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Nathalie Greenan
Silvia Napolitano
Imad El Hamma

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Centre d'études de l'emploi et du travail

« Le Descartes »
29, promenade Michel Simon
93166 Noisy-le-Grand CEDEX/
Téléphone : (33) 01 45 92 68 00

ceet.cnam.fr

DIGITAL TECHNOLOGIES, LEARNING CAPACITY OF THE ORGANISATION AND INNOVATION: EU-WIDE EMPIRICAL EVIDENCE FROM A COMBINED DATASET

NATHALIE GREENAN

nathalie.greenan@lecnam.net
Cnam-Lirsa, Cnam-CEET et TEPP

SILVIA NAPOLITANO

Silvia.napolitano@lecnam.net

Cnam-Lirsa, Cnam-CEET

IMAD EL HAMMA

imad.elhamma@gmail.com
Cnam-Lirsa, Cnam-CEET et TEPP

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TECHNOLOGIES NUMÉRIQUES, CAPACITÉ D'APPRENTISSAGE DE L'ORGANISATION ET INNOVATION : RÉSULTATS EMPIRIQUES À L'ÉCHELLE DE L'UE À PARTIR D'UN ENSEMBLE DE DONNÉES COMBINÉES

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RÉSUMÉ

Cet article étudie les effets de la digitalisation et des pratiques organisationnelles sur l'innovation en Europe, entre 2010 et 2016. Les différences entre pays et secteurs en matière d'investissements et de capacités des entreprises à adopter et à utiliser les nouvelles technologies sont analysées ainsi que les effets des technologies numériques sur les innovations. En plus des moteurs traditionnels de l'innovation, tels que les dépenses de R&D, deux indicateurs sont construits. L'un englobe des mesures directes de l'adoption et de l'utilisation par les entreprises d'un ensemble de technologies numériques. L'autre mesure la capacité d'apprentissage de l'organisation, prenant en compte l'utilisation d'outils de gestion et de pratiques organisationelles visant à améliorer l'apprentissage individuel et organisationnel. Les innovations de produit, de procédé, organisationelles et marketing sont identifiées ainsi que leur combinaison dans l'entreprise, afin d'explorer les éventuelles synergies quelles entretiennent entre elles. L'analyse empirique mobilise un ensemble de données unique, reposant sur l'intégration au niveau des secteurs au sein des pays de plusieurs enquêtes couvrant l'Union Européenne (UE) et conduites auprès des employeurs d'une part, des salariés d'autres part : l'enquête communautaire sur l'innovation (Eurostat), l'enquête sur l'utilisation des TIC et le commerce électronique dans les entreprises (Eurostat) et l'enquête européenne sur les conditions de travail (Eurofound). Les statistiques descriptives montrent que l'adoption et l'utilisation des technologies numériques augmentent rapidement en Europe alors que la capacité d'apprentissage des organisations stagne. L'analyse économétrique montre cependant que leur interaction a des effets positifs sur les innovations. En particulier, la combinaison d'innovations de produit/procédé et d'innovations organisationelle/marketing repose sur des investissements conjoints dans la R&D, l'adoption et l'utilisation des technologies numériques et la capacité d'apprentissage.

Mots clefs : technologies numériques ; capacité d'apprentissage ; innovation ; fonction de production de connaissances ; intégration des données des enquêtes auprès des employeurs et des salariés.

NB : Ce document fait partie des travaux menés dans le cadre du projet Beyond4.0 (https://beyond4-0.eu/the-project). BEYOND 4.0 répond aux priorités globales du programme de travail H2020 (2018-2020) " L'Europe dans un monde qui change - Des sociétés inclusives, innovantes et réfléchies " et a reçu un financement du programme de recherche et d'innovation Horizon 2020 de l'Union européenne sous la convention de subvention n° 822296.

DIGITAL TECHNOLOGIES, LEARNING CAPACITY OF THE ORGANISATION AND INNOVATION: EU-WIDE EMPIRICAL EVIDENCE FROM A COMBINED DATASET

ABSTRACT

This paper investigates the effects of digitalisation and organisational practices on innovation in Europe, between 2010 and 2016. We analyse the cross-country and industry differences in firms' investments and capabilities to adopt and use new technologies and their effects on innovation outputs. Along with traditional drivers of innovation, such as R&D expenditure, two indicators are constructed. One encompasses direct measures of the adoption and use in enterprises of a set of digital technologies. The other measures the learning capacity of organisations, which captures the use of management tools and organisational practices concerned with the improvement of individual and organisational learning. Product, process, organisational and marketing innovations are identified as well as their combination in the company, in order to explore possible synergies between them. Empirical evidence is provided by a unique dataset based on the integration at the sector within country level of EU-wide employers' and employees' surveys: the Community Innovation Survey, the Community ICT usage and e-commerce in enterprises surveys (Eurostat) and the European Working Conditions Survey (Eurofound). The descriptive evidence shows that Digital technologies adoption and use is rapidly growing across Europe while the Learning capacity of organisations remains stagnant. By contrast, our results from the econometric analysis show that their interaction has positive effects on innovations. In particular, a mix of product/process innovations with organisational/marketing innovations rests on joint investments in R&D, digital technology adoption and use and learning capacity.

