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ABSTRACT

This study aimed to understand whether the increased use of digital technologies improves innovation performance of firms. Previous studies reveal that the more the firms use digital technologies, the more they can be potentially innovative. However, this is a myth. In fact, one of the main limitations of such studies is their undifferentiated approach toward the vast ocean of digital technologies. Yet, given the increasing pervasiveness of digital technologies at all levels, business and society, a question emerges: how they impact the capability of firms to be innovative? Counter-intuitively, we argue that most frequently used digital technologies have very low impact on innovation performance of firms as innovation is the result of creativity and of constant R&D efforts. By contrast, excess use of digital technologies may even deplete the long-run innovation capability of firms, for instance, by impoverishing the relational capital.

We performed two different statistical analysis to understand whether this intuition was grounded and hypotheses would be confirmed. First, we used a principal component analysis to identify the digital technologies that are salient for innovation performance. Second, we conducted a multivariate analysis of variance to understand if the identified technologies predicted innovation performance. All tests were conducted on a large-scale sample of firms operating the European Union. The findings confirmed that digital technologies have very low impact on innovation performance, whilst R&D expenses are the most reliable predictor of innovation. These results challenge the false belief that digital technologies improve innovation performance. At a practical level, the results suggest that decision makers should debias themselves from considering digital technologies as the ultimate ingredient for a successful innovative firm, as this may backfire eventually.

1. Introduction

In 1993, Kahneman and Lovallo stated that people tend to overestimate their future possibilities based on their status quo decisions. In the same line, most people tend to consider digital technologies as a magic ingredient that may amplify the innovation capabilities of firms (Nambisan et al., 2017; Urbinati et al., 2020). Consistently, there is a growing emphasis on digitisation of businesses and society, along with the almost undiscussed belief that the use of digital technologies may foster innovation performance per se (Scuotto et al., 2017). However, previous studies do not differentiate the impact of each group of digital technologies (e.g., mails, 3D, and Big Data) on innovation performance. Often, they assume a reductionist position, as they only study the effect of one specific digital technology at a time. They do not study whether and how such technologies interplay with different R&D modes—open versus closed.

Although anecdotal evidence suggests that digital technologies may boost efficiency and productivity in the short run, they can have serious negative consequences on learning and relational capabilities, creativity, emotions, etc. Otherwise stated, they may even deplete the relational capital and the capabilities of human capital. For example, after the COVID-19 outbreak, companies, schools, and universities were

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Table 1
Descriptive statistics on ICT usage by technology type.

ICT Usage in Enterprises	N	Mean	Standard Deviation	Variance
3D printing and robotics	28	3,71	1,630	2,656
Big Data	28	12,43	5,160	26,624
Integration with partners	28	25,93	17,649	311,476
Cloud computing	28	29,32	15,207	231,263
Internal integration	28	35,71	9,420	88,730

Table 2
Descriptive statistics on ICT usage by Country.

Country	N	Mean	Standard Deviation.	Variance
Austria	5	19,20	15,707	246,700
Belgium	5	28,00	18,480	341,500
Bulgaria	5	10,60	7,956	63,300
Croatia	5	16,40	11,675	136,300
Cyprus	5	15,40	13,957	194,800
Czechia	5	18,00	13,928	194,000
Denmark	5	36,20	24,191	585,200
Estonia	5	19,20	12,677	160,700
Finland	5	42,60	30,213	912,800
France	5	22,40	16,227	263,300
Germany	5	17,60	8,877	78,800
Greece	5	15,00	13,620	185,500
Hungary	5	10,00	6,325	40,000
Ireland	5	23,20	15,222	231,700
Italy	5	22,20	16,724	279,700
Latvia	5	12,60	11,929	142,300
Lithuania	5	23,60	16,592	275,300
Luxembourg	5	20,40	13,722	188,300
Malta	5	23,40	12,157	147,800
Netherlands	5	29,00	18,682	349,000
Norway	5	32,00	21,296	453,500
Poland	5	13,20	10,183	103,700
Portugal	5	22,20	14,481	209,700
Romania	5	13,20	8,408	70,700
Slovakia	5	15,80	10,826	117,200
Slovenia	5	27,00	22,804	520,000
Spain	5	22,40	16,149	260,800
Sweden	5	29,00	21,413	458,500

forced to smart working and distance learning. Even though this may generate savings and lead to increased efficiency, the reduced interaction between people, the forced use of tools for remote connections reduced the possibilities of interactions and cross-fertilisation of knowledge. At the same time, digital technologies incorporate a standardised knowledge that can be imitated by competitors. The competitive advantage, though, depends exclusively on owning unique resources and knowledge, that cannot be easily imitated by competitors (Baia, Ferreira, and Rodrigues, 2020). Thus, the current study aimed to tackle these gaps, by arguing that the innovation potential of digital technologies maybe overrated, because most of them add very little in terms of new and relevant knowledge creation. Differently, open and closed R&D activities keep their prominent role with regard to improving innovation performance.

