ARE DIGITAL TECHNOLOGIES KILLING FUTURE INNOVATION? THE CURVILINEAR RELATIONSHIP BETWEEN DIGITAL TECHNOLOGIES AND FIRM'S INTELLECTUAL PROPERTY

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MANUSCRIPT DETAILS

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:study aims to investigate the interplay among digital technologies, intellectual capital, and innovation. Thus far, there were scant researches studying such intricate bundle of interactions. Also, the findings of previous studies were rather inconclusive, because conflicting results emerged over-time. Building on the existence of heterogenous evidences, this study solved the detected criticism by suggesting a curvilinear relationship among digital technologies, digital skills of human capital, and intellectual property. Specifically, we argue that the relationship between digital technologies and intellectual property is inverted u-shaped.are tested by applying a generalized linear model (GLM) regression analysis and a quadratic model for non-linear regression. The study analysed a large-scale sample of micro-data drawn from Eurostat. Such sample embraces the population of firms operating in all European member states., the results of the study confirm that digital technologies are curvilinearly related to intellectual property. Precisely, the curve is inverted u-shaped. Notably, results show that digital skills only matter when employees have very demanding duties to accomplish. In all other cases, digital skills do not affect intellectual property significantly.research is solely focused on firmsâ€™ operating in the European Union. Future studies should extend the analysis to other geographies.a real impact level, the study suggests that intellectual property is only partially fostered by digital skills and digital technologies. In this sense, digital skills might be overrated.from prior research, this study originally detangles the impact of digital technologies on firmâ€™s intellectual capital by suggesting the existence of an inverse u-shaped relationship between variables.

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Purpose: The study aims to investigate the interplay among digital technologies, intellectual capital, and innovation. Thus far, there were scant researches studying such intricate bundle of interactions. Also, the findings of previous studies were rather inconclusive, because conflicting results emerged over-time. Building on the existence of heterogenous evidences, this study solved the detected criticism by suggesting a curvilinear relationship among digital technologies, digital skills of human capital, and intellectual property. Specifically, we argue that the relationship between digital technologies and intellectual property is inverted u-shaped.

Design/methodology/approach: Hypotheses are tested by applying a generalized linear model (GLM) regression analysis and a quadratic model for non-linear regression. The study analysed a large-scale sample of micro-data drawn from Eurostat. Such sample embraces the population of firms operating in all European member states.

Findings: Overall, the results of the study confirm that digital technologies are curvilinearly related to intellectual property. Precisely, the curve is inverted u-shaped. Notably, results show that digital skills only matter when employees have very demanding duties to accomplish. In all other cases, digital skills do not affect intellectual property significantly.

Research limitations/implications: The research is solely focused on firms' operating in the European Union. Future studies should extend the analysis to other geographies.

Practical implications: At a real impact level, the study suggests that intellectual property is only partially fostered by digital skills and digital technologies. In this sense, digital skills might be overrated.

Originality/value: Differently from prior research, this study originally detangles the impact of digital technologies on firm's intellectual capital by suggesting the existence of an inverse u-shaped relationship between variables.

Keywords: intellectual capital, intellectual property, innovativeness, digital technologies, ICT

1 Introduction

There is a popular belief for what digitization is extremely positive for business and society. However, digital technologies also have negative effects on businesses. As a matter of fact, digital technologies have massively changed the way firms compete on the market (Aloini et al., 2017; Olivo et al., 2016), because they lowered the barriers in many sectors, they increased the pace of competition, and they made the imitation phenomenon extremely at hand and frequent. Despite anecdotal evidences of the dark side of digital technologies, scholars seemed curiously caught by a sort of digitization spell: they kept praising and seeing only the bright side of digital technologies, at a business level. As the consequence, it is not rare to find, in this research domain, studies that emphasize the importance of digital technologies for firms' intellectual activities and for the generation of new knowledge (Berger et al., 2019; Sung et al., 2012; Urbinati et al., 2017). However, there is one relevant missing tile in this landscape and it concerns the lack of robust studies focusing on the interplay between digitization, skills of human capital, and innovation. As a matter of fact, digital technologies may also inhibit employees' productivity and innovation capabilities (Nambisan et al., 2019; Tarafdar et al., 2015).

The retrieved gap goes hand in hand with the general concern of management studies to overcome the limit of over-simplistic assumptions such that of linearity (Haans, Pieters, and He, 2016). As the authors stated: "we find serious underdevelopment of U-shaped relationships, where researchers fail to explicate the latent mechanisms underlying such relationships." (Haans, Pieters, and He, 2016, p. 1177).

Given the complexity of the matter, is highly unlikely that there can be a linear relationship among digital technologies, digital skills, and intellectual property.

Based on above considerations, current study aims to unveil the negative latent effect of digitization on intellectual capital. Traditionally, firms strive for outperforming competitors by grabbing unique and scarce resources that are also hardly imitable. As a matter of fact, boosting firm's knowledge and intellectual capital (IC) is deemed the ultimate weapon both to takeover markets (Carayannis and Alexander, 1999; Del Giudice and Della Peruta, 2016) and to enable firm's growth and innovation (Duodu and Rowlinson, 2019). By and large, previous evidences suggested that intellectual capital and innovation are strongly entwined (Bontis et al., 2005; Kianto et al., 2017; Subramaniam and Youndt, 2005). However, intellectual capital is a broad concept that embeds several dimensions, each one is related differently to innovation. Broadly speaking, there is a large consensus between scholars on the role of human capital as the very engine of firms' innovation (Edvinsson, 1997; Nonaka and Takeuchi, 1995). Similarly, the relational capital exerts a positive influence on firm's innovation performance thanks to those interaction mechanisms that promote knowledge sharing, stimulate creativity and generate cross-fertilization of ideas (Berraies and Chaher, 2014; Delgado-Verde et al., 2015, 2016). Structural capital is a further component of intellectual capital. Structural capital includes intellectual property (Bollen et al., 2005). Intellectual property – e.g. patents, copyrights, and trademarks, etc.. – is the outcome of firm's innovation activity, and it is essential for firm's growth (Bollen et al., 2005). As instance, intellectual property is commonly used by innovation scholars to quantify or rate firms' innovative activities during a defined period of time (Gangopadhyay and Mondal, 2012; Jensen and Webster, 2009; Papageorgiadis and Sharma, 2016).