Keywords: Digital technologies, learning capacity, innovation, knowledge production function, data integration of employers' and employees' surveys.

N.B : This paper is part of the work carried out in the Beyond4.0 project (https://beyond4-0.eu/the-project). BEYOND 4.0 responds to the overall priorities of the H2020 (2018-2020) work program "Europe in a Changing World - Inclusive, Innovative and Thoughtful Societies" and has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 822296.

1. INTRODUCTION

The fifth technological revolution has started in the 1970s with the entry into the age of Information and Telecommunication (Perez, 2003). Since the big bang of the announcement of the Intel microprocessor in Santa Clara, the Information and Communication Technologies (ICTs) revolution has accelerated three times: with the generalisation of the personal computer, with the entry in the Internet age and today with the progress in artificial intelligence. However, those economies that have invested heavily in ICTs have not yet entered a phase of accelerated and inclusive growth.

To understand this puzzle, we look for a missing element in our current understanding of the technological transformation in the digital age. The literature about productive complementarities (Milgrom and Roberts, 1990) points to the existence of synergies among technological choices and organisational and skills-related practices. Creating a unique dataset from macroeconomic sources on the US non-farm business sector between 1948 and 2007, Corrado and Hulten (2010) have demonstrated that a major shift in the composition of investments and capital formation towards intangibles had occurred. Thus, organisations face a number of options when adopting ICTs and digital technology on how to embed them into the organisation in order to innovate by taking advantage of the opportunities they open. In particular, they need to build synergies in combining them with other tangible and non-tangible investments, while directing their productive effort towards the production of new goods and services, new organisations and business models. A complex process of investment in technological expertise, product design, market development and organisational learning is generating the knowledge that is the source of today's growth. Hence, the key skill for organisations is not only technical, nor purely incorporated in the individual, it is a collective skill, built in the workplace, and allowing the orchestration of knowledge from various fields of expertise. However, these pioneering researches have focused on productivity when we want to address innovation issues.

We thus refer to the theoretical frame of the knowledge production function in the so-called CDM model, developed by Crépon, Duguet and Mairesse (1998). It gives a good description of how the technological transformation takes place within companies. In the most advanced version of this model, firms invest in R&D and ICTs to increase the stock of productive knowledge, a latent variable that translates into innovation outputs, with product and process innovations being the two types of innovations generally considered. We are going to explore firms' investments and capabilities to adopt and adapt to new technologies and their effects on innovation outputs, by augmenting this knowledge production function in three main directions.

First, on the input side, along with the traditional drivers of innovation such as R&D expenditure, we enrich the direct measurement of ICT investments. We develop a synthetic indicator that takes into account the heterogeneity of ICTs and digital technologies and their constant renewal. We expect that investment in ICTs and digital technologies drives innovation, and we test whether this is especially true when technology investments are combined with R&D expenditure and other intangible investments.

Second, we add the learning capacity of the organisation as a new argument in the knowledge production function. The learning capacity captures the adoption of management tools concerned with the improvement of individual and organisational learning. In particular, we refer to the concept of "organisational learning" that is key in understanding the capability of an organisation to process new knowledge and to nimbly adapt to it. A learning organisation is able to create, acquire, transfer and integrate knowledge, to distribute it among its members as well as to encourage employees to develop innovative work behaviours (Jerez-Gomez et al., 2005; Greenan and Lorenz, 2010). The economic and management literature stresses that learning organisations are adaptive. They have the managerial capacity to design and adjust business models in rapidly changing environments, without disrupting their structure, thus preserving their inertial forces and ensuring their sustainability (Teece, 2018). In this sense, organisational learning is a dynamic process of strategy renewal, which involves a number of trade-offs between exploration, new opportunities, innovation and change on the one side and exploitation, established practice, continuity, routinisation and standardisation on the other one (Greenan and Napolitano, 2021). The relation between innovativeness, technology adoption and human and organisational capital is something still scantly explored by the empirical literature (Bresnahan, Brynjolfsson and Hitt, 2002; Greenan, 2003; Bloom et al., 2019). We aim to provide some new evidence in this respect, assuming that the learning capacity is an important driver of innovation and that its combination with ICTs and digital technologies is likely to generate synergetic effects. Indeed, improving skills endowments as well as implementing managerial practices that incentivise employees' innovative work behaviour can foster the implementation of new technologies and facilitate the absorption of externally available knowledge (Piva and Vivarelli, 2009). It is this second way of increasing the knowledge production function that makes our contribution the most original.

