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How to assess firms' digitalisation: a micro-level indicator

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ABSTRACT

This paper introduces microDESI, a novel firm-level indicator designed to measure digitalisation readiness and diffusion across Italian firms. While the Digital Economy and Society Index (DESI) provides valuable country-level insights, our micro-founded approach offers granular information that can be fruitfully exploited for economic analysis and policy purposes. The indicator has been tested on two rounds of the Italian section of the Eurostat ICT survey (2018 and 2020) to ensure data comparability. By integrating survey data with Frame-SBS performance metrics and AIDA-Moody's financial records, we capture multiple dimensions affecting digital transformation outcomes and relate them to firm performance. The resulting indicator identifies firm-level determinants of successful digitalisation while enabling comparisons over time and across firm characteristics. Our analysis reveals significant regional and sectoral heterogeneities in digitalisation readiness across Italian firms that must be accounted for in policy design. In this respect, the indicator serves dual policy functions: as a targeting mechanism for ex-ante intervention design and as an evaluation tool for measuring the effectiveness of industrial digitalisation policies. As European economies pursue digital transformation through initiatives such as the EU Digital Decade programme, microDESI provides an essential analytical tool to support policymakers and monitor digitalisation dynamics at the firm level.

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1. Introduction

The measurement of a socio-economic phenomenon is a necessary condition for understanding its implications, which makes it possible—for institutions and economic agents—to limit potential drawbacks or to magnify desirable aspects. The choice of the subject to measure, and the appropriate level of detail, becomes particularly relevant when analysing a multifaceted phenomenon such as digitalisation and its impact on firms and the overall industrial structure.

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The diffusion of digital technologies is profoundly shaping the environment in which firms operate, enabling productivity gains and new business models, associated with innovative goods and services, cost reduction, and new revenues (Jung and Gómez-Bengochea 2025). Even though the impacts on firms are heterogeneous, studies on Italian firms have shown that the spread of digital technologies enhances firms' productivity (Nucci, Puccioni, and Ricchi 2023), sales, and wages (Cirillo et al. 2023b), improves access to credit and credit conditions (Bronzini et al. 2025), and also reshapes the firm-level composition of the workforce, with an increase in the hiring rate and a decrease in the separation rate (Cirillo, Mina, and Ricci 2024). The country-level evidence available for Italy is consistent with findings in other major European countries such as France (Cette, Nevoux, and Py 2022), Germany, where Industry 4.0 technologies and artificial intelligence enhance innovative outcomes (Niebel, Rasel, and Viete 2019; Rammer, Fernández, and Czarnitzki 2022; Sarbu 2022), and European SMEs more broadly (Segarra-Blasco, Tomàs-Porres, and Teruel 2025). However, the adoption and successful implementation of these technologies depend on firms' readiness—defined by their skills and knowledge, organisational practices, and infrastructure (Ciarli et al. 2021; Nicoletti, Von Rueden, and Andrews 2020).

Since achieving a sustainable and more prosperous digital future is one of the central aims of the EU Digital Decade policy programme (European Commission 2023), this work proposes the construction of a novel firm-level indicator to summarise different digitalisation-related dimensions that correlate with firm performance. The objective of the proposed indicator is to capture the factors enabling successful implementation of digital-related policies, and to track the evolution of these factors at the highest level of detail possible. The indicator mimics the composition and objectives of the well-known Digital Economy and Society Index (DESI), which has been extensively used—in its aggregate country-level form—by the European Commission to monitor the progress of member states towards a digital European Union and to design appropriate policies. The novelty of a micro-founded indicator may prove useful to policymakers in addressing various issues. First, it can be used to identify firm-level characteristics to target with policy intervention in the context of ex-ante policy evaluation, at EU, national and regional levels. Second, it can support ex-post evaluations of the effects of industrial policies promoting the digitalisation of firms. This is particularly relevant, as both ex-ante and ex-post policy evaluation activities—are essential tools for supporting the transformation of the production system and enhancing its competitiveness (OECD 2020).

This paper makes a twofold contribution. First, from a methodological perspective, we build a novel firm-level indicator for Italy, the microDESI, by integrating multiple data sources. Second, we exploit this indicator to provide a detailed picture of regional and sectoral heterogeneities in firm-level digitalisation.

The remainder of the paper is organised as follows. Section 2 presents an overview of the methodologies used to measure digitalisation at the European and national levels, ultimately proposing the novel firm-level microDESI indicator. Section 3 outlines the construction of the integrated dataset, while Section 4 presents descriptive evidence exploring the different dimensions of the indicator, its coherence with the DESI indicator, and its correlation with relevant, firm level, performance variables. Finally, Section 5 concludes by highlighting potential applications of the indicator in informing the design of policy interventions.

2. Measuring digitalisation

Measuring the progress in the digitalisation of the economy and the society has become a priority for economic research and for policymakers, since it is an essential tool for informing effective public policies. To this aim, the European Commission and member states have developed indicators to capture progress in the transition toward a digital EU, with different levels of granularity. In this section we provide an overview of the main tools used, concluding with the proposal of a novel instrument.

2.1. DESI: a European country-level perspective

The Digital Economy and Society Index (DESI) is an indicator which has been used from the European Commission since 2014 to monitor and summarise member states performance in terms of digitalisation (European Commission 2020b).

It is constructed by Eurostat and the national statistical offices of the EU member states, combining different data sources. The composite index summarises five dimensions concerning the diffusion of the digital economy and its uptake by individuals, households, and enterprises. It combines five dimensions, which relate to: (i) connectivity; (ii) human capital; (iii) use of internet services; (iv) integration of digital technologies by firms; and (v) digital public services (e.g. availability and usage). For each country, the annual score is determined through a weighted average of the five dimensions, and scaled using fixed minimum and maximum values to ensure longitudinal consistency. The resulting DESI index has the advantage to condense an important number of information related to several dimensions in a unique score. This allows to track the changes between years, and to compare the dynamics across the other EU economies.

The dimension related to human capital ranges from internet use and basic digital skills across households, to the availability of ICT skills in the labour force. To do so, it uses data from Eurostat Survey on 'ICT usage in households and by individuals' (ICT-HI, hereafter), and Eurostat Labour Force Survey. On the other hand, the dimension related to the digital infrastructures—i.e. connectivity—mainly relies on studies elaborated for the European Commissions by external entities. These studies cover information related to broadband speed, coverage, and prices, or 5G coverage and prices. This dimension also integrates information from the ICT-HI survey to evaluate the broadband take-up across households. The 'Integration of digital technology' dimension exploits data, for the most part, from the Survey on 'ICT usage in enterprises' (ICT-Ent, hereafter). Here data are used to assess a 'basic level of digital intensity' for SMEs, which is combined with the diffusion of the major digital technologies—e.g. electronic information sharing, social media, big data, etc.—and with the share of SMEs being active with e-commerce. Finally, the dimension related to 'Digital public services' reflects the progress of member states in providing the access to public services using digital devices, or the availability of open data, using information from the eGovernment benchmark,¹ and the quantity and quality of open data available on the European data portal.

As this overview makes clear, the building of the DESI requires the integration of many sources of different nature—from surveys to country-level or technical studies, as reported in Table 1 and provides only a country-level perspective. In this regard, some attempts have been made to construct regionalised versions of the DESI, while preserving the

Table 1. Sources used for European Commission's DESI.

Dimension	Data sources
1. Connectivity	Eurostat Survey on ICT usage in households and by individuals; EC Communications Committee; Studies for EC by IHS Markit, Omdia, Point Topic, Empirica
2. Human capital	Eurostat Survey on ICT usage in households and by individuals; Eurostat Labour Force Survey; Eurostat Survey on ICT usage in eCommerce in Enterprises
3. Use of internet services	Eurostat Survey on ICT usage in households and by individuals
4. Integration of digital technology	Eurostat Survey on ICT usage and eCommerce in enterprises; Survey of business on the use of digital technologies by Ipsos and iCite
5. Digital public services	Eurostat Survey on ICT usage in households and by individuals; eGovernment Benchmark; European data portal

Note: Sources used to build the 2020 version of the DESI (European Commission 2020b).

aggregated resolution of the indicator. For instance, a regional DESI—i.e. the rDESI index—is built for Italy by Benecchi et al. (2023). The authors highlight that the regionalised version of the index is useful tool for policymakers to help the planning of intervention, in particular for infrastructures, to achieve an inclusive digitalisation for local institutions, individuals, and firms.

On the one hand, the integration of a high number of different sources in an efficient way, together with a wide focus on a range of challenges (e.g. availability of skills among individuals, diffusion, speed, and price of connectivity, adoption of digital technologies, or availability of digital public services), makes it a useful tool for policy makers to address a spectrum of issues related to the digital transition in the society at large. At the same time, the wide focus hampers the ability of targeting specific economic agents—such as firms—actively involved in supporting the digitalisation of the economy.

2.2. Eurostat's digital intensity index

An attempt to measure digital technology adoption at the firm level is represented by the Digital Intensity Index (DII), which is calculated by Eurostat—in collaboration with national statistical offices—and contributes to the evaluation of the aggregated DESI, specifically in the dimension related to 'integration of digital technologies'.

The index ranges from 1 to 12, quantifying how many of 12 selected technologies are utilised by European firms. The final scores are aggregated into four categories: very low DII (0–3), low (4–6), high (7–9), and very high (10–12).

The DII facilitates efficient comparison between firm categories and across EU member states. However, the index presents two significant limitations. First, it focuses exclusively on the adoption of specific technologies, omitting other essential enabling factors—such as the availability of skills or infrastructures—which may be crucial for an effective absorption. Second, the variability over time in the composition of the index presents challenges in terms of longitudinal comparability. As technological evolution proceeds at a rapid pace, the composition of technologies included in the index is significantly modified annually to incorporate emerging technologies. This evolution limits the comparability over time of the index and consequently reduces its usefulness for policy evaluation purposes.