Over time, the increasing pervasiveness of digital technologies in business and society might have altered the way intellectual capital and innovation are generated. As a matter of fact, digital technologies - as a set of innovative and collaborative tools – transformed work places and the way employees perform their tasks (Tarafdar et al., 2015). In this sense, firms are struggling to understand how to digitize and integrate new technologies, in order to optimize and synergize intellectual capital (Berraies, 2019; Duodu and Rowlinson, 2019).

However, despite all the fuss around digital technologies, there is still a poor understanding of what their contribution to growth really is and how they affect innovation and intellectual capital. Prior research found a significant effect of both Information and Communication Technologies (ICT) on IC (Kianto et al., 2010; Ramadan et al., 2017) and of IC on firm's innovativeness (Dakhli and De Clercq, 2004; Kianto et al., 2017). Literature also suggested that the adoption of digital technologies can contribute to developing and enhancing intellectual activities within a firm, boosting the generation of new products and services (Sung et al., 2012; Urbinati et al., 2017). In brief, many scholars believe that digital transformation is one of the most important drivers of innovation (Berger et al., 2019),

However, to the best of our knowledge, prior research did not capture how digital skills of human capital and digital technologies impact intellectual property. Though, intellectual property is at the basis of innovation and growth (Pisano and Teece, 2007). So, we originally argue that the relationship among digital technologies, intellectual capital, and innovation is inverted u-shaped. In other words, the positive impact of digital technologies on intellectual property is limited and it depends on a firm-subjective optimal apex. An enormous amount of digitization does not necessarily increase the probability of making an innovation. Paradoxically, excess digitization can be value destroying.

In addition, digital technologies can have another underexplored dark side, because they can undermine employees' innovation capabilities. Specifically, the qualities that make digital technologies useful (such as reliability, portability, user-friendliness and real-time processing) may also have negative consequences for individuals and their skills that could inhibit future creative and innovative endeavours (Nambisan et al., 2019; Tarafdar et al., 2015). Thus, the relationship among digital technologies, innovation, and intellectual capital is not so straightforward as one might think.

Above considerations and retrieved gaps, along with digitization of businesses and the massive use of remote working during the global Covid-19 pandemic, provided a solid motivation and the main rational for current study.

As a matter of fact, the long-run influence of the massive use of digital technologies might have serious effects on firm's competitive capabilities. Are these effects positive or not? In what terms? How they affect human capital, relational capital, and intellectual property? These considerations are extremely important considering that excess digitization may hamper, and even endanger, firm's survival and growth.

To understand such mechanisms, we conducted a regression analysis on a large sample of data drawn by Eurostat. Data refers to information on firm's intellectual property, patents activity by country, usage and purchase of digital technologies by firms, impact of digital technologies on individual tasks.

The sample includes all countries of the European Union. The digitization process in still ongoing within these countries and it is marked by the presence of national and infra-national digital divides, as shown by official statistics provided by the Eurostat (see webgraphy for more information). For this reason, EU represents an ideal setting for the analysis. The results of the study originally confirm that the relationship among of digital skills of human capital, digital technologies, and intellectual property is inverted u-shaped.

Thus, this paper largely contributes to theory and practice. It originally introduces a curvilinear model for digital technologies and intellectual capital. Furthermore, the paper challenges scholars to understand the real impact of digitization on firm's growth. Excess digitization may scarcely contribute to innovative processes and it may also hamper the long-run growth capability of the firm. At a practical level, this finding solicits firms to rethink their excess focus on digitization before it backfires and it turns into a value destroying mechanism.

For the remainder, the paper is structured as follows: first, we review the relevant literature on the theme, second, we design the model and the hypotheses, third, we conduct and discuss the empirical analysis. Finally, we present the study's implications and conclusions.

2 Literature background

According to resource-based view, firms leverage on unique resources and capabilities to create and sustain the competitive advantage (Barney, 1991). As a result, intangibles, such as knowledge, competence, intellectual property, brands, reputation, and customer relationships, have become key value drivers, because they effectively contribute to firms' value creation process (Dženopoljac et al., 2016). Intellectual capital is a knowledge-related, intangible asset of firms. It improves firm's ability to innovate and create value (Dost et al., 2016; Kianto et al., 2017). Yet, intellectual capital is not a static component of the organization. By contrast, it is a dynamic and ideological process that leverages on having and using knowledge and skills (Chang and Hsieh, 2011). In particular, it refers to a set of internal factors - such as knowledge, applied experience, organizational technology, customer relationships, professional skills, brands, trademarks, intellectual property and processes - possessed by a firm and useful to create high valued assets and relationships (Edvinsson, 1997; Tovstiga and Tulugurova, 2009; Zhou and Fink, 2003). Intellectual capital is also described as a bundle of intellectual assets that creates knowledge for future usage (Carayannis and Alexander, 1999; Del Giudice et al., 2010, 2014).

Drawing from Bontis' (1998) definition, intellectual capital can be classified into human capital (HC), relational capital (RC), and structural capital (SC). Human capital refers to that tacit knowledge embodied in individuals, such as skills, experience, commitment and motivation. It also refers to employees' tools and tasks, and to their connections and networks (Namvar et al., 2010). Relational capital, also called social capital, refers to knowledge inflows and outflows between different stakeholders, including the organization itself, their employees, partners, suppliers, customers, communities, and other external agents. Structural capital, also called organizational capital, refers to enabling mechanisms and organizational structures that support employees' task – e.g. investments, processes, structures, systems, manuals, and activities - (Bontis, 1998).