Third, on the output side, we are going to enlarge the definition of innovation to include non-technological forms. Indeed, we consider four types of innovation – product, process, organisational and marketing – as well as their combination to account for more complex forms of outputs from innovative activities in the digital age. The notions of innovation outputs and their measurement are drawn from the Oslo Manual (OECD/Eurostat, 2005), which are to date state of the art to tackle the various facets of the potential change resulting from the technological transformation. It summarises how organisations have managed to be creative by taking advantage of the new opportunities opened up by the digital revolution.

To provide empirical evidence about this augmented knowledge production function, we built a unique dataset at EU-wide level over 2010-2016. The construction of the dataset required substantial effort, which is core in the value added of our contribution. It combines, through a "common cell", that is an industry in a country in a given year, three main data sources: two employer level data sources, the Community innovation survey and the Community ICT usage and e-commerce in enterprises survey (Eurostat) and an employee level one, the European Working Conditions Survey (Eurofound). This dataset allows us to develop our enriched measurement frame of the ongoing technological transformation with the three desired novelties: a synthetic indicator of *Digital technology adoption and use* that takes into account the diversity of ICTs and digital technologies as well as their technological intensity, a composite indicator of the *Learning capacity* of the organisation based on information gathered at the employee level and combined measures of technological and non-technological innovations within industries. To our knowledge, Nicoletti et al. (2020) are the first that have made such an attempt to link employer with employee level surveys with the aim to better understand the diffusion of digital technologies.

Our descriptive evidence shows that *Digital technologies adoption and use* is rapidly growing across Europe while the *Learning capacity* of organisations remains stagnant. By contrast, our results from the econometric analysis confirms that the interaction between the *Digital technology adoption* and the *Learning capacity* indexes has positive effects on innovations and, that, in particular, a mix of product/process and organisational/marketing innovations rests on joint investments in R&D, technology adoption and learning capacity.

In a first section, we review the empirical literature on drivers of innovation and complementarities in the knowledge production function within companies. We then present our combined dataset where the unit of observation is an industry in a country on a given year. A third section is dedicated to the construction of our two main indicators of *Digital technology adoption and use* and of *Learning capacity* of the organisation and to first descriptive evidence across the EU. We then present our econometric analysis and our results. A last section concludes.

2.COMPLEMENTARITIES IN THE KNOWLEDGE PRODUCTION FUNCTION

The literature about the drivers of innovation stresses that complementarities exist between tangible and intangible investments as well as between different forms of innovation outputs. Innovators usually adopt a number of strategies that simultaneously touch upon performing R&D, adopting and using new technologies, embedding these technologies in the production process and hence re-designing the organisation of work and skills utilisation. By combining different practices, a higher gain and better performances are expected because of the presence of productive complementarities (Milgrom and Roberts, 1990).

R&D has been traditionally considered as an innovation input. Since the seminal work by Griliches (1979), the empirical literature has produced evidence about the positive return of investments in R&D in terms of innovation and productivity growth. The seminal paper by Crépon, Duguet and Mairesse (CDM) (1998) went deeper into the insight that innovation inputs explain innovation outputs, which then determine productivity outcomes. In particular, their study establishes a production function augmented by a knowledge production function by including the R&D efforts among the innovation inputs. The CDM structural model has become a key reference in the empirical literature on the drivers of innovation and on its productivity impacts.

Inspired by the CDM model, some more recent studies expand the knowledge production function by including the usage of ICTs and digital technologies. Research has pointed to the fact that R&D and technological investments are mutually reinforcing: on the one hand, R&D may become more effective because ICTs facilitate knowledge sharing and collaboration between researchers; on the other hand, technological developments rely on the generation of new knowledge (Mohnen et al., 2018). Technology use allows firms to better share and access technological knowledge, even when it is external (Venturini, 2014). However, the empirical literature that investigates R&D and ICT investments jointly is still limited (Greenan et al., 2001; Polder et al., 2010; Hall et al., 2013; Venturini, 2014). The empirical research has focused on the inclusion of ICT variables in innovation models, maintaining that they are key to explain innovativeness differences (van Leeuwen and Farooqui, 2008). Moving from measures of ICT investments or ICT capital stocks, some studies have narrowed the focus on the adoption of specific digital technologies. Their findings have highlighted the existence of significant complementarities among technologies (Polder et al., 2010; Bartelsman et al., 2017), so that it seems preferable to jointly cover a range of digital technologies in order to take into account the diversity of technological strategies implemented by companies (Nicoletti et al., 2020).