The concept of innovation radicalness is the actual discriminant to explain the problem. Innovation radicalness is said to be 'the degree to which innovations depart from existing structural and technological principles' (Azar and Ciabuschi, 2017, p. 324). Thus, it typically entails a paradigm shift, which requires the ability to detach one company to bureaucracy and old routines by rethinking the business model (Nijssen, Hillebrand, and Vermeulen, 2005) and a massive dose of creativity (Moorman and Miner, 1997), along many other relevant factors. Though, the most diffused digital technologies are a significant part of everyday organizational routines. If they do not explicitly inhibit the kind of creativity that drives innovation, they might not foster it, at least. A study found that the most diffused digital technologies may increase the individual propensity to engage in a few creative activities (e.g., video creation and multimedia presentation), but there is no evidence they can trigger other, more complex forms of creativity (Hoffmann, Ivcevic, and Brackett, 2016).

However, there has been no explicit or exhaustive analysis of the impact of digital technologies on innovation performance.

So far, scholars and practitioners emphasised the potential benefits of digital technologies for innovation (Andal-Ancion, Cartwright, and Yip, 2003; Fitzgerald et al., 2014; Westerman and Bonnet, 2015; Singh and Hess, 2017; Ardito, D'Adda, and Petruzzelli, 2018; Del Vecchio, Di Minin, Petruzzelli, Panniello, & Pirri, 2018; Bresciani, Ferraris, and Del Giudice, 2018; Bharadwaj et al., 2013; Matt, Hess, and Benlian, 2015; Olivo et al., 2016).

Several studies also reported that digital technologies open opportunities for innovation and entrepreneurship by changing value creation and value capture mechanisms (Del Giudice and Straub, 2011; Scuotto et al., 2017a and b; Del Giudice et al., 2018; Bonfanti, Del Giudice, and Papa, 2018; Nambisan, Wright, and Feldman, 2017). Precisely, most people believe that digital technologies leverage radically novel technologies. In contrast, disruptive technologies mostly emerge from trials and errors (Andriole, 2017).

In fact, innovation radicalness is commonly linked to those individual characteristics of the entrepreneur and human capital, which allow to detect and seize opportunities, for example, experience, education, and prior knowledge (Marvel and Lumpkin, 2007). Innovation radicalness is a discontinuous change, whilst incremental innovation is a small improvement (Pavitt, 1991). Yoo, Boland, Lyytinen, and Majchrzak (2012) suggested that digital technologies are drivers of innovations characterised by convergence and generativity. To some degree, digital technologies are deemed as an innovation democratising factor, because they shift the innovation locus from a single hub to multi-peripheral loci (von Hippel, 2005).

In sum, the positive effect of digital technologies for innovation seems almost unquestioned so far (Dodgson, Gann, D. M, and Salter, 2002; Boeker et al., 2019; Verstegen, Houkes, and Reymen, 2019), except for a few, moderated attempts (Lember, Brandsen, and Tõnurist, 2019). Moreover, many of these antecedent studies are based on qualitative analyses (Brock and von Wangenheim, 2019; Warner and Wäger, 2019; Galindo-Martín, Castaño-Martínez, and Méndez-Picazo, 2019; Urbinati et al., 2020), rather than on robust empirical tests.

We argued that such emphasis is somewhat short-sighted, and it lacks an understanding of the phenomenon as a whole.

Intuitively, the generative and combinatorial properties of digital technologies are potential innovation killers because they are associated to coded, reusable, and imitable knowledge.

Consistently, this study aimed at understanding to what extent digital technologies exert a positive impact on innovation performance, if any. To have a clear view of the phenomenon, we differentiated digital technologies based on categories. Then, we also tried to understand if they exert a positive and additive/multiplicative effect on innovation performance when they occur jointly with open or closed R&D.

We questioned that digital technologies might have a significant positive effect on innovation performance. We used a large-scale sample of data gathered from firms operating in the European Union for hypotheses testing. We also compared the impact of digital technologies, open innovation, and closed innovation on innovation radicalness.

The results from principal component analysis (PCA) and multivariate multiple regression (MANOVA) proved that digital technologies do not foster innovation performance, differently from any kind of R&D activity. Consistently, we suggested that scholars, practitioners, and policy makers should focus on actual knowledge-booster factors when aiming at the improvement of firm's innovation capability (Palacios-Marques, Popa, and Mari, 2016; Ferraris, et al., 2018; Ferraris, Belyaeva, and Bresciani, 2018; Ferraris, Erhardt, and Bresciani, 2019).

Table 3
Descriptive statistics of innovative firms by class-size.