Broadly speaking, intellectual capital is deemed an important predictor of organizational innovation, because the latter ultimately depends on organizational knowledge capabilities (Kianto et al., 2017). Accordingly, previous studies agreed on the crucial role played by intellectual capital as one of the main sources of innovation (Edvinsson, 1997).

According to extant literature, intellectual property - such as patents, copyrights, trademarks, and other rights - allows firms to achieve superior performances (Bollen et al., 2005; Namvar et al., 2010; Quinn et al., 1996). Intellectual property was also described as the legal mechanisms for protecting firms' assets, including infrastructures, know-how, trade secrets, copyright, patents, design rights, and marks (Bontis, 1998; Brooking, 1996).

In the innovation literature, intellectual property is commonly used as a quantitative proxy of the firm's innovative activities (Jensen and Webster, 2009).

In an intellectual capital perspective, intellectual property is part of the firm's structural capital (Bican et al., 2017). It refers to "a legal construct which enables an entity to claim ownership of an asset" (Carayannis and Alexander, 1999, p. 6). According to Polanyi's taxonomy (1962), it can be deemed a form of codified and explicit knowledge, whose scarcity is artificially generated. Differently, the knowledge embodied in the human capital is tacit and highly fleeing (Garrick and Chan, 2017; Del Giudice et al., 2010; McIver and Lepisto, 2017).

Both human capital and relational capital play a fundamental role for the generation of intellectual property. Employees' knowledge and skills, namely human capital, lead to the development of new patents, trademarks and brands. Similarly, relational capital fosters intellectual property, thanks to continuous knowledge exchange between stakeholders (Audretsch and Link, 2018; Bollen et al., 2005). Despite there is vast and solid body of research confirming that intellectual capital is one of the main antecedents of innovation, it is still unclear how the three components of intellectual capital have been affected by increasing digitization (Novas et al., 2017).

Some scholars argued that digital technologies may foster the development of intellectual capital (Namvar et al., 2010, Zhou and Fink, 2003). At a practical level, we observed that firms have digitized and integrated digital technologies within the organization, in order to optimize interpersonal collaborations, to synergize knowledge and to promote innovation (Berraies, 2019). In this sense, different previous studies underscored that information and communication technologies (ICT) enabled the development of both intellectual capital and innovation (Mueller et al., 2013), thanks to mechanized information search, storage, and sharing (Dženopoljac et al., 2016; Ramadan et al., 2017).

Thus, ICT and digital technologies represent a driving force that, so far, was transforming the way through which organizations create, develop, and use their knowledge or intellectual assets for growth (Ramadan et al., 2017). Consistently, Sag et al. (2019) stated that digital technologies are a key determinant of intellectual property. Furthermore, according to Berraies (2019), digital technologies can improve the way through which employees do their tasks. Hence, digital technologies may increase the autonomy, engagement and creativity of employees (Cai et al., 2020; Flores et al., 2020). They can also stimulate employees to build new relationships, or to share and create new knowledge, because of increased connectivity and interpersonal interactions (Boeker et al., 2019; Li and Herd, 2017; Stachová et al., 2020). For the above reasons, firms are increasingly adopting digital technologies from external sources, as a means to further intellectual capital, knowledge creation, and innovation performance (Bianchi et al., 2016; Ferraris et al., 2017, Tortorella et al., 2020, Forman and van Zeebroeck, 2019).

So far, then, literature was mostly concerned with positive, linear effects of digital technologies on intellectual capital.

However, the idea that digital technologies may also bring negative consequences is making its room in scholars' mind.

As instance, there are some recent studies that found that the use of digital technologies may slightly decrease the perceived well-being (Orben and Przybylski, 2019) by inducing technology stress, addiction and misuse in the workplace (D'Arcy et al., 2014; Tarafdar, Darcy, et al., 2015; Tarafdar, Pullins, et al., 2015; Turel et al., 2011) and they may determine a negative engagement in learning activities (Selwyn, 2016).

Thus, accordingly, digital technologies may also be a double-edged sword, because they can undermine employees' creative and innovative endeavours (Nambisan et al., 2019).

2.1 Model and Hypotheses

As it emerged from the literature analysis, there is a misconception for what digital technologies are deemed linearly and positively related to innovation and intellectual capital anyway. However, this envision is short-sided because it skews the consideration that the effect on intellectual property depends on the kind of technology, on the degree of digitization, and on the digital skills involved in the process. Sometime, the effect can be even negative.

In this sense, previous studies seem to be more focused on efficiency rather than on effectiveness of the process. Counterintuitively, digital technologies may also reduce human creativity and discretionary. Yet, digitization and fast-relationships may deplete the social and relational dimension, reducing the occasions of in-person meetings, the depth of attachment in relationships, the transparency of processes through real life contacts, and many other critical learning and cognitive processes

At an anecdotal level, the increased digitization of firms and the massive recourse to smart working showed that such tools might increase productivity, indeed, but they also reduce occasions for in-person knowledge sharing. In brief, they have an undoubtfully negative effect on the social dimension of the human being and on the creation of tacit knowledge.

This matter raises questions of the utmost relevance about the long-run effects of massive digitization on businesses. The problem is even more cogent when thinking about the growth capability of firms, in terms of intellectual capital and innovation. Unfortunately, little research about this problem was done to date.

Building on literature antecedents and above considerations, this paper aims to tackle this resounding and extremely important gap.

By and large, we argue that digital technologies generally exert a positive influence on innovation, but the relationship is not straightforward as it is broadly deemed.

First, we assume that the effective use of digital technologies depends on digital skills of the human capital. As for that, digital skills are a covariant, whilst digital technology is the predictor of intellectual property, as showed in figure 1. Digital skills may interplay variously with digital technologies. So, they can have a various effect on intellectual property.