As a further step, some studies explore the complementarity between investments in ICTs and intangible assets other than R&D activities. A strand of literature describing ICTs as general purpose technology (Bresnahan and Trajtenberg, 1995) points that ICTs may have larger impacts compared to traditional capital investments because they enable complementary innovation and particularly organisational innovation (Brynjolfsson and Hitt, 2000; Bresnahan, Brynjolfsson and Hitt, 2002; Brynjolfsson, 2011). While some studies explore complementarities between investments in R&D, ICTs and organisational innovation on firm-level data from national data sources (Polder et al., 2010; Brynjolfsson and McElheran, 2016, Mohnen et al., 2018), we focus here on those studies that have a cross-country and cross-sector coverage.

Bartelsman et al. (2017) study the complementarity between different enterprises' IT strategies. The authors use the Micro-Moments Dataset (MMD), a dataset linking firm-level data from different sources (Bartelsman et al., 2013) and providing averaged and aggregated data at the country-industry-level of firm's innovation inputs and outputs. The authors include in their model direct measures of ICT usage (electronic buying and selling) and broadband intensity - and measures of ICT skill levels of employment. They also look at the existence of productive complementarities between three enterprise systems with embodied software that they consider as sources of organisational innovations. They find that ICTs correlate positively with the probability to innovate and that, in particular, a combined use of different ICTs is associated with higher productivity.

Corrado et al. (2017) exploit cross-country and cross-industry data on intangible assets and productivity to study their correlation in 10 major EU countries, from 1998 to 2007.

Measuring intangible capital as investments in R&D, design, brand equity, firm-specific training and organisational change, they demonstrate that intangibles, irrespective to the introduction of R&D, are complements with ICTs capital in production. As well, they find that increases in intangible assets have spill over effects on productivity as well as on improvements in workforce skills.

Nicoletti et al. (2020) focus on the adoption of specific digital technologies, namely cloud computing and back and front-office integration software, and relate them to the human capital capabilities and to market incentives that enterprises have in adopting new technologies. To this aim, they use the share of workers involved in high performance work practices as a proxy measure for good managerial practices. Using in an integrated manner data from the Community ICT usage by enterprises 2010-2016 and the OECD's PIAAC survey, they find that digital adoption is more widespread in environments characterised by high quality management and skilled workers. They conclude that, in order to fasten digitalisation, policies aimed at building capabilities should be accompanied by business dynamism and efficient resource allocation.

These evidences about complementarities within the knowledge and the production functions provide some clues about the productivity puzzle. Even though ICTs have the properties of a general purpose technology, they have not yet accelerated the growth of those countries that have invested heavily in their conception and use. Inventing or adopting a technology is just a first step towards increased productivity. To realise the potential of the new technologies further step must be taken that touch upon meshing selected ICTs with existing analogue technologies, finding new organisational solutions and business model, build motivated and skilful work collective.

Bodrožić and Adler (2018) argue that up to now, by focusing on the ICT aided optimisation of the business process up and down the value chain in a context of globalisation, corporations have chosen a path favouring exploitation and short term returns to the detriment of innovativeness and long-term growth. The effort deployed at all level of the organisation to better understand dysfunctions and develop truly innovative solutions should be prioritised as it is key for long term growth. The latest developments of the high performance work practices literature (Bloom and Van Reenen, 2007; Bloom et al., 2019), inspired by management practices focusing in the improvement of operational processes such as business process reengineering, does not offer a guide towards those organisational practices likely to balance exploitation and exploration efforts. This is why, following Greenan and Napolitano (2021), we turn to the literature from organisational psychology on innovative work behaviour to build the measurement frame of the learning capacity of the organisation, a third core input complementing R&D and digital technologies in the knowledge production function.

3. DATA

Our analysis builds on the construction of a unique cross-country and cross-sector dataset that is based on the integration of EU wide surveys and that allows exploring the relations between company level decisions and characteristics of the economy, at a meso level (Greenan et al., 2022). The final dataset covers 32 countries (the EU 27 Member States, plus North Macedonia, Norway, Serbia, Turkey and UK); 11 sectors (the NACE Rev. 2 at 1-digit level, sections C to N, but with sections D and E aggregated), and 3 time periods (2010-2012, 2012-2014, 2014-2016). This wide country and sectoral coverage allows to take into account those differences due to the market structure, the policy drivers and the macroeconomic patterns that shape the technological transformation.