Innovative firms by class size	Mean	Standard Deviation	Variance
250 employees or more	765,29	1293,680	1673608,952
From 50 to 249 employees	2860,96	4748,168	22545094,999
From 10 to 49 employees	9050,61	14556,773	211899641,062

The paper is structured as follows: first, we briefly reviewed the literature on the theme and formulated the hypotheses; second, we explained the empirical analysis, and, finally, we concluded by illustrating the implications of the work and by designing the roadmap of future research.

2. Research background and hypotheses

2.1. Digital technologies

Traditionally, IT strategies have been seen as the management of ICT infrastructures within a firm (Teubner, 2013). However, over time, this envision was enriched as a means to including a more far-reaching array of functions and opportunities. In this vein, digital technologies can be defined as a strategy whose scope is 'broadly designed and explicitly includes digital activities at the interface with or fully on the side of customers, such as digital technologies as part of end-user products' (Matt, Hess, and Benlian, 2015, p. 340). Thereon, digital strategy is the fusion between IT and business strategies (Bharadwaj et al., 2013). Kane (2019) proposed a three factor model for successful digital transformation, based on navigating the digital disruption, rethinking leadership and talent, and becoming a digital organization.

Scholars recognised that digital technologies can make a difference in achieving competitive advantage (Helfat, 2000; Afuah, 2002; Pavlou and El Sawy, 2010; Allred et al., 2011; Koch and Windsperger, 2017; Mikalef and Pateli, 2017; Scuotto, Ferraris, and Bresciani, 2016; Scuotto et al., 2017; D'Ippolito et al., 2019), for value creation (Magistretti, Dell'Era, and Petruzzelli, 2019), for strategic initiative (Piccoli and Ives, 2005), and for firm's agility (Sambamurthy, Bharadwaj, and Grover, 2003; Ghezzi and Cavallo, 2018). Coherently, the firm's digital strategic posture is the result of the awareness and responsiveness of the competitive environment (Mithas, Tafti, and Mitchell, 2013).

By and large, the strategic fit approach focuses on the consistence among digital technologies and the firm's dynamic capabilities (Venkatraman, Henderson, and Oldach, 1993; Drnevich and Croson, 2013; Rogers, 2016; Shih and Tsai, 2016). Dynamic capabilities are deemed the key enablers of digital transformation (Yoo et al., 2012; Warner and Wäger, 2019; Kane, 2019). Digital transformation further requires digital capabilities, which are characterised by digital materiality and are incorporated in digital objects (Zammuto, Griffith, Majchrzak, Dougherty, & Faraj, 2007). Interestingly, digital transformation is also associated to digital culture (Guy, 2019; Roth, 2019).

Despite a fringe of scholars finding a positive relationship between digital technologies and innovation capability of firms, recent evidence suggested that the effect of digital technologies on innovation performance may be ambiguous.

Digital technologies do not imply disruption, or, at least, less frequently than imagined (Furr and Shipilov, 2019).

Kane, Palmer, Phillips, Kiron, and Buckley (2015) proposed to shift the attention back to the managerial level, the real determinant of growth. Apparently, digital transformation only worked for those firms that were able to change organizational culture, mindset of organization's members, and future envision (Tabrizi, Lam, Girard, & Irvin, 2019; Sousa and Rocha, 2019).

In a 'more revolutionary' vision, digital technology processes have led to the creation of radical innovations and the upheaval of pre-existing business models (Ismail et al., 2014)

The role of knowledge is crucial in finding the right balance between open and closed innovation (Enkel et al., 2009).

The field of knowledge management (Chase, 1997; Armistead, 1999; Del Giudice and Maggioni, 2014; Papa, Dezi, Gregori, Mueller, & Miglietta, 2018) emphasises the importance of digital technologies (as facilitator) developing useful processes of knowledge creation, retention, and recombination (Wu, Chen, 2014; Ferraris et al., 2018).

Entrepreneurial orientation indicates the paths to run across; intellectual capital and human capital allow the budding of innovative processes based on the company's cognitive heritage (Wiig, 1997; Wu et al., 2008)

From a cognitive point of view, new paths for innovation processes (Scuotto et al., 2017; Wu et al., 2008; Usai, Scuotto, Murray, Fiano, & Dezi, 2018) require absorption capabilities dedicated to acquiring the necessary information/knowledge (Madsen et al., 2002; Santoro et al., 2018); thanks to new technologies, firms have more possibilities for capturing such knowledge.

2.2. Impact of digital technologies on innovation performance

Digital technologies are based on re-programmability and data homogenisation, which create an environment of 'open and flexible affordance' (Yoo et al., 2012, p. 1398), where affordance is the property through which the technology potential can be purposively exploited by an organization. Thanks to these peculiar characteristics, such technologies create the basis for combinatorial and distributed innovation (Yoo et al., 2012). In fact, with a single digital artefact, it is possible to create multiple artefacts, usable in previously separated industries. Also, digital technologies are both generative, because they can foster unprompted changes (Yoo et al., 2012), and combinatorial, because they are based on the combination of different modules in their system architecture (Baldwin and Clark, 2000).