2.3. A novel firm-level indicator

Previous sections have provided an overview of existing measures—both at an aggregate (national and regional) and a micro level—of digitalisation. In this section we propose a novel indicator, the microDESI, which attempts to overcome the limitations of existing measures, preserving two of their essential aspects: (i) the ability to synthesise different dimensions related to the digitalisation process, and (ii) the micro-economic perspective related to the enterprise level. The microDESI offers several distinct advantages over existing firm-level indicators, such as the DII. First, it adopts a broader scope by moving beyond simple technology adoption to capture essential enabling factors, including workforce skills, connectivity infrastructure, and institutional interactions with digital public services. Second, while technology-count indices often suffer from shifting compositions over time, the microDESI is explicitly designed to maintain consistency across survey waves, ensuring its suitability for longitudinal analysis and robust policy evaluation. Third, the indicator is structured to maximise policy utility; its close alignment with the aggregate DESI framework provides direct interpretability for policymakers, while its granular firm-level nature supports both ex-ante targeting and ex-post impact assessments. In this perspective, it assumes a valuable role as a critical and timely monitoring instrument for the National Recovery and Resilience Plan, specifically for tracking the outcomes of the digitalisation-related missions. It offers a granular framework to evaluate whether the broad financial allocations of the Plan are translating into structural digital upgrading, thereby supporting more evidence-based assessments of public policy effectiveness and the long-term sustainability of these investments. Finally, the index is constructed to be easily integrated with administrative and balance-sheet datasets, facilitating a systematic analysis of the relationship between digital readiness and various dimensions of firms' performance.

From a theoretical perspective, the indicator should be interpreted as a measure of firm-level digital readiness, as it synthesises the multidimensional nature of digitalisation. This phenomenon encompasses the firm's organisational structure, workforce skills, physical infrastructure, and the institutional counterparts with which it interacts. It is designed to capture a set of complementary capabilities and technological practices that, together, determine a firm's capacity to effectively adopt, absorb, and exploit digital innovations.

Methodologically, the microDESI synthesise four dimensions, mirroring the DESI index, which are related to: (i) firm-level skills; (ii) availability of infrastructures; (iii) integration of digital technologies; and (iv) ability of using e-Government services.

The index is constructed using one data source, that is, the survey on 'ICT usage in enterprises', which is the Italian section of the corresponding harmonised Eurostat survey, which in Italy is conducted by the Italian National Institute of Statistics (ISTAT). This also represents a potential advantage, since reduces the effort to combine different sources and increases the overall consistency of the composite indicator.

The dimensions and the related indicators—i.e. the survey's variables—used to construct the microDESI are presented in [Table 2](#).

The four components replicate the composition of the country-level DESI while maintaining the firm-level dimension, which is essential to be exploited in ex-ante or ex-post assessments of policy evaluations.

Table 2. Dimensions and sub-indicators of microDESI.

Dimension	Sub-Indicator	Variable	Weight	Measurement
1. Skills and competences	a. Specific IT training	<i>TRAIN^{Spec}</i>	0.5	Dummy for having provided Specialistic ICT training to the IT specialists
	b. IT training for non-ICT specialists	<i>TRAIN^{Gener}</i>	0.5	Dummy for having provided Generic ICT training to the workforce
2. Connectivity	Broadband connectivity	<i>CONNECT</i>	1	Dummy for having a broadband connection of at least 100 Mbps
3. Integration of digital tech.	Number of technologies adopted	<i>DIGINT</i>	1	Fractional count of the number of technologies adopted (total number of techs. adopted by the firm divided by the number of techs. surveyed in the round)
4. Usage of e-Gov services	Number of public services used	<i>EGOV</i>	1	Fractional count of the number of services used (total number of services used without reporting any issue divided by the number of services surveyed, 1–12)

Note: All the variables in the table used to build the microDESI come from the harmonised ISTAT 'Survey on ICT usage in enterprises'.

The first dimension is represented by 'Skills and competences', and reflects the propensity of the firm to engage in activities related to the updating, upskilling and reskilling of its workforce. The inclusion of a 'human capital' component is of particular relevance to overcome the limitation of a pure technology-based measure, like the DII, providing a more accurate representation of the firms' absorptive capacity. By integrating a 'Skill and competences' component, the index reflects the consensus that digital diffusion is not merely about equipment, but is strictly conditional on the presence of internal capabilities and specific human capital (Nicoletti, Von Rueden, and Andrews 2020). This approach is particularly relevant for capturing how the integration of advanced technologies depends on the synergy between investment, skills, and work organisation (Cirillo et al. 2023a). To have an updated skill component in the workforce is of primary importance for enabling the effective and profitable adoption of digital technologies (Antonelli, Orsatti, and Piali 2025; Pedota, Grilli, and Piscitello 2023), which is also a key driver to an inclusive digitalisation for firms and regions (Caisl, Guarascio, and Reljic 2025; Caravella et al. 2023).² The two sub-indicators are dummy variables reporting whether the firm has organised—or participated in—training activities to develop or update ICT skills for its workforce. One variable relates to employees engaged in ICT tasks and functions (i.e. ICT specialists), while the other relates to all the other employees, which—outside the ICT-intensive sectors—represent the vast majority. To be comparable with the other dimensions, the indicators are weighted by calculating the firm-level arithmetic average between the two dummies.

The second dimension relates to 'Connectivity and infrastructures'. The availability and use of a (high-speed) broadband connection is found to affect many firm-level dynamics, such as innovation and productivity (Akerman, Gaarder, and Mogstad 2015; Bertschek, Cerquera, and Klein 2013), and may be particularly relevant in Italy, where the high-speed network lags, in terms of coverage, with respect to other European countries, due to supply and demand factors³ (Bugamelli et al. 2018; Ciapanna and Roma 2020). Therefore, we use an indicator which is related to the presence of a high-speed broadband connection, to account for the enabling nature of this infrastructure. The relative dummy variable takes the value equal to 1 when the firm has a broadband connection for which the minimum broadband guaranteed by the provider is 100 Mbps, while assuming 0 otherwise.⁴

The third dimension relates to the ‘Integration of digital technologies’. In order to overcome the limitations in terms of comparability over time that characterise DII, we here propose to measure the intensity of adoption over a composite basket of digital technologies. We therefore focus our analysis on the technologies for which comparable information in the latest waves of the survey are available. Specifically, we use data on the following technologies in our analysis: 3D printing, cloud computing, big data analytics, applications, e-commerce, augmented reality, cybersecurity, Internet of Things, and robots.⁵ We measure the intensity of digital adoption by counting how many technologies are adopted by the firm and then computing the ratio over the total. It is worth highlighting that the harmonisation strategy prioritises temporal comparability and conceptual consistency with the DESI framework over the inclusion of frontier technologies, thereby capturing the breadth of adoption of core digital technologies at the cost of abstracting from the most recent technological shifts.⁶

Finally, the last dimension pertains to the firm’s ability of using digital public services. The provision of e-Government services facilitates the relationship between institutions, public offices, citizens and firms, enabling greater efficiency in bureaucratic processes. The survey collects information on a set of digital public services used by the firm, and for which the firm has not reported any issues. We interpret this information as an indication that the firm is both willing and able to use digital services without difficulties. The total number of services surveyed are twelve,⁷ for which we sum the number of positive replies and divide it by the total.

Therefore, at the firm level, we compute an indicator that synthesises the overall readiness of the firm for digitalisation, using the following formula:

$$microDESI_{it} = \frac{\frac{1}{2}TRAIN_{it}^{Spec} + \frac{1}{2}TRAIN_{it}^{Gener} + CONNECT_{it} + DIGINT_{it} + EGOV_{it}}{4} \quad (1)$$

3. Data

To build the microDESI indicator we leverage enterprise level information from the ISTAT ‘Survey on ICT usage in enterprises’, which is the most important harmonised survey developed by Eurostat with national statistical offices, in collaboration with the European Commission. It is conducted yearly since 2001, and its aim is to collect a comprehensive and detailed set of information regarding the use of digital technologies in enterprises with at least 10 employees. The survey is sample-based for firms with a number of employees between 10 and 249, while it is census-based for those with more than 250 employees. From this survey we build the composite indicator–microDESI–, by using the information related to skills updating (i.e. training), available connectivity, number of technologies adopted, and number of e-Gov services used.

The advantage of a composite firm-level indicator is represented by its ability to summarise several characteristics of the firm associated with the phenomenon under scrutiny, that is, the firm’s overall digitalisation readiness. Moreover, it can be used to analyse the correlation between firms’ digitalisation readiness with other firm level indicator such as performance, liabilities, and financial indicators.

In this direction we merge data from the ICT survey with the Frame-SBS, also obtained from ISTAT, that is the Structural Business Statistics thematic register. This source contains

the main economic variables related to enterprises, which are developed using administrative and fiscal data to estimate key variables, while using sample data to estimate information not available in administrative archives (Luzi and Monducci 2016). Finally, we integrate the dataset with balance sheet data and profit-and-loss accounts from Aida-Moody's Analytics. This source allows us to construct performance variables, and to compare firms controlling for liabilities, investments, and other structural characteristics.

The final dataset resulting from the integration is composed by 6,719 firms for the year 2018 and 2020, for which we have complete information on ICT usage, performance, and financial data.

The choice of focussing on the period from 2018 and 2020 is due to issues related to data availability and comparability over time. In particular, for more recent years the statistical unit targeted by the survey has changed radically—shifting from the firm to the enterprise group level—preventing us from using the most recent waves of the survey.⁸

4. Digitalisation of Italian firms

4.1. Evidence from microDESI

This section presents a descriptive analysis of the sample comprising firms included in two waves of the ISTAT-ICT Survey (2018 and 2020). Table 3 presents the descriptive statistics for the synthetic index and its components: the overall microDESI averages 0.34 with a standard deviation of 0.23, while its components exhibit higher variability in the training and connectivity dimensions and more limited variability in the digital intensity and e-government components. The index experienced growth between the two years under study, driven by increases in the availability and usage of high-speed connectivity and e-government services. Changes in the integration of digital technologies (i.e. DIGINT) were limited, while the TRAIN component remained stable. The temporal dynamics are reported in Table 4.

From a sectoral point of view, digitalisation is still a heterogeneous phenomenon which does not permeate all the sectors with the same intensity, as shown in Figure 1.

Table 3. Descriptive statistics for microDESI and its components.