As instance, if skills are not consistent with the task, that might hamper the innovation process, despite the technology used. Also, there are different digital technologies and each of them contribute differently to intellectual property. For example, the use of e-mails may have a milder effect on innovation rather than that of Big Data Analysis. Prior literature assumed there is a linear and positive impact of digital technologies on innovation. Consistently, we also test such hypothesis:

i. Hp1: intellectual property is linearly and positively related to digital skills of human capital and digital relational capital.

However, as aforementioned, the linearity hypothesis does not capture the variegated contribution per technology type and the effects of digital skills on the use of such technologies. Yet, intellectual property does not benefit infinitely from increasing digitization. The contribution of digital technologies is limited and it does not replace factors such as intuition, serendipity, creativity, knowledge sharing and knowledge spillovers.

In addition, according to Tarafdar et al. (2015), the qualities that make digital technologies useful, such as reliability, portability, user-friendliness and fast processing, may also erode employees' productivity and innovation capabilities.

Hence, we argue that the relationship between digital technologies and intellectual property is curvilinear. Precisely, the relationship between variables inverted u-shaped, because digital technologies, in general, may foster the process, but excess digitization is useless and it can be even negative. As a matter of fact, excess digitization may be value destroying, as instance because it depletes creativity. The inverted u-shaped curve is depicted in figure 2.

Therefore, we define the following second hypothesis:

ii. Hp2: there is a curvilinear relationship between the intellectual property of the firm and digital technologies. The form of the relationship is inverted u-shaped.

As a matter of fact, according to Haans et al. (2016), many relationships in management follow an inverted u-shaped pattern, because "too much of a good thing can be harmful to performance" (Haans, Pieters, and He, 2016, p. 1177).

In detail, according to Haans et al. (2016), curvilinear relationships provide better explanations of complex phenomena and of causality between events Thus, as instance, scholars used such kind of models to explain the link between slack resources and innovation (Nohria and Gulati, 1996). In brief, testing curvilinearity allows the emersion of latent mechanism underlying a phenomenon (Haans, Pieters, and He, 2016). In the case of the interplay among digital skills, digital technologies, and intellectual property, there are latent factors – e.g. human related or structural related – that influence the relationship. Some factors moderate the relationship, by flattening the curve, - e.g. digital skills. Others factors make the sign of the relationship to change – e.g.. type of digital technology and consistency with firm's business and innovation goals.

3 Research design and Empirical Analysis

3.1 Sample

The analysis is based on the use of secondary data, that were entirely drawn by the Eurostat website, the European central office for statistical analysis. First, we collected data on intellectual property of innovative firms. This information is included in the Community Innovation Survey (CIS). We used the last available CIS (2016-2019). The CIS is the most famous and comprehensive dataset about innovation at business level in European Union (EU, EFTA, and EU candidates). It is specifically designed to cover various aspects of business innovativeness, such as sector, size and types of firms, alongside with radicalness, expenditures, funding, objectives and collaborative approaches. The survey is based on a previously validated questionnaire and it collects information at the microlevel – owners and firm's top managers. The concepts and methodology underlying the survey are based on the Oslo Manual (2005) 3rd edition. The CIS is extremely popular within the innovation scholars' community (Blind et al., 2017; Giannopoulou et al., 2019; Horbach, 2016). Amidst other works, there are: the famous study of Laursen and Salter (2006) on the innovation search strategy of firms, the work of Frenz and Ietto-Gillies (2009) on the relationship between innovation and source of knowledge, the analysis of Battisti and Stoneman (2010) on the connection between technological and organizational innovations. The firms' sample embraces either large or SME's enterprises, classified by sector according to NACE rev. 2 codes and by Country. Further information on the sample are reported in Table 1.

Second, we selected data on the impact of ICT (Information and Communication Technologies) on task and skills of individuals for the same period of time and, obviously, the same geographical distribution. These data are drawn by the Eurostat survey on the ICT usage by individuals. This survey questionnaire is based on the conceptual 2011 - 2015 benchmarking framework, the i2010 Benchmarking Framework and the eEurope 2005 Action Plan. Specifically, we used data related to digital skills and impact of ICT on tasks and skills. There are six different typologies of impact that induced a change in tasks, and, namely: individual's main job tasks changed as a result of the introduction of new software or computerised equipment, individuals that had to learn how to use new software or computerised equipment for the job, individuals who needed further training to cope well with the duties relating to the use of computers, software or applications at work, individuals' whose skills correspond well to the duties related to the use of computers, software or applications at work, individuals who had the skills to cope with more demanding duties related to the use of computers, software or applications at work, individuals that were involved in choosing, modifying or testing the software or computerised equipment used at work.

Finally, we drawn data about the use of digital technologies at business level from the Eurostat survey on ICT usage in enterprises. We consider the following technologies: firms using 3D printing or big data analysis and buying cloud computing services, emails, host database, finance and accounting software applications, Customer Relationship Management software, computing power, and other high cloud computing services.

In brief, the sample includes three main kind of information: intellectual property of EU firms, digital skills of human capital at a firm level, and digital technologies adopted by firms.

The first one is a proxy measure of the innovation capital of the firm. The second one refers to human capital. The third one expresses both the structural capital and the digital relational capital.

Few clusters in the dataset presented some missing data. Since data were reasonably considered as missing at random, such cases were deleted listwise. All data are expressed in numbers.

The focus on Eu zone was motivated by the large availability of significant and reliable data, along with a massive use and of digital technologies within this territory, the ongoing digitization process, and the existence of a digital divide, either between countries or within countries.