Another key characteristic of the constructed dataset is that it gathers information both at the employers' and the employees' level from three different surveys, taking advantage of the richness of having two different and complementary sources of information. It covers enterprises with more than 10 employees and employees in the same size-class of enterprises. Table 1 summarises the sources of data and the related key measures that they provide. The first enterprise level source is the Community ICT usage and e-commerce in enterprises (Eurostat), which yearly provides direct measures on the use of Information and Communication Technologies and e-commerce in European enterprises. It is a central survey to measure the digital revolution. Because of confidentiality issues, Eurostat releases only the aggregated data at the country and sector level. We gather data about the adoption rates, at the country-sector-year level as well as at the European level, of a number of specific technologies and we construct a synthetic indicator of technology adoption and use.

The second enterprise level source is the Community Innovation Survey (CIS, Eurostat), carried out every two years. It provides information on different types of innovation outputs, defined on the basis of the conceptualisation provided by the Oslo Manual (OECD/Eurostat, 2005), as well as on various aspects concerning the companies' innovation activity, such as the cooperation with other organisations or the provision of public funding. We use these data to identify the innovation outputs as well as some controls for our models. The aggregated dataset provided by Eurostat ensures a EU-wide coverage and a fine (at 2-digit) sectoral level information. While the CIS also provides information about R&D expenditure, we prefer to use another specific source from Eurostat, the Statistics on Business enterprise expenditure on R&D (BERD by NACE Rev. 2 activity). The level of information from this source is more complete because data are collected through random samples or censuses, as well as from administrative registers or through a combination of sources and the information is provided on a yearly basis.

The third source is the European Working Conditions Survey (EWCS, Eurofound), which is targeted to employees or self-employed individuals. It is a reference survey for mapping and following up in time forms of work organisation (Holm and Lorenz, 2015) or critical dimensions of work (Greenan et al., 2014) across Europe. In the absence of employer-level surveys that track the use of new management tools and organisational practices over time, the EWCS is an essential survey for understanding the forms of work organisation that stimulate creativity, human development through improved skills and meaningful work, and feelings of trust and fairness. We use this source of information to construct an indicator of the learning capacity of the organisation.

The three datasets are used in an integrated manner. We combine them through a "common cell", constructed on key variables (country, sector and year) present in all the surveys and harmonised[1]. Even though we aimed at obtaining the largest coverage, we had to face limitations for two main reasons. First, the revision of the NACE classification of industries in 2008 imposed a starting date in 2008, as the information available in the surveys did not allow bridging the NACE Rev. 1 with the NACE Rev. 2. Second, the Community ICT usage and e-commerce in enterprises survey does not provide sector data at the 2-digit level, but only for a grouping of sectors in between the 1- and the 2-digit levels. Nevertheless, we have chosen not to use this finer grouping of sectors because, since in the CIS not all sectors are considered core[2], more detailed sectoral information goes hand in hand with heterogeneous coverage across countries. Still, the final dataset presents a number of missing values originating from the employer level surveys, mainly due to the harmonisation and confidentiality rules applied by Eurostat (see Table A3 in Appendix for the number of observations and summary statistics of the selected variables).

Table 1: Key measures and related sources of data

	Measures	Source of data	Available years	Level of information
INPUTS at t-2	R&D expenditures	Statistics on Business enterprise R&D expenditure (aggregated data, Eurostat)[3]	2010, 2012, 2014	Employers
	Digital technology adoption and use	Community survey on ICT usage and e-commerce in enterprises (aggregated data, Eurostat)[4]	2010, 2012, 2014	Employers
	Learning capacity	European Working Condition Survey (EWCS, Eurofound)	2010, (2012 imputed), 2015	Employees
OUTPUTS at t	Innovation outputs	Community Innovation Survey (aggregated data, Eurostat)[5]	Δ2010-2012 Δ2012-2014 Δ2014-2016	Employers

[1] See table A1 in appendix for information on the coverage of each surveys and table A2 for the geographical groups that are considered.
[2] Core sectors are mandatorily included in the survey. They are: manufacture industries and construction (NACE B to E); wholesale trade (NACE G46); and some services sectors (NACE H, J, K and M71 to M73).
[3] https://ec.europa.eu/eurostat/databrowser/view/rd_e_berdindr2/default/table?lang=en
[4] https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database
[5] https://ec.europa.eu/eurostat/web/science-technology-innovation/data/database