Variable	N. obs.	Mean	SD	Median	Min	Max
microDESI	13,116	0.3425	0.2351	0.31	0	1
TRAIN	13,116	0.3432	0.4145	0.00	0	1
CONNECT	13,116	0.3651	0.4815	0.00	0	1
DIGINT	13,116	0.2723	0.2378	0.20	0	1
EGOV	13,116	0.3894	0.2967	0.33	0	1

Note: Units in the sample are divided across the two years as follows: 6,534 firms in 2018, and 6,582 firms in 2020. The variable TRAIN is defined as $(0.5TRAIN_{it}^{Spec} + 0.5TRAIN_{it}^{Gener})$.

Table 4. Evolution over time of microDESI and components.

Year		microDESI	TRAIN	CONNECT	DIGINT	EGOV
2018	Mean	0.2944	0.3434	0.2652	0.2409	0.3283
	SD	0.2283	0.4131	0.4415	0.2414	0.2819
2020	Mean	0.3902	0.3431	0.4643	0.3035	0.4501
	SD	0.2321	0.4158	0.4988	0.2299	0.2986

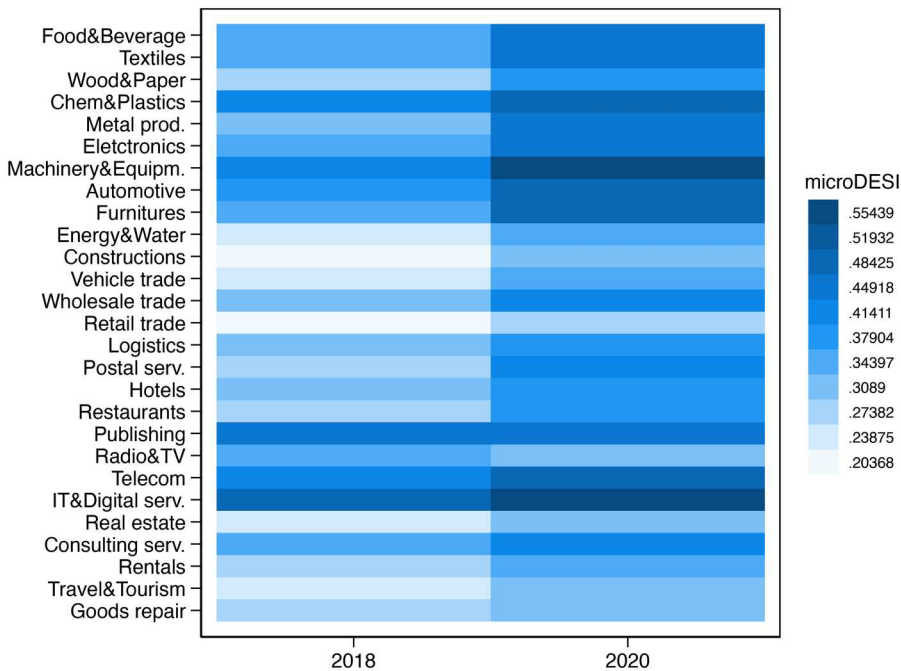


Figure 1. microDESI by year and ATECO sectors.

The figure confirms the improvement of the index between the two years considered, with larger average values in 2020. Still, the heterogeneity across sectors is clear. Higher (average) values of microDESI are reported in manufacturing (ATECO 'C' division), and ICT-intensive sectors (ATECO 'J' division) such as telecommunications, and IT and digital services. The observed disparities between sectors reflect varying degrees of digital permeability across production processes: while service industries such as Knowledge-Intensive Business Services (KIBS) exhibit a natural propensity for digital adoption due to their information-centric nature, in manufacturing, digital intensity remains more concentrated within specific high-tech segments like machinery and equipment.

The heterogeneity is confirmed—and potentially amplified—when ATECO sectors are examined in conjunction with size classifications (Figure 2). Analysing the 2020 values reveals that index scores generally increase with firm size, with the lowest values consistently observed in the smallest size category (10–49 employees). However, a distinct pattern emerges between manufacturing and services, with service sectors consistently demonstrating higher values across all categories. This disparity persists throughout the size distribution, reaching its maximum in firms with more than 250 employees, where service sectors again record the highest values.

Finally, it is worth considering the spatial distribution of the index, that is, the regional heterogeneity of the firms' digitalisation. The regional distribution of the index (Figure 3) follows the traditional dichotomous distinction between northern and southern regions, with the latter being less digitalised than the former. The higher values are reported by Emilia-Romagna and Piemonte in both the years considered, while the lowest are from smaller or lagging regions, such as Calabria and Molise. It is important to emphasise

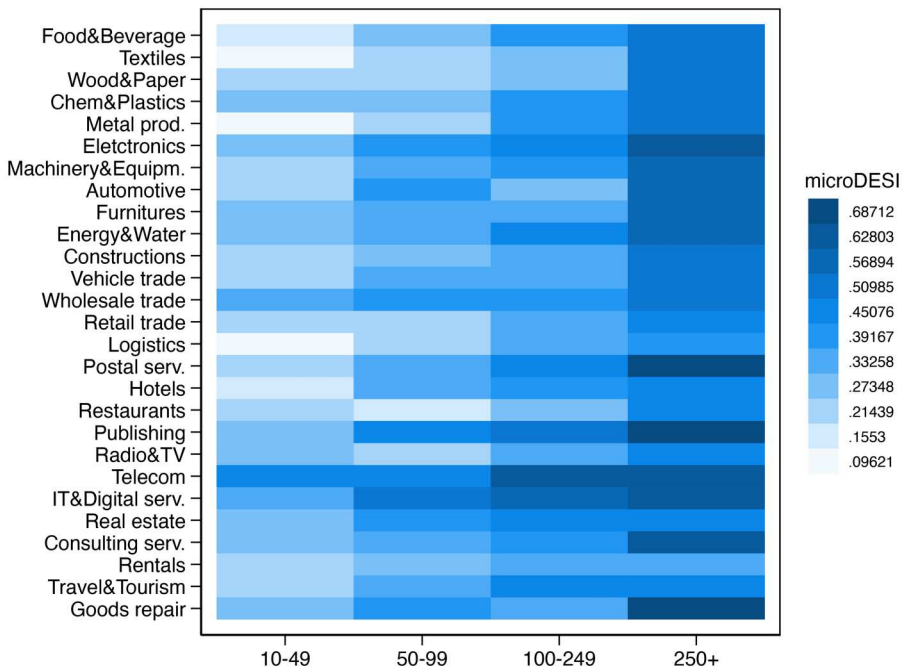


Figure 2. microDESI by ATECO and size classes (year 2020).

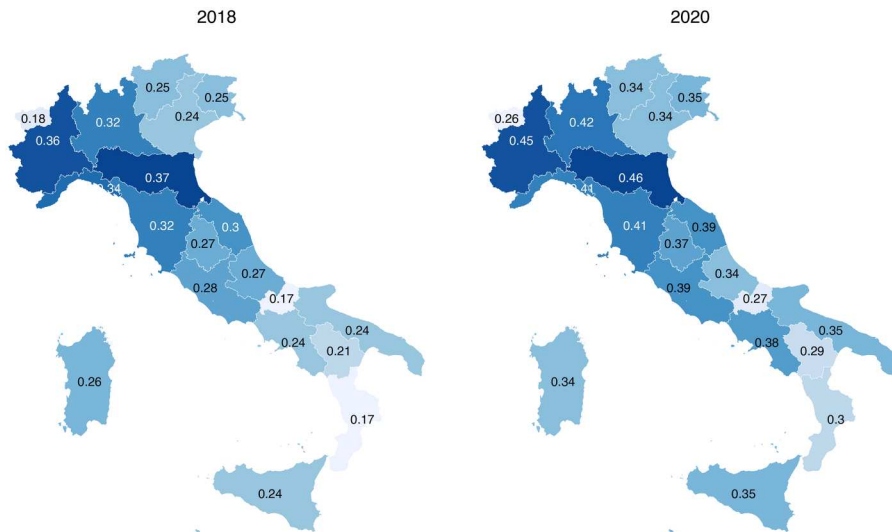
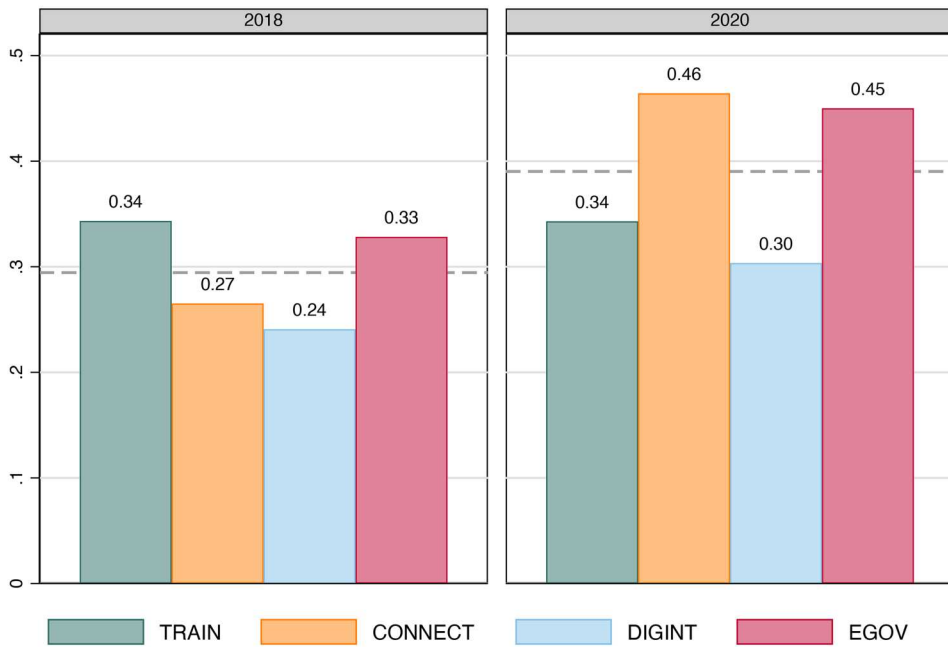


Figure 3. microDESI by NUTS-2.

that the index presents a within variability, since it is the product of the interaction of four distinct components. Therefore, the dynamics may be driven by heterogeneous behaviours of the single dimensions.