3.2 Method

Few studies have previously explored the relationship between IC and digital technologies. Amidst them, the study of Dženopoljac et al. (2016) used a multiple regression analysis to explore how IC creates value in the Serbian ICT sector. Similarly, Ramadan et al. (2017) used multiple regression to test the mediating effect of social capital, knowledge management and intellectual capital in the ICT sector. Other studies in this research field relied on the same methodology (Gan and Saleh, 2008; Shiu, 2006). Also, studies on the relationship between IC, performance, and innovation have often used the multiple regression method (Chang and Hsieh, 2011; Dost et al., 2016; Zéghal and Maaloul, 2010, (Andersen, 2008).

Generally speaking, linear regression models assume that the endogenous variable is normally distributed. However, this rarely happens in real word and specifically in our case, where we assume that there are both digital technology and digital skills gaps.

To solve this problem and to stay consistent with prior literature, along with the purpose of the analysis, we used a Generalized Linear Model (GLM). GLM allows to consider response variables that are non-normally distributed, such as in our case, and to test for both linear and non-linear responses.

Precisely, with GLM, each outcome Y of the dependent variable is generated by a particular probability distribution in an exponential family.

The general equation is the following:

$E(Y) = \mu = g^{-1} \cdot (X\beta)$

Where E(Y) is the expected value of Y; Xβ is the linear predictor, a linear combination of unknown parameters β; g is the link function.

We used both normal and gamma logarithmic distribution as for the link function (also consistently with indications to test for curvilinearity). As a matter of fact, the gamma logarithmic distribution is useful for exponential-response data with negative inverse distribution (as in the case of the of the inverted u-shaped curve). Typically, in order to allow the regression to have a U shape, the standard approach has been to include a quadratic or an inverse term in a linear model (Simonsohn, 2018), as in our case.

Simplifying, in order to validate the non-linearity hypothesis and the u-shaped curve hypothesis, firstly, we needed to check for linearity. Precisely, in this case the linearity hypothesis H_1 must be rejected, based on tests, and the null hypothesis H_0 must be accepted. On the contrary, when testing for u-shaped curve, we need to accept the alternative hypothesis H_1 and reject the null hypothesis H_0.

In addition, we checked for the effects (all 5 types of effects) between the factors and the covariates.

We also measured descriptive statics, covariances and we run different robustness checks: as instance, we tested for the presence of heteroscedasticity, non-correlation of residuals, and the presence of outliers. The curvature was also checked through bootstrapping.

Our quadratic regression model for the bootstrapping is the following:

$y_i = M + U(x - L)2$

Where y_i is the outcome variable (intellectual property), M is the maximum value of y if U<0 and the minimum if U>0. L refers to the maximum and minimum of our x coordinates, which in our case are the impact of digital technologies on individual tasks – human capital -, and digital technologies. U is the degree of curvature with positive or negative values corresponding to an upright/downright U shape and higher values (positively or negatively) indicating a greater degree of curvature.

3.3 Operationalization of variables

We consider intellectual property as our dependent or response (outcome) variable. Broadly speaking, intellectual property is deemed as a proxy for firm's innovativeness – innovation capital – and it is part of the structural capital of a firm (Mueller et al. 2013).

Intellectual property includes patents, trademarks, copyright, trade secrets utility models, and industrial design. The outcome variable is expressed in numbers.

Our independent variables are related to the impact of digital technologies on both human capital and on relational capital. Human capital refers to "the personal knowledge, skills, experience, and capabilities of workers" (Ramadan et al., 2017, p. 440).

Consistently, the impact of digital technologies on human capital is measured considering the influence of ICT on six different tasks: 1) individual's main job tasks changed as a result of the introduction of new software or computerised equipment, 2) individuals had to learn how to use new software or computerised equipment for the job, 3) individuals needed further training to cope well with the duties relating to the use of computers, software or applications at work, 4) individuals' skills correspond well to the duties related to the use of computers, software or applications at work, 5) individuals had the skills to cope with more demanding duties related to the use of computers, software or applications at work, 6) individuals were involved in choosing, modifying or testing the software or computerised equipment used at work.

This information was retrieved through the use of the survey questionnaire named "ICT usage by individuals" distributed, collected, and validated by the Eurostat.

Similarly, the firm adoptions of digital technologies by purchasing them from third-parties are also considered a proxy of firms' relational capital (Youndt et al., 2004). For this variable, we gathered data from the Eurostat survey named "ICT usage in enterprises". Data refer to purchase and usage of cloud computing services, office software, host database, storage of files, finance and accounting software applications, Customer Relationship Management software, computing power, other high CC services, 3D printing, big data analysis.

Finally, our control variables are: firm's size and sector, number of patents by Country and priority years (Mueller et al., 2013).

Table 2 synthesizes the variables used in the analysis and their measures.

4 Results

The results of the analysis confirm model's hypotheses at a level of huge statistical significance. Table 3 shows that the covariance between intellectual property and digital technologies is mostly negative, except for 3D printing, robotics, and big data analysis.

The first GLM analysis tests the linearity hypotheses using the maximum likelihood method and robust estimators for hypotheses testing. This test is due to disconfirm previous orientation of the literature. In this test, intellectual property is the response variable, digital technologies are the factors, digital skills of human capital are the covariates, to check for various kinds of effects. The probability distribution is normal and the link function is identity. According to the first test - with a confidence interval of 95% - the alternative H_1 hypothesis is accepted with $\alpha=0,05$. However, it is rejected with $\alpha=0,01$, that leads to accept the null hypothesis H_0.

As a matter of fact, the χ squared test shows a value of 4, 674 with 1 degree of freedom and a significance level of 0,031. Considering the χ squared distribution table, such value is accepted because is greater than the value considered in the distribution, χ =3.84, with 1 degree of freedom, and α= 0,031 < α=0,05. However, as said the null hypotheses is accepted when α=0,01> α= 0,031 and χ =4,674 < χ =6,64. Based on such results, the linearity hypothesis seems very week. Results are reported in table 4.