4.INDICATORS AND FIRST DESCRIPTIVE EVIDENCE

4.1 Digital technology adoption and use indicator

Digital technology is pervasive and it is rapidly being adopted by organisations, even if with significant differences depending on their nature (Yoo et al., 2012). Table 2 gives the diffusion rates at the EU level and their evolution from 2010 to 2014. There are also significant differences across countries and industries (Remes et al., 2018). Figure 1 shows that even for mature technologies such as the access to the internet, in some sector-country observations the rate of diffusion remains relatively low (the minimum is 67%). For other technologies such as mobile broadband connection, technologies for online purchase, customer relationship management software or social networks the range is close to 90%, pointing to large inequalities in diffusion across sectors and countries.

Table 2: The Digital technology adoption and use dimensions and diffusion rates at the EU level in 2010, 2012 and 2014

			EU diffusion rates *(imputations in italic)*		
			2010	**2012**	**2014**
Basic technologies	**E-commerce**	Enterprises purchasing online	37%	34%	38%
		E-commerce sale (web sales)	15%	16%	18%
	Connection technologies	Access to the Internet	94%	95%	97%
		Fixed broadband access	84%	90%	92%
		Mobile broadband connection (3G modem or 3G handset)	27%	49%	64%
	Web and Social media technologies	Website or Home Page	67%	71%	74%
		Use social networks (e.g. Facebook, LinkedIn, Xing, Viadeo, Yammer, etc.)	*0%*	*16,5%*	33%
	E-business technologies	ERP (Enterprise Resource planning) software package to share information between different functional areas	21%	22%	31%
		Customer Relationship Management (CRM)	25%	*27,5%*	30%
Emerging technologies	**Cloud computing**	High CC services (accounting software applications, CRM software, computing power)	*0%*	*4,5%*	9%
		Medium CC services (e-mail, office software, storage of files, hosting of the enterprise's database)	*0%*	*4,5%*	9%

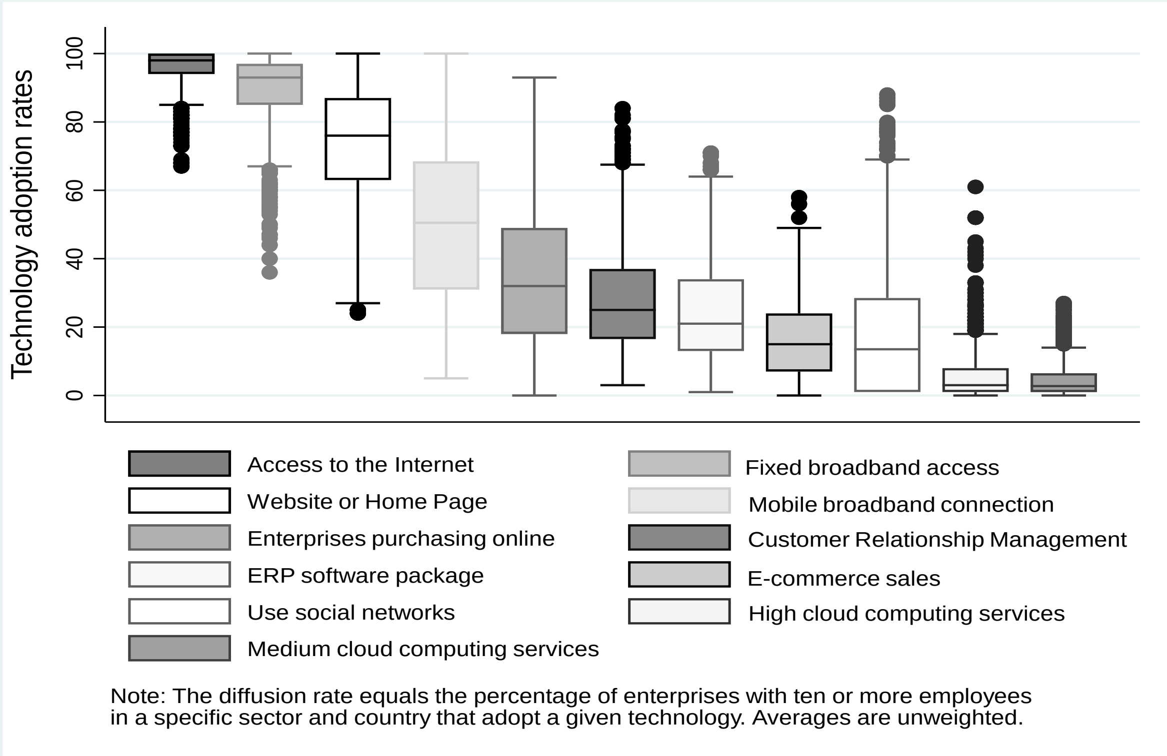
Source: Beyond 4.0 integrated database CIS-CICT-ECWS (2010, 2012 and 2014)
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