This heterogeneity across dimensions is evident looking at the [Figure 4](#). While three dimensions out of four increased from 2018 to 2020, even though with different intensity,



Gray dashed lines represent the value of the microDESI

Figure 4. Index components by year.

the one related to training (the green bars in Figure 4) remains stable over the two years. The evidence appears to be driven by a composition effect, as shown in Figure 5. Between 2018 and 2020—the two years under scrutiny—generic training activities were scaled back

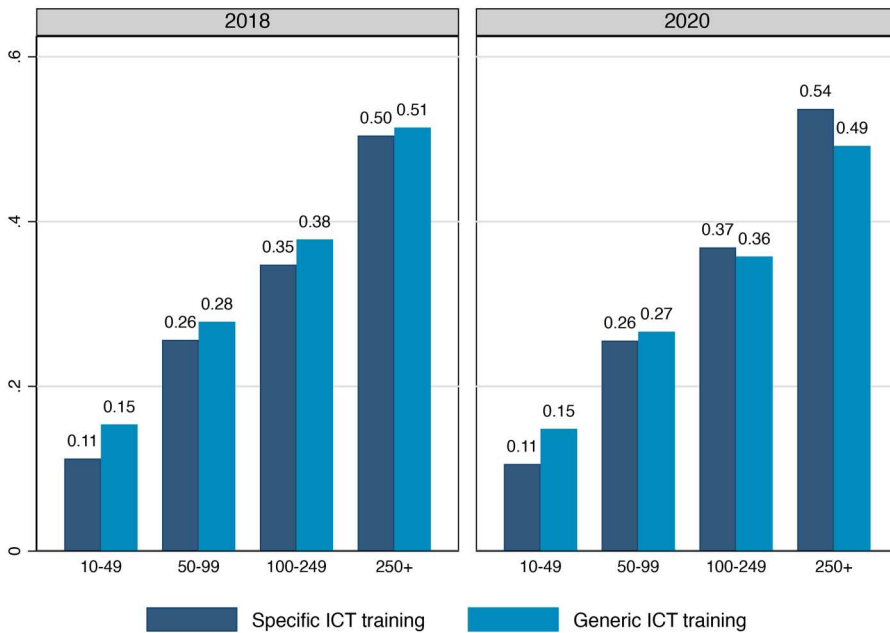


Figure 5. Training components by year and size classes.

by medium-large firms (100–249 employees) and large firms (more than 250 employees). In contrast, small and medium-small firms continued to organise and participate in ICT training activities—for both IT specialists and the general workforce—albeit at very low rates. The decline in generic IT training among larger firms may be attributed to the fact that such training had already been implemented in previous years, whereas smaller firms are still in the process of catching up. This dynamic likely contributed to the observed composition effect: in 2020, fewer large firms engaged in generic IT training, resulting in a decline in the aggregate indicator.

It is important to acknowledge that the 2020 wave coincides with the COVID-19 pandemic, a shock that likely influenced firm-level digitalisation in non-neutral ways. While the increase in the microDESI between 2018 and 2020 reflects a general growth trend, certain components (e.g. connectivity and e-government services) may partly represent short-term adaptive responses rather than purely structural upgrading. Therefore, the 2020 results should be interpreted as a combination of pre-existing capacity and a crisis-induced acceleration of specific practices. This distinction is crucial for separating long-term investment decisions from immediate adjustments triggered by the pandemic. This consideration is particularly relevant also for the training component, which was significantly affected by the timing of the survey. The evidence suggests that the 2020 lockdowns may have caused a temporary pause or suspension in formal training programs. While firms quickly adopted digital tools to stay operational during the emergency, the structured training needed to master them was likely delayed. Consequently, these results likely reflect a short-term reaction to the crisis rather than a permanent change in long-term strategy.

4.2. Statistical overview

Between the two years analysed, the index demonstrates an overall increase, as evidenced by the distributions across years ([Figure 6](#)). In 2018, a high concentration of firms clustered around low index values (i.e. below 0.2), while in 2020 firms exhibited a relatively strong shift toward higher values. The left tail of the distribution diminished, allowing a substantial number of firms to move toward the centre, while firms in the right tail experienced only limited shift. However, the benefits have not been distributed evenly across size classes.

In [Figure 7](#) we split the distribution—and the dynamics—of the index according to the size (in terms of the number of employees). The most significant shift has been experienced by small firms (those between 10 and 49 employees), and in all size classes is more pronounced the reduction of the left tail with respect the increase in the right one.

The shift of the distribution between 2018 and 2020 is also evidenced by the values of the skewness ([Table 5](#)). Its value is positive in 2018 (i.e. observations concentrated on the left), but is lower when considering the 2020 round, that is, less skewed to the right. This is verified for the overall index, but also when splitting the index according to the size class.

To assess the robustness of the proposed indicator, it is important to underline its consistency with the aggregate country-level DESI used by the European Commission. Even though we perform an analysis using a different level of aggregation also using a different source of data—we only use the ICT survey, while Eurostat combines multiple sources, different from ours—the main evidence, both as single dimensions and as the composite

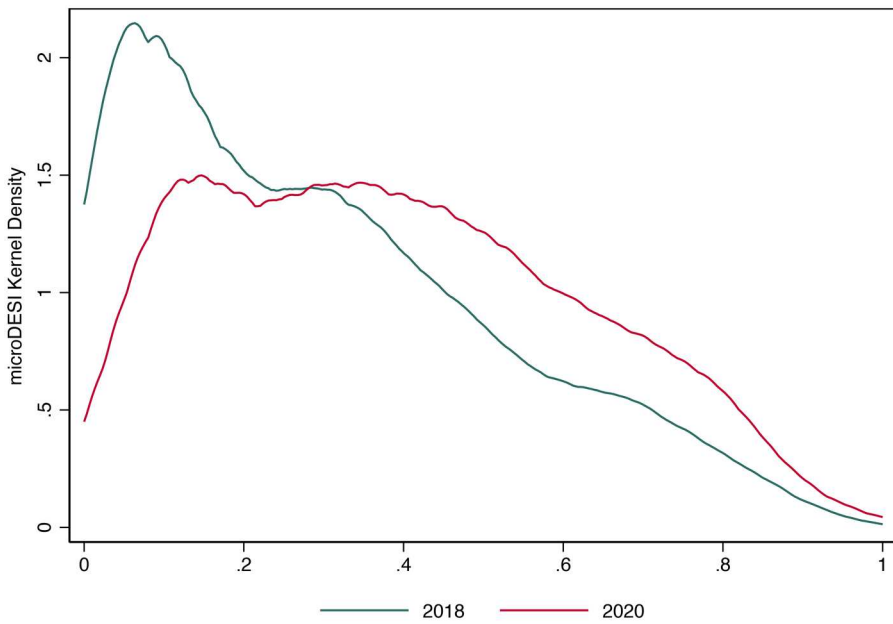


Figure 6. Kernel density of microDESI by year.

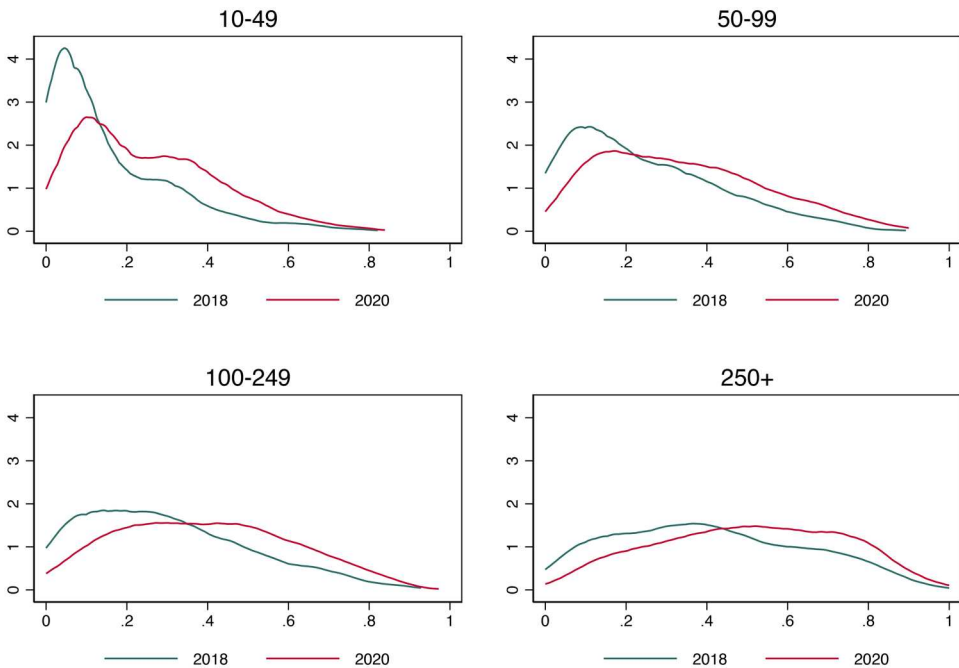


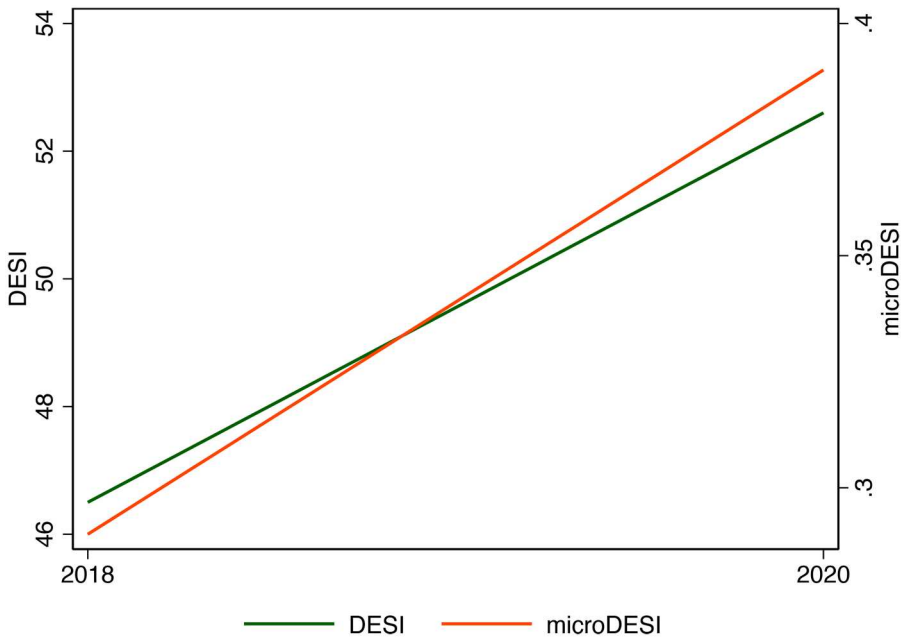
Figure 7. Kernel density of microDESI according to the size class.

index, describes the same patterns of digitalisation for Italy. The comparison between the country-level index and the microDESI is shown [Figure 8](#), while [Figure 9](#) reports the comparison between the single dimensions considered.

