mean

more).[47] The share of e-government users is highly correlated with the presence of basic digital skills, while the correlation with the endowment of advanced skills is very low. This suggests that e-government instruments can be successful only if they can rely on a wide mass of citizens with basic digital skills. Moreover, if skills were constant across regions, the share of old age residents would unsurprisingly have a negative correlation with the e-government users index. The offer of online public services is less correlated with basic digital skills and the correlation with the advanced ones is close to zero.[48]

In order to shed further light on this intuition, we consider the sub-components of e-government, distinguishing between supply and demand-side ones and analyse both their correlations and their degree of variability. Table 12 shows that the share of e-government users is more correlated with online service completion and less with pre-filled forms and open data sub-indices. Moreover, the latter are more homogeneous among regions, showing a relatively lower coefficient of variation, also due to the fact that their development follows policies and mandatory requirements set by the national Government.

Given the strong correlations among DESI components, we conduct a principal component analysis (PCA) on these sub-indices. The digitalisation metrics resulting from the PCA has a 97 percent correlation with the regional DESI, (see Appendix 3). This result logically descends from the strong correlations among almost all the series which entail that the index is rank robust to changes on the weights (see e.g. Foster et al., 2013). In other words, the weighting choice has only a minor impact on the ranking, since a poor (or good) performance in one indicator is likely to be replicated by the other components; a particularly desirable feature for a composite index. However, this also suggests that the aspects of demand are (numerically) over-represented in the DESI framework and that greater weighting could be assigned to the supply indicators in order to improve the effectiveness of the metrics in capturing both sides of the market.

5 Conclusions

In this study, we have presented the regional DESI for Italy, explaining differences and similarities with other works in the digitalisation literature. We have reviewed the methodology to build the regional indicators by adapting the European Commission's approach to the data available for the Italian NUTS2 regions.

[47] Note that we calculate "e-government supply" as the simple mean of indicators 5b, 5c, 5d, and 5e, since they all represent different aspects of local government services provision.

[48] Unfortunately we are not able to control for education or skills of local civil servants.

Furthermore, we have shown some statistical properties of the rDesi index and its components; in particular, we have observed that weighting has little impact on the overall ranking of regions since the different dimensions are highly correlated. Based on this and other evidence, we proposed some amendments to the original methodology, to better capture some key aspects of digitalisation and to address some of the current data limitations. Some of our suggestions have been already incorporated in the 2022 edition of the European Commission DESI, while further improvements are still expected to be adopted in the years to come, since the digital transition carries out its effects continuously and the technologies that are today at the frontier are gradually replaced with more advanced ones. This process is sometimes smoother, other times subject to unexpected shocks which affect its evolution, also by giving it a strong acceleration, as it was the case with the recent Covid-19 pandemic, which greatly affected consumption habits and the organisation of work. While we do not have the data to consider the impact on the rDESI dimensions yet, we expect that the positive shock to the demand of digital services will lead to a general increase of the sub-components in the next edition. In this context, the National Recovery and Resilience Plan (PNRR) can potentially leverage private investments in ICT and digital technologies. In July 2021, the Italian Government has earmarked almost 34 billion euros to the innovation and digital transition of firms and public Government; for firms resources will be allocated through the Transition 4.0 Plan. The rDESI's results suggest that the large gap in human capital compared to the other European countries may represent the greatest challenge for the investment plan of the Italian Government in the years to come.

In this work, we have also pointed out the wide regional disparities in the digitalisation levels across Italy. We believe that more efforts should be made at every administrative level to properly measure the advancements in the relevant digital dimensions and, for this reason, we have proposed some ways forward. Along the same line, with a view to monitoring the digital developments of European regions and more broadly in the context of cohesion policy assessment, the European Commission might consider to transition towards a regional version of the DESI, even though the process would not be free from flaws due to the lack of relevant, comparable and regularly updated data at the NUTS2 level for all the European Countries (e.g. broadband speed data are unavailable at the local level for most of the EU countries). Finally, the rDESI represents a useful policy instrument, providing a regional mapping of the lacks and strengths of digital development, which could be referred to as a guideline for policy makers when deciding about funds allocation and public investment, fostering a homogeneous diffusion of digital technologies all over the country.

Appendices

Appendix 1 rDesi Detailed Ranking

In Fig. 3 we report the value of the rDESI and its components for each Italian region.