Some studies deepen the link between digital technologies, innovation, and their impact on the job market (Dolphin, 2015; McKinsey Global Institute, 2017).

Several scholars found a positive relationship between digital technology platforms and innovation (Gawer and Cusumano, 2002; Gawer, 2009; Boudreau, 2012; Aloini et al., 2017).

Table 4
Descriptive statistics on firm's sample by innovation type.

Type of Innovation	Sum	Mean	Standard Deviation	Variance
Organisation and/or marketing innovative enterprises only	2,016,054	87654,52	95314,525	9084858703,079
Product and/or process innovative enterprises only (including enterprises with abandoned/suspended or on-going innovation activities)	3,880,915	168735,43	199784,981	39914038609,075
Enterprises that have not introduced any innovation and have no innovation activity	9,870,781	429164,39	551868,923	304559308013,431
Product and/or process and organisation and/or marketing innovative enterprises only (including enterprises with abandoned/suspended or on-going innovation activities)	11,426,331	496797,00	604793,391	365775045657,091
Enterprises that have either introduced an innovation or have any kind of innovation activity (including enterprises with abandoned/suspended or on-going innovation activities)	17,323,302	753187,04	880251,290	774842333893,498

Table 5
KMO and Bartlett tests for PCA 1.

KMO test		,635
Bartlett test	χ	97,388
	Df	21
	Sign.	,000

Previous researchers suggested that digital technologies play a vital role in innovation (Stock et al., 2002; Parida, Westerberg, and Frishammar, 2012; Wang, Zhou, and Li-Ying, 2013).

Based on the conceptual scaffolding of dynamic capabilities, Rialti et al. (2019) proposed a model that explores whether organizational ambidexterity and agility mediate the relationship between digital technologies (BDA specifically) and organizational performance.

However, there is less research interest on the impact of digital technologies on radicalness of innovation and innovation types.

Yet, prior research mostly deemed digital technologies all equally useful for innovation (Trantopoulos, von Krogh, Wallin, & Woerter, 2017; Grover and Kohli, 2013). In contrast, we argue that each category of digital technology impacts firms' innovation performance differently.

Some of these technologies are more innovative than others and can have a positive impact on the way processes are run and ideas are generated (for instance, Big Data analysis can help to detect previously undetected interdependencies between variables). Others, for example, e-mails, video-conferences, etc., are a part of the routine. Hence, they do not affect innovation capabilities of the firm and its human capital. Conversely, by reducing interaction and relationships, they may even deplete the relational and human capital of the firm, through impoverished creativity. At the time of the writing this article, cogent debate existed on smart working and distance learning, which are both massively used because of social distancing imposed by restrictions due to the COVID-19 pandemic. Despite the lack of scientific evidence at the moment, the remote workers and students experienced a series of negative effects owing to social distancing. These factors, unavoidably, have a negative impact on the learning capabilities of individuals. Supposedly, this may negatively affect their creativity in the long run.

Thus, this cutting-edge study aims to tackle an absolutely relevant literature gap by examining the impact of digital technologies on innovation performance. Different from previous studies, we question whether digital technologies have an impact on innovation performance at all. The explanation, at a firm level, can be given in terms of a trade-off between standardised versus unique knowledge. In fact, digital technologies embed a codified knowledge, that is easily replicated.

Consistently, we argue that the potential impact of digital technologies on innovation performance is mild, compared to unique knowledge developed by firms, thanks to their R&D efforts.

Thus, we formulated the following proposition:

3. Proposition 1: Digital technologies exert a mild impact on innovation performance.

Differently, both closed and open R&D have a positive influence on radicalness and on all types of innovation (Dias and Bresciani, 2006; Godoe, 2000; Chiaroni, Chiesa, and Frattini, 2010; Aylen, 2010; Inauen and Schenker-Wicki, 2012; Lai, Lin, and Lin, 2015; Forés and Camisón, 2016). So, we argue that:

II. Hp1: Closed R&D is linearly and positively related to innovation radicalness and innovation types

III. Hp2: Open R&D is linearly and positively related to innovation radicalness and innovation types.

Finally, we studied the interplay between digital technologies and R&D closed versus open innovation modes. In a nutshell, we explored whether there is an optimal combination of digital technologies and R&D modes, producing a multiplicative effect on innovation performance. In other words, if digital technologies do not exert a positive impact per se, they might foster the effects of one or the other R&D mode. This specific proposition was never examined before, to the best of our knowledge.

So, we argue that:

4. Hp3: Digital technologies, closed R&D, and open R&D are positively and linearly related to innovation radicalness and innovation types.

Thereby, Hp3 assumes that digital technologies, by means of increased efficiency, amplify the potential linked to R&D expenses.