Table 5. Skewness of the index by size class.

	microDESI	10–49	50–99	100–249	250+
2018	0.6830	1.4020	0.7750	0.6093	0.2387
2020	0.3204	0.6825	0.4814	0.1940	–0.0911
Δ	–0.3626	–0.7195	–0.2937	–0.4153	–0.3298

Note: Size classes in terms of number of employees. The delta row indicates the difference $\Delta = 2020 - 2018$. A negative value signifies a reduction in asymmetry (i.e. the distribution shifts to the right).

**Figure 8.** Evolution of country-level DESI and microDESI.

It is clear that there is a strong correlation between the components, which display similar dynamics over the period considered. The only sub-dimension exhibiting a different behaviour—a decline between the two years—is that related to generic ICT training for the workforce. In this case, the indicator shows a slight decrease, from 0.36 in 2018 to 0.34 in 2020, whereas the sub-dimension related to specific IT training aligns with the ‘Human Capital’ dimension of the country-level DESI. Overall, this evidence supports the view that the dimensions included in our firm-level measure are consistent with those deemed relevant by the European Commission for assessing, tracking, and addressing the digitalisation of the economy through public policy.

The index is positively correlated with several firm performance variables, albeit with differences in correlation intensities and between macro-industries (i.e. manufacturing versus services). The variables selected as proxies for firm performance are: labour productivity, profitability (i.e. EBITDA), average firm-level wages,⁹ and the share of exported turnover. The correlations between microDESI and these variables are shown in [Figures 10 to 13](#).

Examining the correlations ([Table 6](#)), we observe a weak correlation with labour productivity, slightly stronger in services than in manufacturing, which is primarily driven by the training component (approximately 5%), while remaining very low for the

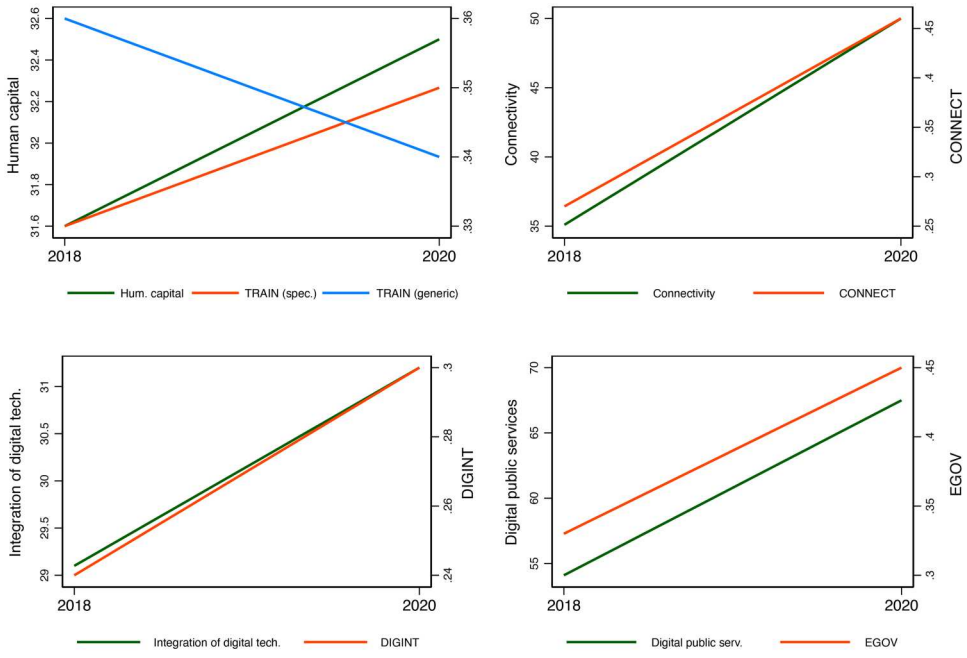


Figure 9. Evolution of country-level DESI and microDESI components’.

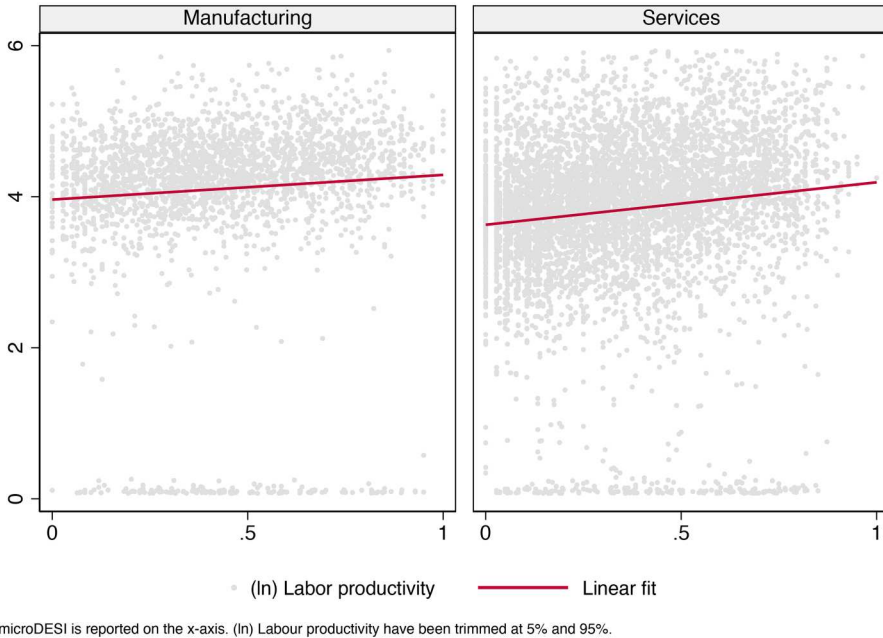


Figure 10. Correlation between microDESI and labour productivity.

DIGINT component in manufacturing (approximately 2%). Conversely, the correlation between microDESI and profitability—measured as EBITDA—is substantial (38% in manufacturing and 40% in services) and is driven by the TRAIN and DIGINT components,

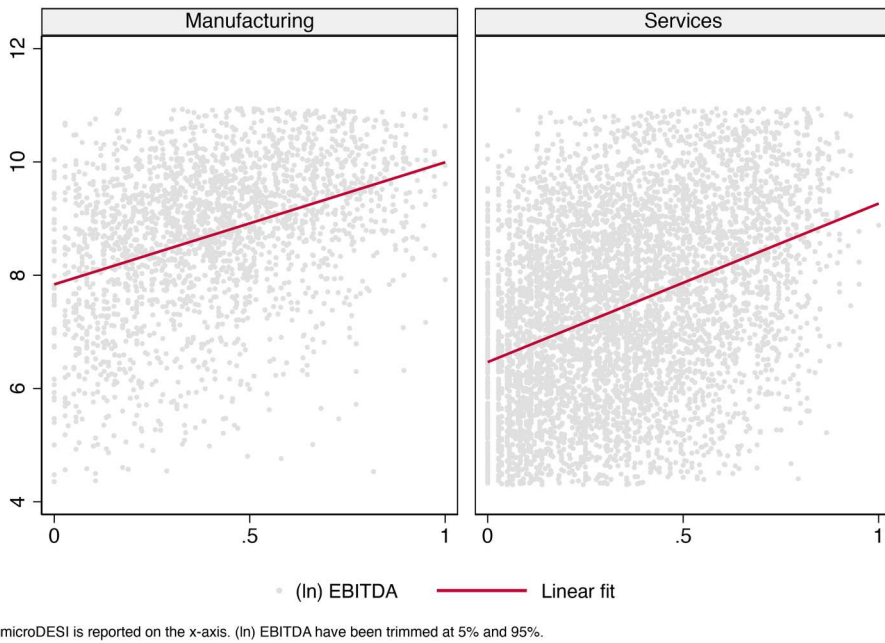


Figure 11. Correlation between microDESI and profitability (EBITDA).

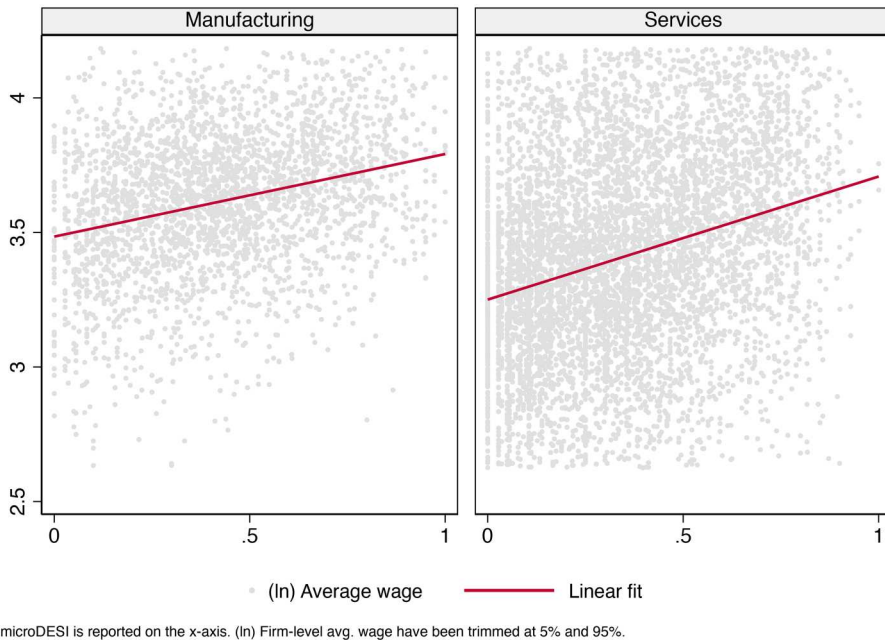


Figure 12. Correlation between microDESI and average firm-level wage.