Appendix 2 Robustness Check with DESI 2022 Methodology

As robustness check, we compute the indicator following the new DESI 2022 methodology. The main differences are: (i) the exclusion of the Internet users component; (ii) 12 new or different subcomponents in the connectivity, human capital and integration of digital technology legs (respectively the old DESI 1, 2 and 4); (iii) different weights (available in the European commission methodology manual). Table 13 resumes the main sub components changes and the information level of the new series. For NUTS0 and NUTS2 data, sources are AGCOM for 2b3 and 2c3 indicator and ISTAT for the others. We use the weight provided by the DESI 2022 methodology and we keep the normalization process as described in Sect. 2.

The new indicator provides this ranking (Fig. 4; for further details, see Table 14):

Appendix 3 Robustness Check with PCA Weights

In principle, the purpose of principal component analysis (PCA) is to reduce a large number of series into a set of few variables containing most of the information of the original data.[49] In our setting, this methodology might shed some light on the limitations of relying on pre-set arbitrary weights to aggregate the main components. It should be noted that PCA has two main limitations: firstly, since each component is a linear combination of all underlying series, it is generally harder to interpret; secondly, since PCA relies on estimated correlations, we do not have enough regions to use this methodology on a large set of variables.[50]

For these reasons we attempt PCA on all aggregated sub-indices with regional variation, except for (1c) and (3b), which perform very poorly on the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy.[51] The eigenvalues we obtain are reported in Table 15.

We select the first four principal components, whose eigenvalues are largest, thus keeping most (88%) of the original variability in the data.[52] Table 16 shows the corresponding eigenvectors (only the most significant, i.e. that are larger than 0.3 in absolute value). The first components seem to represent mostly demand factors (broadband take-up, internet use, e-government users) and basic skills. The second one correlates most with both connectivity indices and the advanced skills index. The indicators of business digitalisation, e-commerce and the group of e-government services, are more closely related to

[49] See Mooi et al. (2018) for an introduction to PCA with STATA applications.

[50] In the literature, a commonly used rule of thumb is to have at least five observations for each input series—see e.g. Osborne and Costello (2004).

[51] The KMO estimates how much of the variables' variance could be due to a common underlying factor. While values close to 1 are ideal (i.e. validating the use of PCA), the minimum that should be achieved from this test is a value of 0.5. Overall, our KMO score is barely sufficient (0.7), consistently with the low number of observations.

[52] In the literature it is common to keep only the components whose eigenvalues are larger than one, however we have relaxed this rule of thumb to make sure all original components contribute to the composite index.

	rDESI	connectivity	human capital	internet users	integration of digital technologies	e-government
Lombardia	0.66	0.66	0.70	0.76	0.53	0.67
Emilia-Romagna	0.62	0.68	0.63	0.70	0.47	0.64
Lazio	0.62	0.75	0.72	0.63	0.44	0.47
Piemonte	0.60	0.61	0.68	0.58	0.57	0.48
Provincia Aut. Trento	0.59	0.54	0.69	0.64	0.51	0.57
Toscana	0.57	0.61	0.55	0.69	0.48	0.57
Provincia Aut. Bolzano	0.57	0.45	0.57	0.61	0.67	0.60
Umbria	0.57	0.59	0.50	0.67	0.59	0.49
Veneto	0.56	0.66	0.57	0.55	0.33	0.71
Friuli-Venezia Giulia	0.55	0.61	0.59	0.65	0.35	0.53
Liguria	0.54	0.73	0.57	0.53	0.31	0.50
Valle d'Aosta	0.51	0.45	0.56	0.63	0.33	0.64
Sardegna	0.45	0.46	0.37	0.56	0.32	0.63
Puglia	0.45	0.62	0.36	0.37	0.35	0.51
Abruzzo	0.45	0.54	0.40	0.52	0.37	0.39
Campania	0.42	0.67	0.35	0.35	0.34	0.32
Marche	0.42	0.51	0.40	0.59	0.23	0.41
Sicilia	0.34	0.68	0.11	0.27	0.26	0.33
Calabria	0.34	0.51	0.23	0.30	0.36	0.24
Basilicata	0.34	0.45	0.27	0.34	0.27	0.36
Molise	0.30	0.32	0.49	0.34	0.05	0.27

Fig. 3 Detailed rankings of the regional DESI

components three and four which barely contribute to the extracted variance (0.17 versus 0.70 of the first two components).

This methodology can be also used to produce an aggregate index based on correlation of its components (Mahida & Ramadas, 2017). In particular, once PCA is performed, the weight of each indicator i can be calculated according to the formula:

$$W_i = \sum_{j=1}^{4} |L_{i,j}| E_j,$$

where E_j is the eigenvalue of factor j, and $L_{i,j}$ is the loading value of the i-th unit of grouping on the factor j.