In the second GLM analysis we used the gamma logarithmic function. The gamma logarithmic distribution is used for exponential-response data with a negative inverse distribution. In other words, it allows us to understand whether the relationship is inverted u-shaped. Precisely, in this second GLM analysis, intellectual property is the response variable, digital technologies are the factors, digital skills of human capital are the covariates. We checked for all kinds of effects. The probability distribution is a gamma function, whilst the link function is logarithmic. As the results show at a huge level of statistical significance, the inverted u-shaped relationship is confirmed. As a matter of fact, according to this second test, the alternative H_1 hypothesis is accepted with α=0,05 and even α=0,005 . So, the null hypothesis H_0 is rejected

The χ squared test shows a value of 352, 253 > χ =3.84 and > χ =6,64. Hence, they are both greater of the one in the distribution table, with 1 degree of freedom, and a significance level of 0,000< α=0,05 and α=0,005. We used the maximum likelihood method and robust estimators for hypotheses testing. Table 5 shows the result of this second analysis. Finally, the curvature test through bootstrapping confirmed once more the existence of an inverted u-shaped curve between variables, as shown in figure 3.

5 Discussion and originality of the work

The findings confirm that the relationship between intellectual property and digital technologies is inverted u-shaped. This ground-breaking result completely novels the research field and it disconfirms previous models, which proposed a linear and positive relationship between these variables.

Generally speaking, most digital technologies are poorly useful for intellectual capital creation, except for 3D printing, robotics, and Big Data analysis. In addition, based on current results, digital skills have a strategic relevance only when they are used in complex tasks. In other words, small levels of increasing digitization in terms of digital technologies is helpful for intellectual property. By contrast, as the curve clearly shows, excess and undifferentiated digitization might reduce firm's ability to generate intellectual property.

The results can have several explanations. First, digital technologies are standardized, most of them add a little to the process and they solely serve for efficiency motives. In other words, most of these technologies are based on an explicit and codified knowledge, open for anyone to use. So, they do not make a real difference in terms of extra-performance, because they are largely diffused between firms. Only extremely new and ground breaking digital innovations may foster intellectual property.

Second, there is an interplay between the human factor and digital technologies. Digital skills must be in line with task and technology. Time and again, they only matter when they incorporate a unique and scarce knowledge. In addition, excess digitization may deplete the creativity of employee, causing various learning, attention, and misperceptions problems.

Previously, many studies suggested a positive relationship between human capital and innovation (Dakhli and De Clercq, 2004; Kianto et al., 2017; Lund Vinding, 2006), relational capital and innovation (Capello and Faggian, 2005), intellectual capital and ICT (Dženopoljac et al., 2016), human capital or relational capital and intellectual property (Bollen et al., 2005; Namvar et al., 2010). However, all these studies fail to adopt a holistic approach and to consider factor-specific effects. Differently, our findings prove that the relationship between the variables is curvilinear, as the negative intercept indicates.

Reasonable amounts of digital technology usage foster intellectual property, whilst excess digital technologies do not produce any further value.

Notably, we also noticed that some digital technologies that affected individual tasks or that are related to relational capital have a negative effect on intellectual property, whereas others impact positively. As instance, partnerships in big data analysis, cloud computing services, host databases, or 3D exert a positive influence on intellectual property. Less high-tech partnerships, such as those for office software, have a negative impact. Again, training, involving the employee in testing or adapting the digital technology exert a positive influence on intellectual property, whereas changing the job task, or being assigned a task which requires inferior skills than those owned by the individual have a strong negative effect. Clearly, human capital is influenced by emotion, by the status-quo-bias and many other biases (Kahneman et al., 1991). By large and large, the level of satisfaction at work may strongly influence human ability to be creative. Such evidences have a huge relevance for both future research and practice.

5.1 Implications for theory and practice

The findings of this research offer several important implications for both theory and practice.

At a theoretical level, this study answers the call to extend research on the impact of intellectual capital on innovation (Dost et al., 2016). In addition, it intervenes in the debate about how intellectual capital affects innovation processes and outcomes (Duodu and Rowlinson, 2019). Notably, it originally proves the existence of an inverted u-shaped relationship between intellectual property and digital technologies.

Human capital and relational capital lead to the development of intellectual property (Audretsch and Link, 2018; Bollen et al., 2005). However, we know a little about how they interplay with digital technologies (Novas et al., 2017). Therefore, this study adds to the management, intellectual capital and innovation literature, because it sheds light on the link between different forms of intellectual capital and intellectual property. This research pioneers the investigation of the role of digital technologies that, by transforming individual tasks, skills and relational networks, are able to influence the creation and the development of intellectual capital. Previous studies argued that digital technologies are drivers of intellectual property, because they facilitate the sharing of knowledge and ideas, the acquisition of new skills, work efficiency (Berraies, 2019; Cai et al., 2020; Flores et al., 2020; Sag et al., 2019), and new relationships (Boeker et al., 2019; Li and Herd, 2017; Stachová et al., 2020). Differently, we argue that their contribution is limited. We suggest that digital technologies might be a double-edged sword, because an excess usage of digital technologies may hinder the creation of intellectual capital. This research explains that there is a positive impact of digital technologies on intellectual property, because they allow to build new relationships (Boeker et al., 2019; Li and Herd, 2017; Stachová et al., 2020), to share knowledge and ideas, to acquire new skills, to improve existing skills (Berraies, 2019; Cai et al., 2020; Flores et al., 2020; Sag et al., 2019). Though, this impact is curvilinear, which mean that there are latent factors influencing the relationship and making the sign of the relationship to change.

First, the curve is flattened by digital skills of employee, that are a moderator of the relationship. In other words, the contribution of digital technologies to intellectual property depends on the way and the ability of humans to use them, the consistency between technology and skill, between skill and task, between technology and innovation goals and between technology and business.

Second, each firm has an optimal apex of digital technologies, which depends also on technological consistency. Excess digital technology is useless and even wasteful, because it determines sunk costs that do not add any value to the growth process.