while being lower for the other two components. Similar patterns emerge for average wages, which correlate with microDESI at 24.6% in manufacturing and 30% in services. The correlations between the microDESI on the one hand, and with profitability and

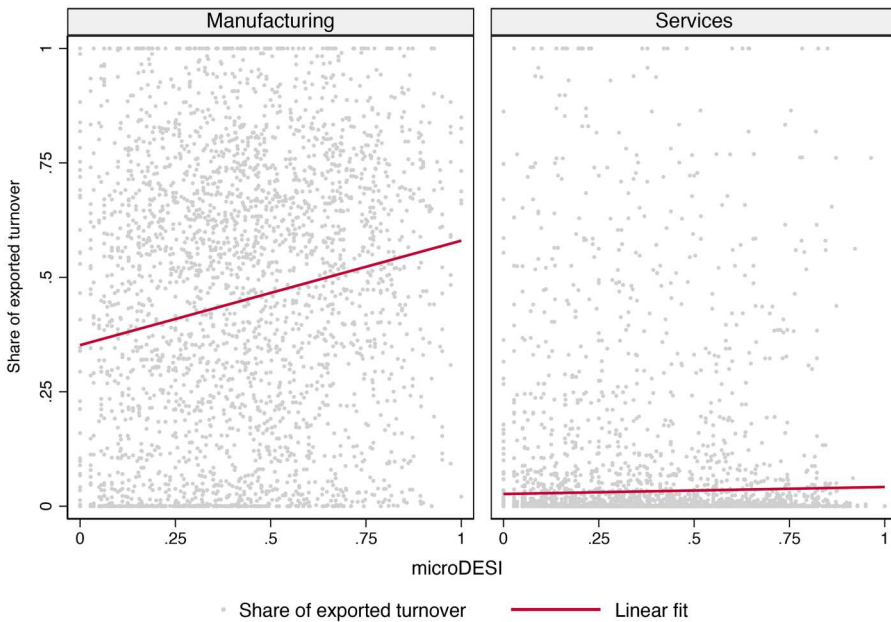


Figure 13. Correlation between microDESI and share of exported turnover.

Table 6. Correlations between microDESI and performance.

	microDESI			
	Manufact.	Services		
Labour productivity	0.0485	0.0593		
EBITDA	0.3816	0.4036		
Avg. Wage	0.2459	0.3016		
Exported turnover	0.1550	-0.0269		
	TRAIN		CONNECT	
Labour productivity	0.0526	0.0577	0.0234	0.0323
EBITDA	0.3195	0.3248	0.1878	0.2116
Avg. Wage	0.2513	0.2838	0.1395	0.1959
Exported turnover	0.1566	-0.0383	0.0743	-0.0328
	DIGINT		EGOV	
Labour productivity	0.0194	0.0479	0.0207	0.0127
EBITDA	0.2723	0.2786	0.1886	0.2324
Avg. Wage	0.1263	0.1724	0.0703	0.0797
Exported turnover	0.1607	0.0401	-0.0033	-0.0050

Note: Number of observations: 2,121 firms in manufacturing, and 4,438 firms in services. Exported turnover is the share with respect to the total turnover. Performance variables are trimmed at 5% and 95%, and expressed in natural logarithm.

labour productivity on the other hand, seems to suggest that digital adoption co-moves differently with various aspects of firm’s performance. The pattern emerging from the sample could reflect that certain digital practices are linked to organisational or cost-efficiency gains (therefore reducing operating costs and affecting the profitability), rather than increasing the value added, at least in the short run. This explanation is consistent with the broader literature of the ‘productivity paradox’, where contemporaneous correlations between digitalisation and productivity are often found to be weak,

potentially reflecting the significant adjustment processes and implementation lags associated with the digital transition (Aghion et al. 2020; Haskel and Westlake 2017).

Finally, the index distribution and correlations are also influenced by firms' exposure to international trade, consistent with existing literature (Keller 2010; Rigo 2021; Saliola and Zanfei 2009). The correlation is high in manufacturing while being zero or slightly negative in services, as also evident in Figure 13. We classify firms according to their import and export status, defining exporters (importers) as firms with a share of exported (imported) goods over revenues greater than 5%. Firms that are both importers and exporters are classified as 'two-way traders', while those that neither import nor export are defined as 'non-traders'. Figure 14 demonstrates that international trade plays a more significant role in shaping the index distribution in manufacturing than in services. In manufacturing, two-way traders exhibit higher average values, whereas non-traders display a larger concentration of firms at lower index values. In contrast, service sector firms appear less affected by international trade, with two-way traders showing higher density than non-traders only at the upper end of the index distribution. These patterns are consistent with a circular relationship between internationalisation and digitalisation: while digital tools help firms reach the productivity levels needed to compete in international markets, exposure to foreign customers and suppliers facilitates the knowledge transfers that encourage further digital adoption.

4.3. Distributional patterns across technological taxonomies

The digitalisation phenomenon is spread in a heterogeneous manner across productive sectors, as different production processes mediate the degree of permeability to digital transformation. Hence, it is of interest to analyse how the indicator—and its

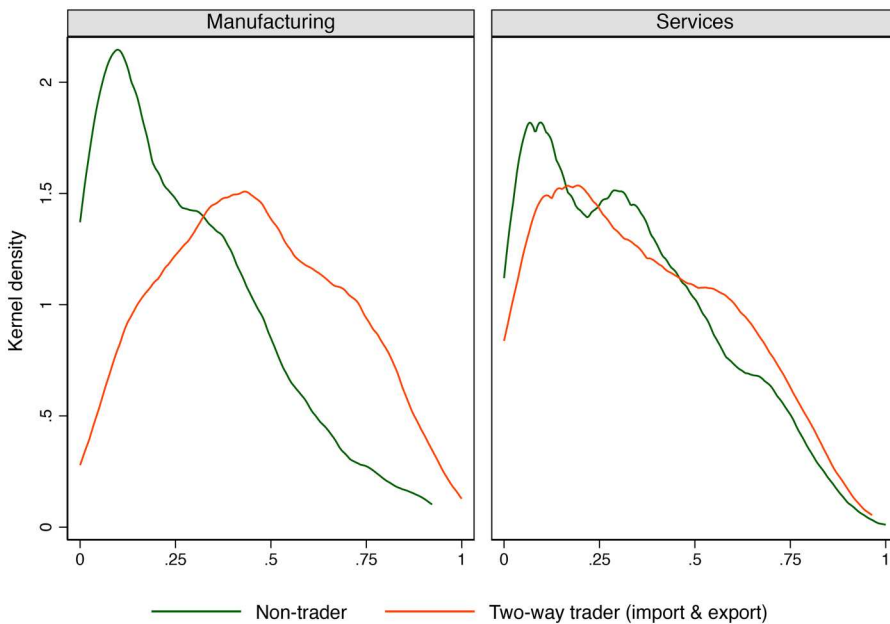


Figure 14. Kernel density by exposure to international trade.

components—is distributed across sectors that share common features, that is, clusters represented by technological taxonomies. To this end, we examine the distributional aspects of the microDESI across two technological taxonomies. The first is the OECD taxonomy of digital-intensive sectors, which provides a classification of the extent to which sectors have embraced digital transformation (Calvino et al. 2018). The second is the revised Pavitt taxonomy, which classifies sectors according to innovation dynamics, extending the traditional Pavitt taxonomy to include IT-related service sectors (Bogliacino and Pianta 2016).

The distribution of the index in Figure 15 according to the OECD taxonomy (left-hand panel) confirms the robustness of the indicator’s construction, as firms in low digital-intensive sectors exhibit a higher concentration around lower values of the indicator, whilst the opposite holds for firms in high-intensive sectors. Symmetrically, the greater concentration of high values according to the Pavitt taxonomy (right-hand panel, Figure 15) is found in the Science Based class, that is, the class with the highest technological dynamics (e.g. high levels of R&D, innovations stemming from scientific research, extensive collaborations with academic research, and strong intellectual property protection). The other classes display distributions concentrated around lower values.

The evolution of the index components across the two years under consideration is also analysed according to the taxonomies.

When we disaggregate the components according to the OECD Digital Intensity taxonomy (Figure 16), we observe that the training components remained stable across the two years for all classes, whilst the integration of digital technologies—the DIGINT component—has grown particularly in the lower classes (i.e. low and medium-low). Finally, the components related to connectivity and e-government usage increase homogeneously across the two years.

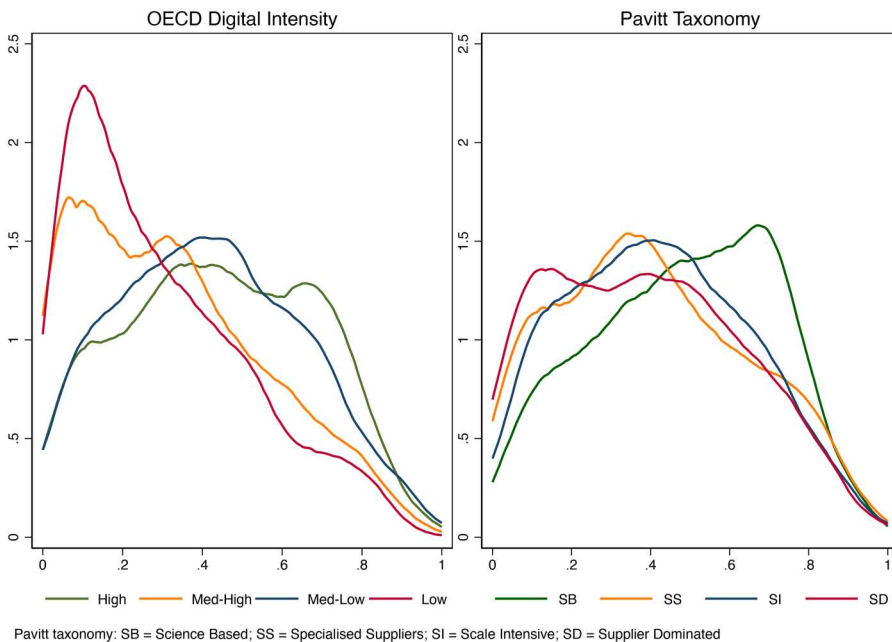


Figure 15. Kernel density by technological taxonomy.