The digitalisation index calculated from the PCA has a 97% correlation with the regional DESI. This result could be explained by the strong correlations among almost all the series; as such, weighting has only a minor impact on ranking since a poor (or good) performance in one indicator is likely to be replicated in the other indicators.[53]

[53] PCA-based weights are evenly distributed: the methodology assigns 18 and 22 percent weight to connectivity and skills, respectively, and around 20 percent weight to each of the other three dimensions. Within connectivity, take-up has a slightly higher weight than coverage.

Table 13 Detail of the DESI 2022 sub-indices and data sources

Sub-indices	Methodology	New information level
1a1 At least basic digital skills	As DESI 2020	
1a2 Above basic digital skills	As DESI 2020	
1a3 At least basic digital content creation skills	New DESI 2022	National
1b1 ICT specialists	As DESI 2020	
1b2 Female ICT specialists	As DESI 2020	
1b3 Enterprises providing ICT training	New DESI 2022	NUTS 1
1b4 ICT graduates	As DESI 2020	
2a1 Overall fixed broadband take-up	As DESI 2020	
2a2 At least 100 Mbps fixed broadband take-up	As DESI 2020	
2a3 At least 1 Gbps take-up	New DESI 2022	National
2b1 Fast broadband (NGA) coverage	As DESI 2020	
2b2 Fixed Very High Capacity Network (VHCN) coverage	As DESI 2020	
2b3 Fibre to the Premises (FTTP) coverage	New DESI 2022	NUTS 2
2c1 5 G spectrum	New DESI 2022	National
2c2 5 G coverage	New DESI 2022	NUTS 2
2c3 Mobile broadband take-up	New DESI 2022	NUTS 2
2d1 Broadband price index	As DESI 2020	
3a1 SMEs with at least a basic level of digital intensity	New DESI 2022	NUTS 2
3b1 Electronic information sharing	As DESI 2020	
3b2 Social media	As DESI 2020	
3b3 Big data	As DESI 2020	
3b4 Cloud	New DESI 2022	NUTS 2
3b5 AI	New DESI 2022	NUTS 1
3b6 ICT for environmental sustainability	New DESI 2022	National
3b7 e-Invoices	New DESI 2022	NUTS 2
3c1 SMEs selling online	As DESI 2020	
3c2 e-Commerce turnover	As DESI 2020	
3c3 Selling online cross-border	As DESI 2020	
4a1 e-Government users	As DESI 2020	
4a2 Pre-filled forms	As DESI 2020	
4a3 Digital public services for citizens	As DESI 2020	
4a4 Digital public services for businesses	As DESI 2020	
4a5 Open data	As DESI 2020	

Appendix 4 Robustness Check for the E-Government Index

For the supply side of the e-government index (Desi 5), we use several proxies to measure the digitalisation level of public authorities at the NUTS2 level. Arguably, these proxies might only noisily capture the aspects covered by the original indicators (pre-filled forms, online service completion, digital public services for businesses, and open data) as the European Commission envisages. For this reason, we compute the principal component analysis of our series and take the absolute value of the factor loadings of the first