At a practical level, this study suggests that firms have to carefully manage their digitization process and investment in digital technologies, before it backfires. Firms should invest in high tech and in superior digital skills. As a matter of fact, such investments will help to foster intellectual property, and, thus, intellectual capital and innovation. Assigning employee to the right digital task and training them to achieve superior knowledge can boost firm's growth. Also, current evidences proved that excess digitization is value destroying, because it massively standardizes knowledge and it depletes the creativity process. The relevance of this study is huge if we consider the fast digitization and the recourse to remote and smart working after the Covid-19 outbreak. Such excess digitization may hamper firm's capability to survive in the long-run, because it can erode the firm's ability to generate innovation and intellectual capital.

5.2 Limit of the analysis and future research avenues

The analysis was conducted using a strong and reliable statistical method. However, neither the use of large-scale dataset or the robustness of method prevents from various kind of biases. First and foremost, the sample of the analysis is limited to European firms and individuals. Second, the authors' bias led to choosing specific variables over others. Changing variables may affect the results of the analysis. A similar consideration can be made for the use of conceptual proxies. As instance, the intellectual capital can be measured and esteemed in different ways.

Future research should focus on the use of alternative methods, to check whether different approaches confirm current results or not. Besides, the current use of archival data allows future replications of the study. In addition, future research should focus on the impact of digital technologies on individual creativity, cognition, and social ability.

Another limitation is linked to the analysis of the effects of digital technologies on the internal rather than on the external disclosure of intellectual capital (Giacosa et al., 2017). Future research should take into account how digital technologies may affect the external disclosure of intellectual capital. Finally, latent variables may also cause the curve to flip, creating more complex curvilinear shapes. This, in particular, can be of high interest for future researches.

6 Conclusions

This study investigates the three different and interrelated aspects of intellectual capital, namely human, relational, and structural capitals. The aim of the work is to understand whether and how changes induced by digital technologies within a firm affect the creation of intellectual property, as a proxy of firm's innovativeness. Specifically, the study provides empirical evidence that there is a curvilinear relationship between the intellectual property of the firm and digital technologies. According to our results, this relationship is inverse u-shaped. In addition, the study highlights that the impact of digital technologies on intellectual property is differentiated per technology type; whilst the impact of changes in human capital tasks due to digital technologies on intellectual property is differentiated per task type.

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Appendices

Figure 1: The relationship between digital technologies and intellectual property

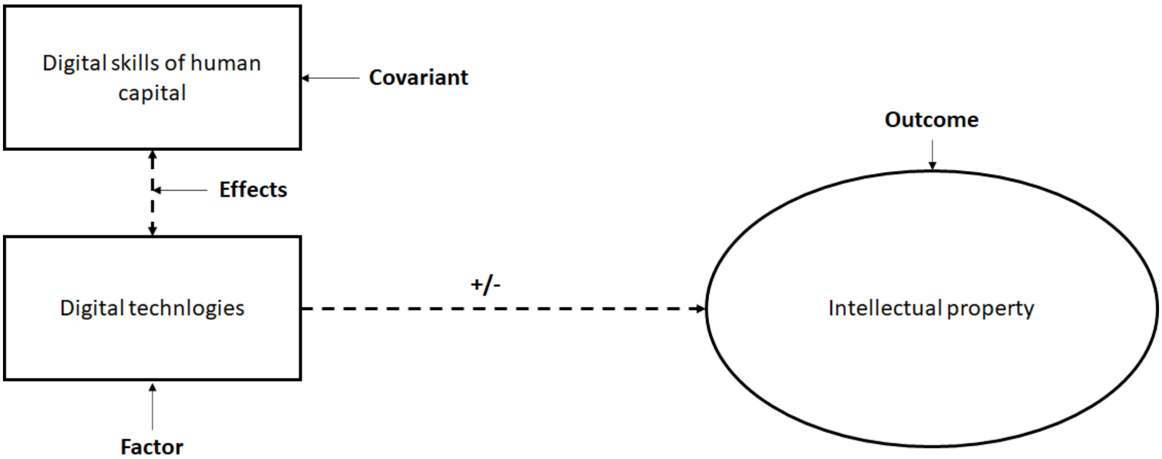

Figure 2: The inverted u-shaped relationship between digital technologies and intellectual property

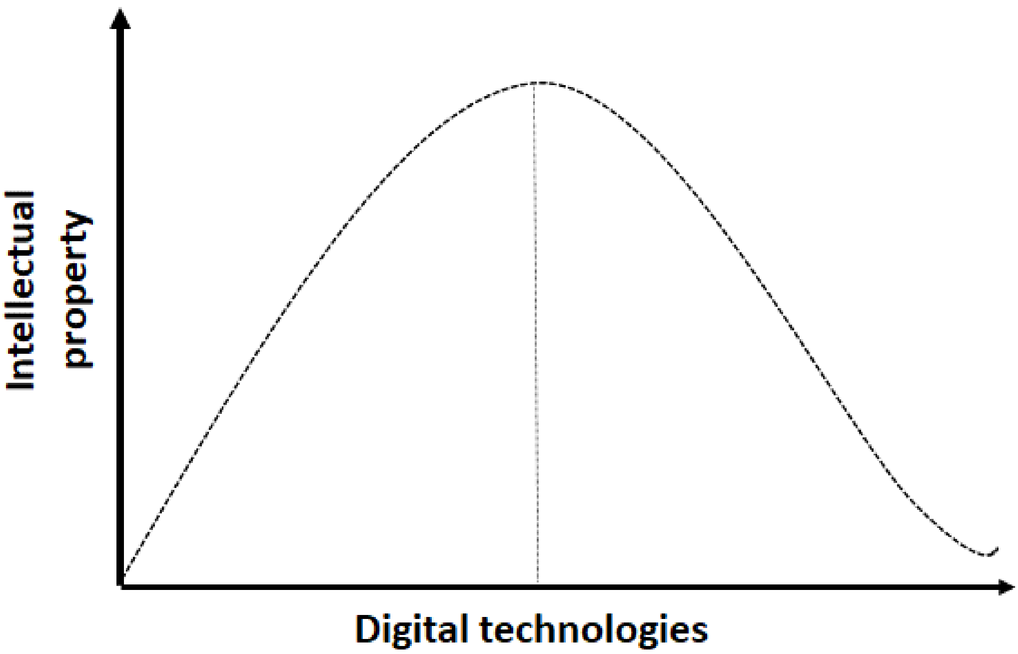

Table 1: Characteristics of the firms' sample. Source: Eurostat – CIS 2016.