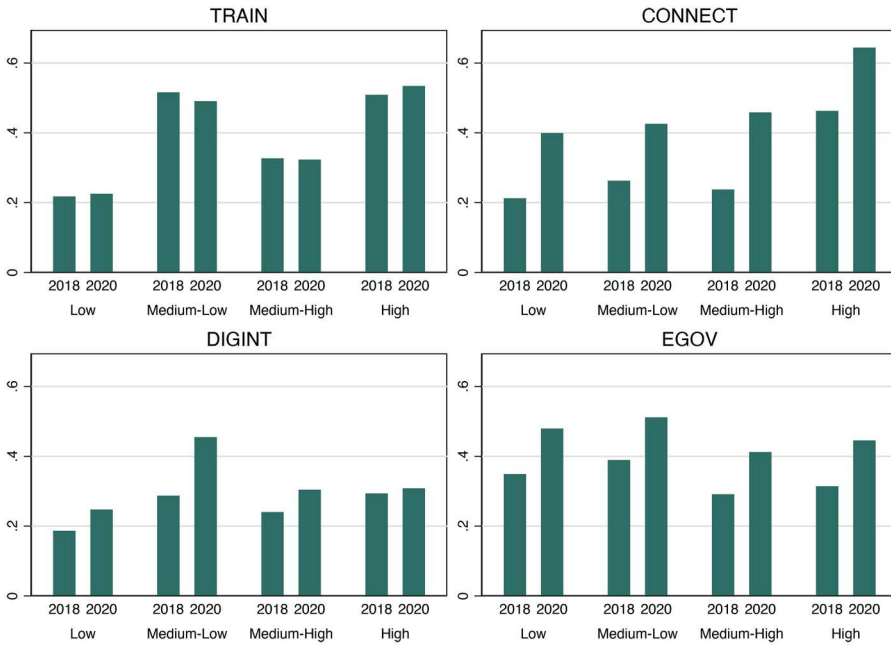


Figure 16. microDESI components by OECD digital intensity.

Finally, in [Figure 17](#), the components are plotted according to the Pavitt taxonomy. The dynamics appear to be similar to those shown for Digital Intensity, that is, with a stable training component and a homogeneous increase in the connectivity and e-government

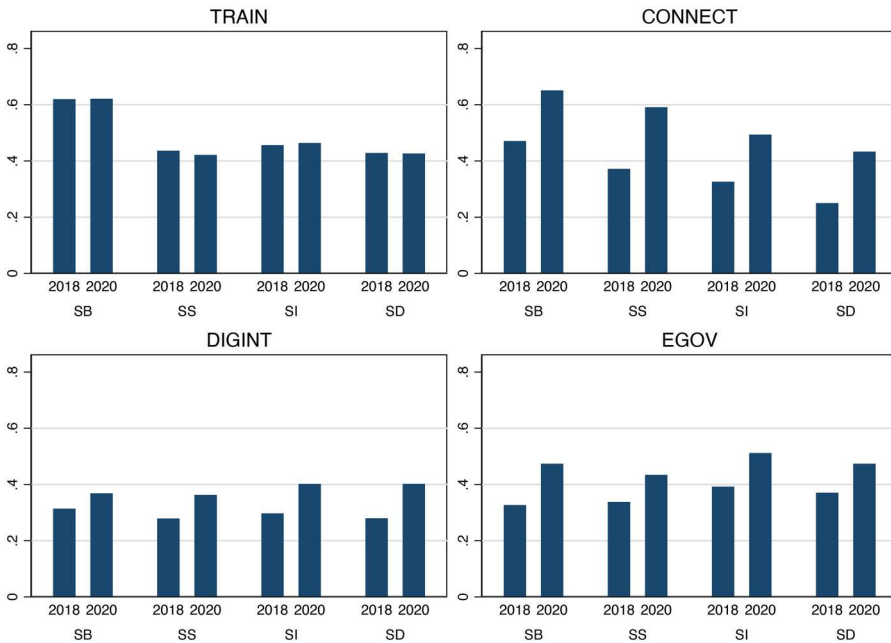


Figure 17. microDESI components by Pavitt taxonomy.

components. What is noteworthy is the increase—although limited—in the integration of digital technologies (i.e. the DIGINT component) within the supplier-dominated (SD) and scale and information-intensive (SI) sectors. This evidence appears to signal the increasingly rapid adoption of digital technologies in more traditional manufacturing sectors as well.

5. Discussion

5.1. The contribution

We propose a novel indicator to investigate digitalisation readiness at the firm-level. The indicator mirrors the dimensions considered in other aggregate measures, such as the European Commission's DESI, which serves as a fundamental tool to analyse, direct, and prioritise interventions in support of inclusive and effective digitalisation policies.

In this context, our first contribution relates to the construction of the firm-level micro-DESI index, which incorporates four dimensions, using only data from the 'Survey on ICT Usage in Enterprises'. This latter is the European harmonised survey collecting data on enterprises' adoption, practices, and attitudes related to information technologies. The exclusive use of variables from this survey reduces the complexity of integrating multiple data sources while preserving an informative dataset that covers the relevant dimensions under analysis. This is a particular strength of the proposed index, which provides relevant insights for policymakers to design and implement public policies to support firms' digitalisation in a rapid and efficient manner.

The four dimensions included in microDESI reflect those of the aggregate DESI: (i) Skills and competences; (ii) Connectivity; (iii) Integration of digital technologies; and (iv) Use of e-Government services. Using survey variables, we summarise these dimensions into a firm-level index that can effectively represent digital readiness, starting from the fundamental economic unit—the firm—while also providing insights into economic sectors and regional productive systems.

5.2. Evidence from a novel indicator

Given the microeconomic nature of the index, it can be used as a descriptive tool, but more importantly also as a key variable in quantitative analyses aimed at (i) targeting public policies to maximise returns for firms and social welfare (i.e. ex-ante analyses), or (ii) evaluating the economic and social impacts (i.e. ex-post public policy assessments).

In this regard, we contribute to the literature by providing a detailed and heterogeneous picture of firm-level digitalisation. We find that small firms, those operating in services, and those located in southern regions struggle to achieve full digital readiness—even though improvements have been recorded between 2018 and 2020, the two years analysed. From an employment perspective, theoretical and empirical literature has underlined the need for a modern, qualified workforce to ensure an inclusive transition towards a digital economy. However, the diffusion of training activities appears to lag behind, especially in small firms, whereas larger firms tend to invest in IT training for specialists instead of the generic training, potentially widening the gap between digitalised and non-digitalised firms.

On the other hand, firms' paths towards digitalisation require the presence of enabling infrastructure (e.g. a fast, stable, and secure broadband connection). The index indicates—in line with the picture provided by the aggregate DESI—that in the period considered in the analysis a greater number of firms were covered by high-speed connections, reflecting public policy efforts in the same years. In particular, this pertained to the first phase of the 'Ultra Broadband Plan' covering the so-called white areas, that is, areas characterised by market failures which require public intervention to activate the infrastructure (Presidenza del Consiglio dei Ministri 2015). Nevertheless, in the period under scrutiny, the policies faced significant bureaucratic and infrastructural delays and difficulties (European Commission 2020a), which have been addressed in subsequent digital plans (Ministero per l'innovazione Tecnologica e la Transizione Digitale 2021; Ministero per l'innovazione tecnologica e la transizione digitale 2023).

Another key firm-level dimension is the integration of digital technologies, that is, the extent to which a firm uses advanced digital tools in production. While empirical literature highlights the positive returns in terms of efficiency and performance, adoption remains heterogeneous across sectors and regions, despite improvements between 2018 and 2020.

Finally, the fourth dimension concerns firms' ability to use digital public services. This reflects both supply-side factors—such as the availability of digital services from public administration—and demand-side factors, such as firms' willingness to use such services to reduce bureaucratic burdens. This dimension experienced a strong increase during the period under analysis. The reason for this significant improvement is the strong commitment of policymakers to achieving a full digital transformation of all public administrations, which is the starting point for providing public digital services to citizens and firms. This commitment has been formalised under the 'Three-Year Plan for ICT in Public Administration', the strategic instrument for promoting the digital transformation of the Italian public administration in alignment with European digital strategies. The first edition of the three-year plan, covering the period 2017–2019, focussed on introducing the strategic model to implement a digital public administration (Agenzia per l'Italia Digitale 2017), while the second edition, covering 2019–2021, focussed on the detailed implementation of the model across central and local public administrations (Agenzia per l'Italia Digitale 2019). The plan, in line with these commitments, has enabled an increasing number of services provided by public administrations to be digitalised, which has in turn driven the increase in the indicator. Accounting for these public sector efforts is essential, given that institutional quality is a key determinant of digital technology diffusion (Labhard, Lehtimäki, and Baccianti 2025). Furthermore, it is important to highlight the role of EU cohesion funds in fostering digital capabilities in local governments, as found by Caravaggio, Resce, and Santangelo (2025).

5.3. Conclusions and limitations of the study

In conclusion, the picture emerging from the microDESI signals a heterogeneous distribution of digital readiness, substantially driven by supply-side factors, such as the availability of high-speed connectivity and digital public services. The dimensions more closely related to a firm's capacity to catch up with digitalisation—namely IT training and the integration of digital technologies—display slower dynamics.

While the microDESI offers a useful methodological tool for policymakers to support and monitor firms' digitalisation efforts, the findings should be interpreted as descriptive associations rather than causal relationships, due to certain constraints inherent in the data source. One key consideration is the exclusion of micro-firms with fewer than ten employees, a choice made to maintain consistency with the international DESI framework. This is especially significant in the Italian context, where small enterprises represent a dominant portion of the productive economy. Furthermore, this omission adds a layer of complexity to our understanding of the digital divide. While it might suggest an underestimation of digital gaps in certain regions, the reality is likely more balanced; for example, micro-firms often perform similarly to larger companies in areas like connectivity or e-government usage, as these services depend heavily on regional infrastructure. This implies that the digital divide in Italy may be shaped by geography (i.e. a centre-periphery gap) just as much as by the structural characteristics of the firms themselves. Finally, focussing on harmonised variables between 2018 and 2020 allowed for a consistent comparison over time, even though it required us to set aside the most recent technological trends. These reflections provide essential context for our results and suggest meaningful directions for future research. It is also important to acknowledge that the data used to build the microDESI refer to the rounds 2018 and 2020 of the ISTAT 'Survey on ICT usage in enterprises', to ensure the comparability of dimensions, with reference to the component 'Integration of digital technologies'. However, the methodology proposed can be fruitfully applied to individual and more recent waves of the survey. In this respect, the proposed micro-DESI shows consistent patterns with the DESI aggregate indicator, despite relying on different data sources, and proved to meaningfully correlate with relevant performance variables, confirming its ability to monitor firms' readiness for digitalisation and to support policy decisions.