Clearly, both closed and open R&D allow to generate unique knowledge for sustainable competitive advantage (Del Giudice, Della Peruta, and Maggioni, 2013; Garrick and Chan, 2017). In contrast, digital technologies drive the standardisation of knowledge, thus, eroding the firm's creativity and hampering its value creation.

Only when they occur jointly, digital technologies boost the effect of R&D on innovation performance.

5. Research design and analysis

5.1. Sample

Data were drawn from the open data platform of the Eurostat, the statistical office of the European Union. The dataset included information on the ICT usage in European firms and their innovation performance, classified according to Nace rev. 2 coding system. The firms' sample was stratified by size class. To obtain the dataset, we merged two different surveys, for the time period 2016–2018. Both datasets were updated in February 2020.

The first survey refers to ICT usage in enterprises. We focused on e-business and retrieved all related data. Descriptive statistics are reported, respectively, in Table 1 and 2.

This choice is consistent with other studies conducted in the same research field (Dini et al., 2008; Galindo-Martín, Castaño-Martínez, and Méndez-Picazo, 2019).

Table 6
Total explained variance–unrotated solution PCA 1.

Components	Initial Eigenvalue			Coefficients sum square extraction			Coefficients sum square rotation		
	Total	% di variance	% cumulative	Total	% di variance	% cumulative	Total	% di variance	% cumulative
Cloud Computing 1	3,251	46,446	46,446	3,251	46,446	46,446	2,766	39,510	39,510
Big Data 2	1,772	25,316	71,762	1,772	25,316	71,762	2,258	32,252	71,762
3D printing and robotics 3	,905	12,934	84,697						
Integration with partners 4	,512	7,315	92,012						
Internal integration 5	,371	5,295	97,307						
In-house R&D 6	,162	2,314	99,622						
External R&D 7	,026	,378	100,000						

Table 7
Varimax Rotation solution, normalised by Kaiser and three iterations for convergence - PCA 1.

	Component	
	1	2
3D printing and robotics	,904	
Big Data	,842	
Cloud computing	,799	
Internal integration	,659	
In-house R& D		,974
External R& D		,957
Integration with partners	,384	,454

The second survey used in this analysis is the Community Innovation Survey (CIS), which is one of the most adopted datasets by innovation scholars (Antonucci and Pianta, 2002; Frenz and Ietto-Gillies, 2007; Battisti and Stoneman, 2010; Blind, Petersen, and Riillo, 2017; Solheim, Boschma, and Herstad, 2020).

The CIS survey is based on constructs and methods as described by the Oslo Manual (2015). It is aimed at exploring and providing a large variety of information on innovativeness in EU firms. Its completeness and reliability made it the reference dataset in the innovation domain. Enterprises' information within Nace rev. 2 population are collected at the micro-level and stratified by activity, size-class, and country.

The following information were retrieved from CIS: basic economic information, innovative enterprises by type of innovation activity, number of enterprises by NACE Rev. 2 activity and size class, product innovative enterprises that have introduced new or significantly improved products, product and/or process innovative enterprises by type of innovation activity. In total, the sample was populated by 345.421 firms. Table 3 and 4 provide specific information on the sample. The few missing data, that are missing completely at random, were excluded listwise.

5.2. Method

Previous studies have reported the use of mixed methods for the analysis of the relationship between innovation and digital technologies, such as PCA (Laursen and Foss, 2003; Hollenstein, 2004), multivariate analysis (Hall, Lotti, and Mairesse, 2013; Pick and Nishida, 2015), and partial least square analysis, also called Projection to Latent Structure (PLS) (Saenz, Aramburu, and Blanco, 2012; Chaparro-Peláez, Pereira-Rama, and Pascual-Miguel, 2014; Donate and de Pablo, 2015; Scuotto, Del Giudice, and Carayannis, 2017; Yunis, Tarhini, and Kassar, 2018; Galindo-Martín, Castaño-Martínez, and Méndez-Picazo, 2019). The last method is a combination of PCA and multiple regression (Hair et al., 2016). Consistently, we used both PCA and multivariate linear regression. The PCA is aimed at making explorations and predictive models. It is based on the orthogonal transformation of a set of correlated variables into linear, uncorrelated variables defined principal components, where the first principal component has the highest variance (Abdi and Williams, 2010). In our case, the PCA is used to reduce the number of independent variables. Typically, innovation factors and ICT are highly correlated between each other. The result of the PCA analysis were used as variables of the predictive analysis.

After that, we performed the multivariate multiple linear regressions, with multivariate analysis of variance (MANOVA), for hypotheses testing.

The multivariate regression is aimed at measuring the degree at which the predictors (independent variables) and the response variables (dependent variables) are linearly related (Hair, Black, Babin, Anderson, & Tatham, 1998).