SIZECLAS	**Total**	**From 10 to 49 employees**	**From 50 to 249 employees**	**250 employees or more**
GEO/TYPE	Innovative enterprises (including enterprises with	Innovative enterprises (including enterprises with	Innovative enterprises (including enterprises with	Innovative enterprises (including enterprises with

	abandoned/suspended or on-going innovation activities)	abandoned/suspended or on-going innovation activities)	abandoned/suspended or on-going innovation activities)	abandoned/suspended or on-going innovation activities)
Belgium	8,690	5,739	2,472	479
Bulgaria	3,725	2,263	1,066	396
Czechia	9,063	5,705	2,482	877
Denmark	3,844	2,618	971	255
Germany (until 1990 former territory of the FRG)	91,120	63,521	21,403	6,196
Estonia	966	618	287	61
Ireland	4,108	3,029	819	260
Greece	7,057	5,886	986	185
Spain	23,470	17,171	4,987	1,312
France	39,672	28,718	8,367	2,588
Croatia	2,748	1,968	598	182
Italy	54,458	43,233	9,294	1,931
Cyprus	670	512	127	31
Latvia	1,276	828	351	97
Lithuania	3,300	2,165	929	206
Luxembourg	1,140	806	265	69
Hungary	3,764	2,502	926	336
Malta	367	252	94	21
Netherlands	13,963	9,820	3,397	747
Austria	9,901	6,954	2,243	704
Poland	12,347	7,161	3,813	1,373
Portugal	10,044	7,574	2,105	364
Romania	3,645	2,527	786	332
Slovenia	1,906	1,282	480	143
Slovakia	2,432	1,614	594	223
Finland	4,742	3,455	996	290
Sweden	9,651	7,215	1,945	491
United Kingdom	52,386	39,722	10,447	2,217
Iceland	489	333	115	41
Norway	5,250	3,813	1,143	294
Switzerland	17,661	12,410	4,427	824
Total	386,194	279,004	84,488	22,701

Table 2: Variables and measures

Name of the variable	Type of variable	Measures	Literature ground
Intellectual property	Dependent variable	patents, trademarks, copyright, trade secrets utility models, and industrial design	Mueller et al. 2013
Digital Technologies	Independent variable - factor	1) individual's main job tasks changed as a result of the introduction of new software or computerised equipment, 2) individuals had to learn how to use new software or computerised equipment for the job, 3) individuals needed further training to cope well with the duties relating to the use of computers, software or applications at work, 4) individuals' skills correspond well to the duties related to the use of computers, software or applications at work, 5) individuals had the skills to cope with more demanding duties related to the use of computers, software or applications at work, 6) individuals were involved in choosing, modifying or testing the software or computerised equipment used at work.	Ramadan et al., 2017
Digital skills of human capital	Independent variable - covariate	to purchase and usage of cloud computing services, office software, host database, storage of files, finance and accounting software applications, Customer Relationship Management software, computing power, other high CC services, 3D printing, big data analysis.	Youndt et al., 2004

Table 3: Covariances between digital technologies and intellectual property

Label	Cloud computing services	e-mails	office softwares	host database	finance and accounting software applications	Customer Relationship Management software	computing power	other high CC services	Use 3D printing	Big data analysis	All intellectual property rights (IPRs)
Cloud computing services	93,85042										
e-mails	67,59557	53,50693									

office softwares	53,58726	41,4903	34,06094								
host database	51,32687	35,39058	30,90582	41,52355							
finance and accounting software applications	52,72299	36,70914	28,77562	32,27978	39,68975						
Customer Relationship Management software	35,55679	24,3241	21,241	26,37396	21,91413	18,72576					
computing power	19,7036	14,72299	12,7036	13,63989	9,792244	8,878116	6,554017				
other high CC services	61,6759	43,40443	34,57064	37,14681	41,5928	25,60111	12,66482	45,85042			
Use 3D printing	7,548476	5,096953	4,33795	4,836565	2,34903	2,958449	2,121884	3,977839	1,883657		
Big data analysis	27,64266	18,02216	16,85319	21,73407	14,6482	13,05817	7,534626	18,67313	4,836565	25,73407	
All intellectual property rights (IPRs)	-3193,39	-15209,2	-12333	-2493,4	-9953,38	-3089,25	-3322,85	-7562,4	7073,407	9929,598	1,41E+08

Table 4: GLM linear analysis

Parameter	P	Dev Error	95% confidence interval		Hypotheses test		
			Inferior	Superior	Chi-squared of Wald	Degree of freedom	Sign.
Intercept	5890,632	2724,6479	550,420	11230,843	4,674	1	,031
Scale response	141050420,864a	45762799,4474	74680658,433	266403934,343			

Table 5: GLM inverted u-shaped analysis

Parameter	P	Dev Error	95% confidence interval		Hypotheses test		
			Inferior	Superior	Chi-squared of Wald	Degree of freedom	Sign.
Intercept	8,681	,4625	7,775	9,588	352,253	1	,000
Scale response	2,070[a]	,5527	1,227	3,494			

Figure 3: The inverted u-shaped curve between intellectual property and digital technologies