At the same time, it is important to emphasise that the primary contribution of this work is methodological. The microDESI serves as a proof of concept for a replicable framework that translates macro-level composite indicators, such as the Eurostat DESI, into a consistent measure defined at the firm level. By preserving the original conceptual structure while adapting it to the specific features of microdata, this approach demonstrates how institutional frameworks can be scaled down for granular analysis.

This fine-grained measure is particularly timely for ex-ante targeting and monitoring, serving as a strategic instrument for the National Recovery and Resilience Plan. It provides a valuable framework to assess whether the extensive commitments to the digitalisation mission are translating into structural and inclusive upgrading, supporting evidence-based assessments of public policy effectiveness and the long-term sustainability of these investments.

From this perspective, the microDESI is not a closed indicator tied to a specific time window or unit of observation. Instead, it offers a flexible architecture that is, in principle, applicable to alternative statistical units (e.g. enterprise groups, ENT) and to longer time horizons as consistent data becomes available. In its current empirical form, the index should be interpreted as a diagnostic and targeting tool; however, it provides the methodological blueprint for a more robust ex-post evaluation system as the longitudinal consistency of the underlying data landscape evolves.

Notes

1. The 'eGovernment benchmark' is a tool to compare and evaluate progress toward the delivery of digital public services across the EU, elaborated by DG-CONNECT of the EU Commission.
2. The presence of digital knowledge and digital skills at the territorial level is not only a pivotal enabling factor for the development of innovative firms (Colombelli et al. 2024), but also a positive predictor of the capacity to specialise in new technological domains (Santoalha, Consoli, and Castellacci 2021).
3. According to Infratel Italia (2021), the percentage of street addresses which will be covered by high-speed connectivity by 2026—with peak speed greater or equal to 100 Mbps—is planned to be equal to 71%. The gap between supply (i.e. high-speed coverage) and demand (i.e. firms declaring to have high-speed connectivity) reflects different firms' characteristics and digital capabilities.
4. To ensure the comparability between rounds of the survey, we refer to the threshold of 100 Mbps, since it is the highest common value among those available in the survey.
5. In particular, a common set composed by 3D printing, cloud computing, and big data analytics is considered in both years. An additional set varies between waves, and considers: (i) applications, e-commerce, augmented reality, and cybersecurity in 2018, or (ii) Internet of Things, and robots in 2020.
6. Therefore, to prioritise adoption breadth, we refrain from further exploring intra-dimensional variability of the component, as a disaggregated analysis of the dynamics of individual technologies would offer a fragmented and analytically less consistent picture.
7. The services surveyed are: Compliance and procedures for employment; Business income tax declaration; VAT declaration; One-stop Shop for Productive Activities (SUAP); Compliance and procedures related to constructions; Customs declarations (tariffs, excise duties); Participation in public procurement tenders and online calls for proposals; Use of electronic invoicing with public administrations; Use of certified e-mail (PEC) to interact with public administrations.
8. In recent years, Eurostat and national statistical offices, including ISTAT, have adopted a new statistical unit called ENT (enterprise) for business registers and economic accounts. This unit represents relationships among legal entities within the same corporate group, distinguishing it from the traditional firm, which coincides with a single legal unit (ISTAT 2020).
9. Average wages are calculated as the ratio between the total amount of wages paid by the firm and the total number of employees, both sourced from AIDA.
10. Specifically, the polychoric framework treats binary indicators as manifestations of underlying continuous latent variables. Under this assumption, a value of one is observed only when a firm crosses a specific latent threshold, while a value of zero indicates that the firm remains below it. This approach makes discrete shifts and marginal changes in intensity mathematically comparable within a unified framework.

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Author contributions

CRedit: **Francesco Crespi**: Conceptualization, Formal analysis, Investigation, Writing - original draft; **Mirko Menghini**: Conceptualization, Formal analysis, Investigation, Writing - original draft; **Eleonora Pierucci**: Conceptualization, Formal analysis, Investigation, Writing - original draft; **Marco Sforza**: Conceptualization, Formal analysis, Investigation, Writing - original draft; **Pietro Zoppoli**: Conceptualization, Formal analysis, Investigation, Writing - original draft .

Data availability statement

The data that support the findings of this study are available from ISTAT. Restrictions apply to the availability of these data, which were used under license for this study, and therefore authors do not have permission to share data.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix

A.1. PCA-based robustness check

To validate the microDESI assumptions and distribution, we perform a PCA-based version of the index to overcome two limitations of the baseline version.

First, the baseline version relies on an exogenous weighting system (mirroring the DESI framework), which assigns equal importance to each dimension. Second, the index combines binary variables with fractional values. From this perspective, a consistent methodological framework is required to ensure that discrete state shifts and continuous changes are mathematically comparable and integrated into a unified scale.

To this end, we perform a polychoric correlation, which accounts for the binary nature of the first two components (i.e. training and connectivity) and ensures their comparability with the fractional components (i.e. digital technologies and e-government).¹⁰ The resulting correlation matrix is displayed in Table A1.

The polychoric correlation matrix is utilised to perform the Principal Component Analysis (Table A2), where components are selected according to the Kaiser criterion, that is, retaining those with eigenvalues greater than unity.

Table A1. Polychoric correlation matrix.

	$TRAIN^{Spec}$	$TRAIN^{Gener}$	CONNECT	DIGINT	EGOV
$TRAIN^{Spec}$	1.000				
$TRAIN^{Gener}$	0.743	1.000			
CONNECT	0.395	0.303	1.000		
DIGINT	0.445	0.382	0.275	1.000	
EGOV	0.213	0.167	0.180	0.179	1.000

Table A2. Principal components/correlation.

Number of obs. = 6,719				
Number of comp. = 5				
Trace = 5				
Rho = 1.000				
Rotation: (unrotated = principal)				
Component	Eigenvalue	Difference	Proportion	Cumulative
PC1	2.406	1.488	0.481	0.481
PC2	0.917	0.166	0.184	0.665
PC3	0.751	0.073	0.150	0.815
PC4	0.678	0.431	0.136	0.951
PC5	0.247	–	0.050	1.000

Finally, the loadings from the first principal component (PC1), the only one retained and which are reported in [Table A3](#), are utilised as weights to construct the PCA-weighted version of the micro-DESI. The resulting index is computed as a normalised weighted average of the original components, defined as follows:

$$microDESI_{it}^{PCA} = \frac{\sum_{j=1}^k w_j x_{ji}}{\sum_{j=1}^k w_j}$$

Where w_j represents the loading of the j -th dimension on the first principal component, and x_{ji} is the value of that dimension for the firm i .

The results from the PCA-weighted index show that, compared to the baseline version where each dimension received an equal 25% weight (with the two training components each accounting for 12.5%), a significantly higher weight is now assigned to training, which together accounts for 50% of the total index. Conversely, lower weights are attributed to supply-side factors, such as connectivity and e-government services. These findings highlight that while supply-side components serve as essential enabling factors for digital readiness, the core of a firm's readiness lies in its internal capabilities (e.g. skills and technological equipment) to actively address the digital challenge. Nevertheless, as shown in [Table A4](#) and [Figure A1](#), this alternative methodology corroborates the validity of the baseline index. The PCA-based version exhibits a highly consistent distribution with only marginal differences in skewness and kurtosis. Overall, the high degree of similarity between the two measures confirms the robustness and soundness of the baseline construction.

Table A3. Component 1 – loadings.

Variable	Loadings	Weight
<i>TRAIN^{Spec}</i>	0.56	26%
<i>TRAIN^{Gener}</i>	0.53	24%
<i>CONNECT</i>	0.39	18%
<i>DIGINT</i>	0.43	20%
<i>EGOV</i>	0.25	12%

Note: Weights in the third column are the single loading divided by the sum of the total loadings of the component.

Table A4. Main moments of the distributions.

	Mean	SD	Skewness	Kurtosis	Median	Min	Max
<i>microDESI^{Base}</i>	0.343	0.235	0.476	2.309	0.311	0.000	1.000
<i>microDESI^{PCA}</i>	0.335	0.276	0.576	2.059	0.281	0.000	0.991

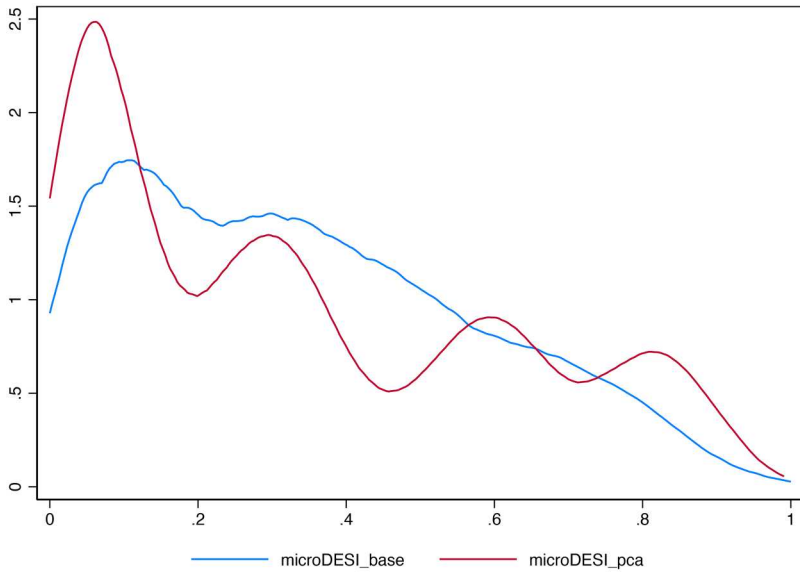


Figure A1. Unweighted and PCA-weighted microDESI distributions.