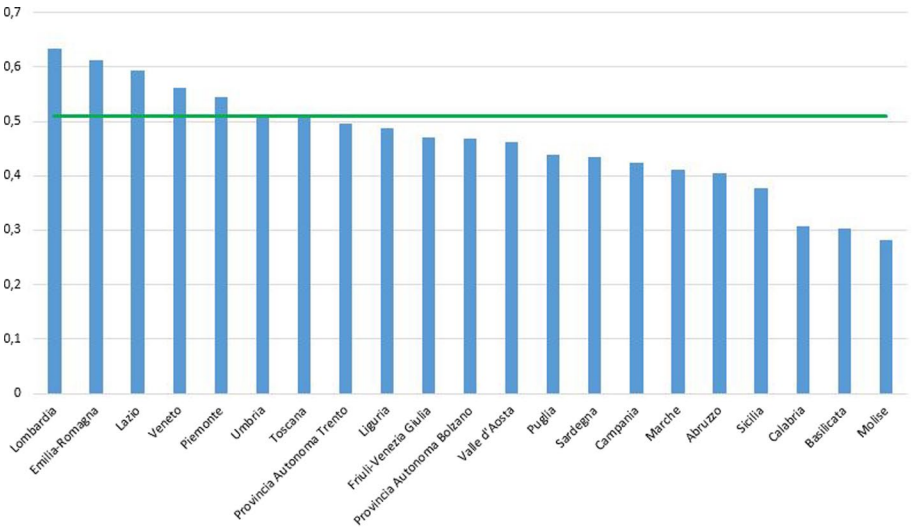


Fig. 4 DESI 2022 methodology

Table 14 rDESI ranking comparison between 2020 and 2022 methodology

Region NUTS 2	New	Old	New rank	Old rank	Change in rank position
Abruzzo	40.5	44.5	17	15	− 2
Basilicata	30.3	33.8	20	20	0
Calabria	30.8	33.9	19	19	0
Campania	42.3	42.3	15	16	1
Emilia-Romagna	61.2	62.2	2	2	0
Friuli-Venezia Giulia	47.0	54.7	10	10	0
Lazio	59.4	62.1	3	3	0
Liguria	48.8	54.5	9	11	2
Lombardia	63.4	66.1	1	1	0
Marche	41.2	42.3	16	17	1
Molise	28.1	30.5	21	21	0
Piemonte	54.4	59.5	5	4	− 1
Provincia Autonoma Bolzano	46.9	57.1	11	7	− 4
Provincia Autonoma Trento	49.7	59.1	8	5	− 3
Puglia	43.9	44.9	13	14	1
Sardegna	43.4	45.0	14	13	− 1
Sicilia	37.8	34.2	18	18	0
Toscana	50.9	57.4	7	6	− 1
Umbria	50.9	56.7	6	8	2
Valle d'Aosta	46.2	51.0	12	12	0
Veneto	56.1	56.2	4	9	5
Correlations		0.95		0.96	

Table 15 Eigenvalues of the principal components

	Eigenvalue	Proportion of extracted variance	Cumulative
Component 1	4.90	0.49	0.49
Component 2	2.15	0.21	0.70
Component 3	0.97	0.10	0.80
Component 4	0.74	0.07	0.88
Component 5	0.51	0.05	0.93
Component 6	0.26	0.03	0.95
Component 7	0.24	0.02	0.98
Component 8	0.13	0.01	0.99
Component 9	0.07	0.01	1.00
Component 10	0.04	0.00	1.00

Table 16 Eigenvectors of the principal components

	Comp.1	Comp.2	Comp.3	Comp.4	Unexplained
(1a) Fixed broadband take-up	0.31	0.41			0.13
(1b) Fixed broadband coverage		0.62			0.13
(2a) Basic skills	0.38				0.10
(2b) Advanced skills		0.43		−0.33	0.14
(3a) Internet use	0.41				0.18
(3c) Transactions	0.40				0.05
(4a) Business digitisation				0.76	0.11
(4b) E-commerce			−0.59	0.40	0.15
(5a) E-gov. users	0.37				0.15
(5b-5e) E-gov. Services			0.71		0.11

component as weights.[54] Using these, we aggregate all the series into an index, and then we compare it with the simple average of pre-filled forms, online service completion, digital public services for businesses, and open data (see Table 17).

As can be noted from the table, the two indexes are broadly consistent and have a correlation of 92%. Only in few occurrences the alternative methodology produces a significant change of a region's relative ranking (namely the Provincia Autonoma di Bolzano and Liguria).

We have also verified that if we remove from the original indicator the pre-filled form index and the open-data index (which have been strongly influenced by the national-wide policies of the central government), the revised index has a 93% correlation with the one we used in the paper.

All in all, these robustness checks suggest that the series we have selected as proxies do provide a consistent and robust picture of the services digitalisation by Italian local authorities.

[54] This approach entails that we give more weight to those proxies which are more correlated with the unobserved principal component and less weight to the series which are less correlated to it.

Table 17 E-government supply-side* index comparison

Region NUTS 2	Original methodology	PCA based approach
Abruzzo	0.32	0.20
Basilicata	0.39	0.35
Calabria	0.26	0.16
Campania	0.33	0.30
Emilia-Romagna	0.65	0.64
Friuli-Venezia Giulia	0.50	0.46
Lazio	0.37	0.31
Liguria	0.46	0.29
Lombardia	0.64	0.59
Marche	0.44	0.38
Molise	0.25	0.19
Piemonte	0.49	0.40
Provincia Autonoma Bolzano	0.50	0.61
Provincia Autonoma Trento	0.48	0.40
Puglia	0.55	0.47
Sardegna	0.53	0.48
Sicilia	0.42	0.25
Toscana	0.56	0.52
Umbria	0.50	0.40
Valle d'Aosta	0.58	0.68
Veneto	0.68	0.67
Correlation		0.92

* The supply-side refer to the four indices: pre-filled forms, online service completion, digital public services for businesses, and open data; excluding e-government users (5a)

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