The general equation for testing the multivariate hypotheses is the following:

i. $Y = XB + \Xi$

Where Y is the n*p response matrix, X is the n*(q + 1) matrix such as that all entries are q predictors, B is the (q + 1)*p matrix of fixed parameters, and Ξ multivariate normally distributed with covariance matrix $\sum$.

5.3. Variables

5.3.1. Information on the variables

In line with other studies on innovation performance (Oke, 2007; Chiang and Hung, 2010; Rosenbusch, Brinckmann, and Bausch, 2011; Chang, Chang, Chi, Chen, & Deng, 2012; Forés and Camisón, 2016; Ritala et al., 2018), we used proxy measures for radicalness and innovation type.

The concept of radicalness is defined based on whether the firms introduced a 'world first' or not. Precisely, we distinguished the following cases: at least one 'world first' product innovation, no 'world first'

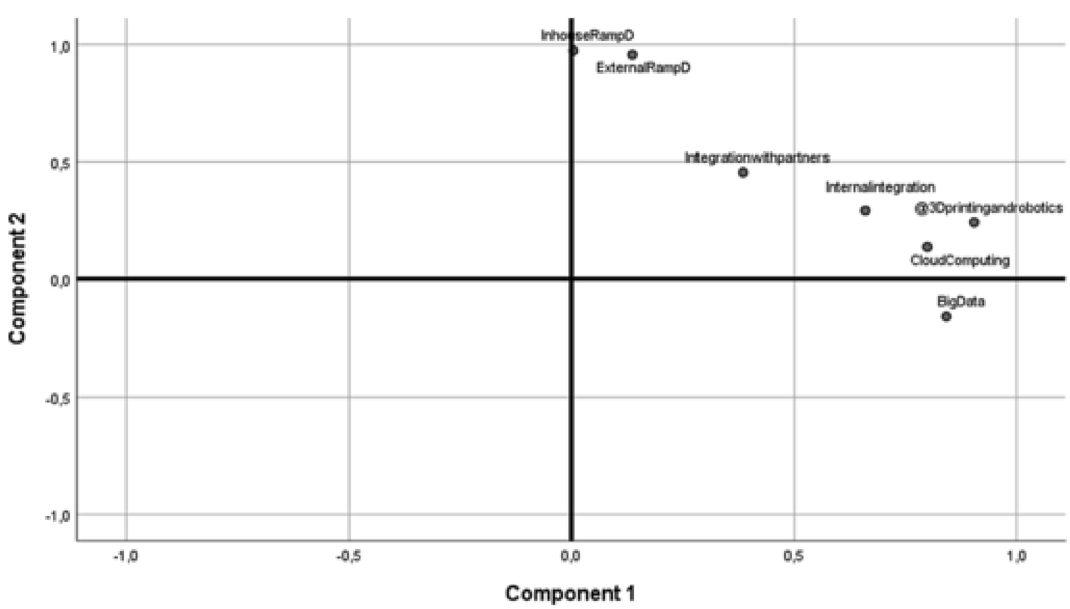

Fig. 1. Loading plots - PCA1.

Table 8
Correlation analysis.

		Big Data	3D printing and robotics	At least one 'world first' product innovation
Big Data	Pearson Correlation	1	,684**	-,010
	Sign. (two tails)		,000	,966
	N	22	22	22
3D Printing and robotics	Pearson Correlation	,684**	1	,245
	Sign. (two tails)	,000		,272
	N	22	22	22
At least one 'world first' product innovation	Pearson Correlation	-,010	,245	1
	Sign. (two tails)	,966	,272	
	N	22	22	22

**. The correlation is significant at 0,01 level (two tails).

Table 9
Correlation analysis.

		At least one 'world first' product innovation	In-house R&D	External R& D
At least one 'world first' product innovation	Pearson Correlation	1	,949**	,898**
	Sign. (two tails)		,000	,000
	N	22	22	22
In-house R& D	Pearson Correlation	,949**	1	,960**
	Sign. (two tails)	,000		,000
	N	22	22	22
External R& D	Pearson Correlation	,898**	,960**	1
	Sign. (two tails)	,000	,000	
	N	22	22	22

**. The correlation is significant at 0,01 level (two tails).

product innovation, unknown 'world first' product innovation, new or significantly improved products that were only new to the firm, and new or significantly improved products that were new to the market. For this measure, the CIS dataset used a validated 5-point Likert scale.

For innovation typologies, we considered two cases: product and/or process innovative enterprises; organisation and/or marketing innovative enterprises.

Building on previous studies (Dini et al., 2008; Galindo-Martín, Castaño-Martínez, and Méndez-Picazo, 2019), we used the variable named ICT usage in enterprise as a proxy for digital technologies. This variable includes information on the number of firms that adopted integration of internal process, or with customers, suppliers, and supply chain, cloud computing services, big data analysis, 3D printing, and robotics.

Other variables were product and/or process innovative enterprises by closed versus open innovation activity.