We construct a synthetic indicator of Digital technology adoption and use through the available direct measures of digital technology use from the Community ICT usage and e-commerce by enterprises. With the aim to distinguish between basic and emerging technologies, we analysed the surveys' questionnaires from 2010 to 2016. Some questions are not asked in every edition; others are introduced to take into account novel technologies while others are dropped because the technology had reached its exhaustion point. Indeed, empirical evidence shows that a new technology (an innovation) is usually adopted at a low rate in the early stage of its diffusion process, followed by an increasing rate favoured by accelerated improvements until market saturation (Perez, 2010).

As we are interested in 2010, 2012 and 2014, the selection of variables is driven by the data availability for these three years. When possible, we impute missing values, first, by replacing the missing value by the previous or following non-missing observation, second, by extrapolating the mean between the previous and following non-missing observations.

Then, we calculate indicators of digital intensity, taking into account both the use and the novelty of the technology: the percentage of enterprises that adopted the technology in a given industry within a country is weighted using the inverse of the European diffusion rate for each technology in 2010, which proxies its technological intensity. In so doing, those technologies that are reaching their exhaustion point have lower weights, while emerging technologies have higher ones. As shown in table 2, the diffusion rate for cloud computing and social networks in 2010 and 2012 are in italic. This is because these technologies were not yet included in the questionnaire. Questions about them appear for the first time in 2014. We imputed the maximum weight for these emerging technologies in 2010, as they had a null diffusion rate, and the inverse of the mid-value between 0 and the diffusion rate of 2014 for 2012.

Figure 1: Diffusion rate of different digital technologies at the country-sector level



Source: Beyond 4.0 integrated database CIS-CICT-ECWS (2010, 2012 and 2014)
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

The overall Digital technology adoption and use index is the sum of the indicators built for each of the five sub-dimensions of digital technologies identified in table 2. It equals the normalised sum of the weighted rates of technology diffusion at the country-sector level. It varies from 0.41 to 95.22 according to the within sector rate of diffusion of the set of ICTs and digital technologies and to its degree of novelty[6].

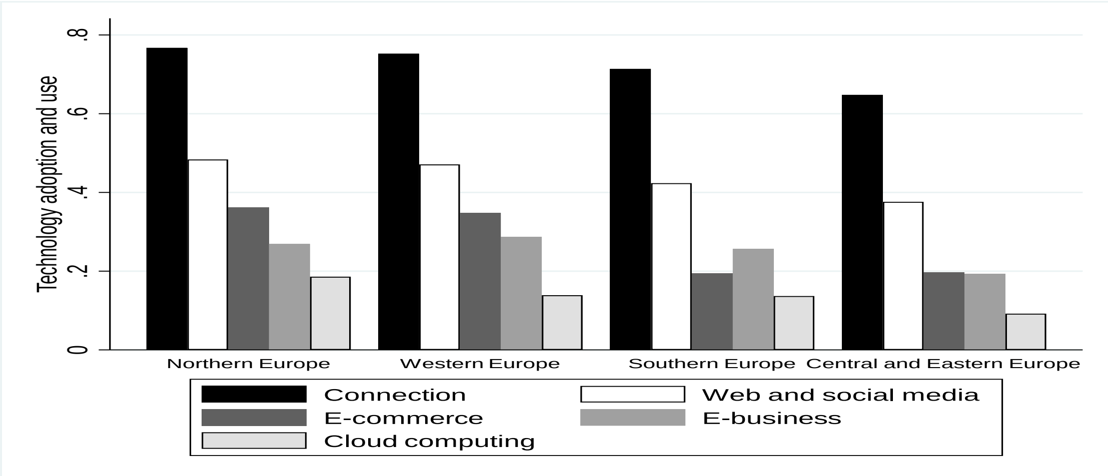
In figure 2, we observe the distribution of the Digital technology adoption and use indicator between different geographical groups[7]. The ranking of the sub-dimensions does not change considerably between these groups: connecting technologies are the most widely spread followed by web and social media, e-commerce, e-business and cloud computing. One exception is however noticeable: e-business technologies (ERP and CRM) are relatively more diffused in southern, central and eastern Europe as they rank third in the first geographical group and are as spread as e-commerce in the second. When we consider the overall indicator, Northern and Western countries show higher average levels than Southern and Central and Eastern countries. As well, when looking at the evolution of the indicator between 2010 and 2014, we see that *Digital technology adoption and use* is rapidly increasing in all groups of countries with one difference. In Northern and Western Europe, this rise was quite steady when sectors in Southern,

[6] See summary statistics in table A3 and A4 in the appendix.
[7] Table A2 in appendix gives the composition of geographical groups.