The variable named "product and/or process innovative enterprises by closed versus open innovation activity" groups firms by in-house and external R&D.

Finally, our control variables were firm size-class and sector of activity.

5.3.2. Variables used in the PCA analysis

The PCA test was used to reduce predictors related to innovation as a whole.

Thus, in this step we considered all factors related to digital technologies and data on product and/or process innovative enterprises by closed versus open innovation activity.

5.3.3. Variable used in the multivariate regression: Model 1

The outcome variables are radicalness and innovation type. Based on the PCA, the predictors are in-house and external R&D, 3D printing and robotics, and Big Data analysis.

5.4. Findings

The first step was the PCA analysis. Table 5 shows the results of the KMO and Bartlett tests for hypotheses testing. Accordingly, the null hypothesis was rejected. In fact, $\chi^2_{21} = 97,388 > 32,67$ with $\alpha = 0,05$. Similarly, the KMO shows a value of 0,635; therefore, it is within the acceptability level. Hence, Table 6 reports the correlation matrix for the unrotated solutions for eigenvalues > 1. The rotated solution is reported in Table 7 and Fig. 1.

Based on the varimax rotated solution of the PCA, we extracted four variables that explained the maximum variance: in-house and external R&D, 3D printing and robotics, Big Data analysis.

After this step, we tested whether digital technologies impact innovation performance or not.

First, we measured the bivariate correlation between variables, as reported in Tables 8 and 9.

Accordingly, the results suggested there is poor correlation between digital technologies and radical innovation, whereas both internal and external R&D have a significant effect.

Finally, the multivariate regression analysis is reported in Table 10. The multivariate test confirmed that digital technologies have very low impact on innovation performance. Differently, in-house and external R&D are strong predictors of innovation, either in case of radical or in case of incremental innovation. Also, R&D investments are related to different types of innovation. In fact, none of the F values of digital technologies are significant. In contrast, the F values of in-house and external R&D are extremely significant.

5.5. Discussion

The analyses confirmed our hypotheses. Although there is a massive adoption and diffusion of extremely sophisticated and high-tech digital technologies, they almost have no linear and direct impact on innovation performance. They boost the efficiency of the firm, but they are not a direct source of competitive advantage. Such technologies are diffused and incorporate a standardised, explicit knowledge, whilst the source of the competitive advantage is the firm's unique knowledge. Conversely, they can deplete the firm's human capital and relational capital, by means of reduced interactions—as instance, community of practice interactions, standardised learning, etc. The PCA analysis showed that the most valuable digital technologies for innovation are, anyway, 3D, robotics, and Big Data analysis. Other technologies have little significance with regard to a firm's innovation performance. Thus, they are not predictors of innovation performance. Differently, R&D investments confirm their overarching role for innovation. Precisely, they are predictors of radical innovation. In other words, despite the R&D mode, the impact of such technologies is often very mild. They do not boost creativity in a direct manner, nor are they a source of unique knowledge. Hence, the additive or multiplicative effect is not verified.

In a nutshell, the analysis suggests that digital technologies cannot replace the role of creativity, intuition, serendipity, and intellectual capital in the innovation process. Very likely, their role is subordinated

Table 10
Multivariate regression analysis.

Effect		Value	F	DF hypothesis	DF Error	Sign.	Partial eta-square	Non-centrality	Estimated Power
Intercept	Trace of Pillai	,472	1,403^{b}	7,000	11,000	,296	,472	9,819	,359
	Lambda of Wilks	,528	1,403^{b}	7,000	11,000	,296	,472	9,819	,359
	Trace of Hotelling	,893	1,403^{b}	7,000	11,000	,296	,472	9,819	,359
	Greatest Roy radix	,893	1,403^{b}	7,000	11,000	,296	,472	9,819	,359
Inhouse R&D	Trace of Pillai	,917	17,442^{b}	7,000	11,000	,000	,917	122,092	1,000
	Lambda of Wilks	,083	17,442^{b}	7,000	11,000	,000	,917	122,092	1,000
	Trace of Hotelling	11,099	17,442^{b}	7,000	11,000	,000	,917	122,092	1,000
	Greatest Roy radix	11,099	17,442^{b}	7,000	11,000	,000	,917	122,092	1,000
External R&D	Trace of Pillai	,882	11,795^{b}	7,000	11,000	,000	,882	82,563	1,000
	Lambda of Wilks	,118	11,795^{b}	7,000	11,000	,000	,882	82,563	1,000
	Trace of Hotelling	7,506	11,795^{b}	7,000	11,000	,000	,882	82,563	1,000
	Greatest Roy radix	7,506	11,795^{b}	7,000	11,000	,000	,882	82,563	1,000
3D Printing and robotics	Trace of Pillai	,296	,662^{b}	7,000	11,000	,700	,296	4,634	,178
	Lambda of Wilks	,704	,662^{b}	7,000	11,000	,700	,296	4,634	,178
	Trace of Hotelling	,421	,662^{b}	7,000	11,000	,700	,296	4,634	,178
	Greatest Roy radix	,421	,662^{b}	7,000	11,000	,700	,296	4,634	,178
Big Data	Trace of Pillai	,205	,406^{b}	7,000	11,000	,879	,205	2,844	,122
	Lambda of Wilks	,795	,406^{b}	7,000	11,000	,879	,205	2,844	,122
	Trace of Hotelling	,259	,406^{b}	7,000	11,000	,879	,205	2,844	,122
	Greatest Roy radix	,259	,406^{b}	7,000	11,000	,879	,205	2,844	,122

a. Regression:: Intercept + Inhouse R&D + External R&D + 3D Printing and robotics + Big Data
b. Exact statistic
c. alfa = ,05

to those of other resources, such as financial resources or human capital. Probably, this is due to their extreme imitability and vast diffusion. For such reasons, they contribute a little to innovation performance.

This original result is impressive, considering the wealth of praises that were showed toward the benefits of digital technologies, from both academia and practitioners, to date. Our analysis suggests that traditional investments are by far more effective for innovation performance than digital technologies.

5.6. Limits of the analysis

The main limit of the analysis is the use of linear models for predicting innovation performance. In fact, there can be an undetected nonlinear and indirect effect of digital technologies on innovation. Ulterior factors, that were not considered by current analysis and that directly impact innovation, may benefit from digital technologies. Also, we did not consider sector specific dynamics. Importantly, we did not consider the effects that such technologies may have on cognitive and relational capabilities of individuals or teams, as the study is focused on the organizational-macro level, or the relational capital of firms.

6. Contribution of the research to theory and practice

Contrary to the fad, this original study unveiled that digital technologies may be not related to innovation. They do not affect radicalness of novelties as well as innovation types.

Thus, the study contributes to both innovation and digital technologies research fields by unveiling the interplay between the two factors. The findings also show that the impact of heterogenous digital technologies on innovation is likewise various. Among others, Big Data, 3D, and robotics are the most promising technologies in this sense.

AI can offer a myriad of possibilities for the development of business and society although, there is a huge ethical debate associated with digital technologies and, especially AI. The point is not whether to use them or not, but how to use them in a manner that does not deprive the human being from those individual characteristics that generate a differential ‘quid’. At a practical level, the study suggests that the grand challenge of the future is to use such technologies to boost all those characteristics that make a human being exactly ‘human’, such as creativity and emotions. Only in this way, they can make a difference for innovation performance.

The study also suggests that too much of emphasis is put on digital technologies. Firms that want to overtake competitors should invest in both closed and open R&D. Besides, excess digitization may sterilise firm’s innovation capacity due to homogenisation. In other words, the firm becomes more vulnerable and more exposed to imitation or knowledge spill-overs. The modularity possibilities of recombination are not exactly infinite or, more precisely, of infinite usefulness. Furthermore, policy makers were incentivising the digital transformation so far. Anyway, they should rather start thinking about the next disruption and how to foster it. Paradoxically, they are investing in a bundle of technologies that was already exploited enough. Creativity, knowledge, and intellectual capital confirm their paramount importance for innovation.

7. Conclusions and roadmaps for future research

After years of over-optimistic expectations about the innovative potential of digital technologies, current evidence cleared that they might not be as innovation-triggering as imagined.

This result opens up to a whole new set of unexplored questions and also reinforces some previous arguments.

We suggest that digital technologies may have and indirect effect on innovation by influencing other variables.

Based on this insight, we define the following roadmap for future studies:

a) Digital capabilities and their impact on creativity, intellectual capital, knowledge and innovation performance
b) Optimal degree of digitisation and digital strategic fit
c) Strategic agility and digital technologies
d) Strategic intent and digital transformation

Potentially, digital technologies may empower users, thus fostering their creativity. Information system and knowledge management have benefited from digital technologies so far. Likely, digital technologies moderate the relationship between knowledge and innovation. Future research should explore the interaction between individuals and digital technologies, as a means to understanding how they impact cognitive, relational and learning capabilities of people, or their emotions. Notably, the future of AI depends on the ability to deploy such technologies for the people, rather than in their place. All these aspects can have huge implications for knowledge (knowledge sharing or hiding), human capital, and relational capital. Perhaps, the answer to the question whether they are good for innovation or not resides in such aspects: creation depends on the encounter between people, who shares knowledge, learn from others, is inspired by others or wants to confront others and prove them they are wrong. Ultimately, creativity is a response to someone's emotion, triggered by the need to find a solution for a problem that occurs at a social level. Connection is not a fast network; it is the dialogue between human beings. Likewise, innovation springs from the encounters of beautiful minds.

Uncited references

Cenamor et al. (2019), Scuotto et al., 2017c.

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