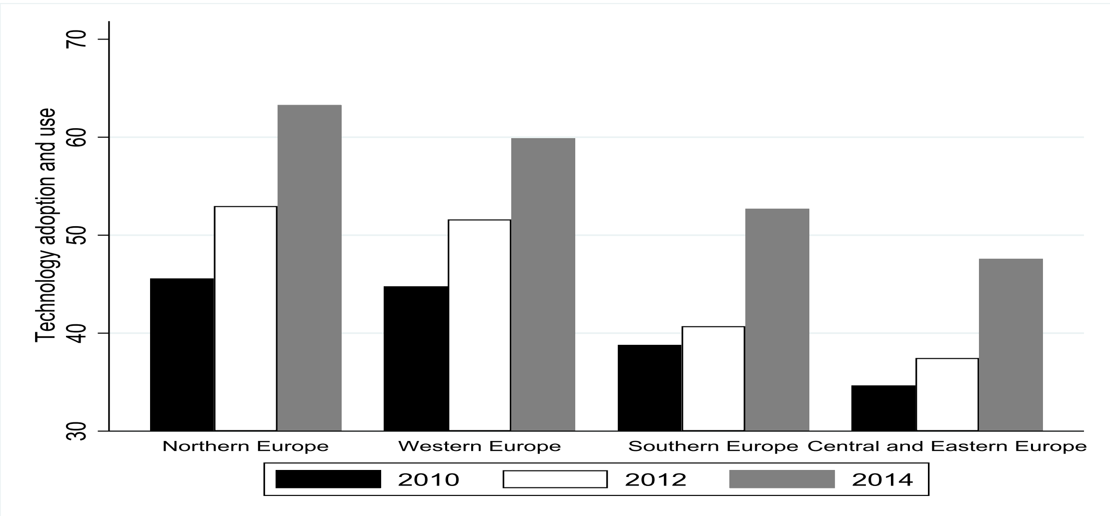
Central and Eastern Europe seem to catch up in 2014 after a sluggish growth between 2010 and 2012.

Figure 2: Average Digital technology adoption and use indicator…

… by geographical groups



… ***in time***



Source: Beyond 4.0 integrated database CIS-CICT-ECWS (2010, 2012 and 2014)
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

5.LEARNING CAPACITY INDICATOR

We develop the *Learning capacity* indicator to measure the ability of an organisation to develop management tools and organisational practices aimed at improving individual and organisational learning. We refer to the notion of "learning organisation", defined as an entity capable of adapting and competing at low cost through learning. A learning organisation promotes the individual learning of workers by encouraging them to develop innovative work behaviours, fostering their autonomy and initiative, and providing training opportunities. Furthermore, through its organised framework, knowledge is also shared and distributed among members, a culture of innovation is supported, and trade-offs between the competing goals of exploration and exploitation are resolved through a dynamic process of strategy renewal (Greenan and Lorenz, 2010; Greenan and Napolitano, 2021).

The indicator is constructed with data from the EWCS 2010 and 2015. We identify eight sub-dimensions of the learning capacity of an organisation in line with the organisational psychology approach about innovative work behaviour and workplace innovation (Janssen et al., 2004; Jerez-Gómez et al., 2005; Costantini et al., 2017).

1. The cognitive dimension of work, which measures whether workers' job involves solving unforeseen problems, performing complex tasks and learning new things;
2. Training opportunities, which measure whether workers' undergone on-the-job training or training paid for or provided by the employer to improve their skills;
3. Autonomy of worker, which measures whether workers' job involves assessing the quality of own work and applying own ideas in work;
4. Motivation, which measures whether the employee agrees that the organisation motivates workers;
5. Autonomous teamwork, which measures whether, when teamwork is implemented, the team members decide by themselves for the task division, for the head of the team and for the timetable;
6. Direct help and support, which measures whether colleagues and management provide help and support;
7. Supportive supervisory style, which measures whether the manager/supervisor provides feedback on work, respects worker as a person and is good at resolving conflicts;
8. Participation, which measures whether the worker has a say in choice of working partners, is consulted to set targets, is involved in improving work processes and can influence decisions.

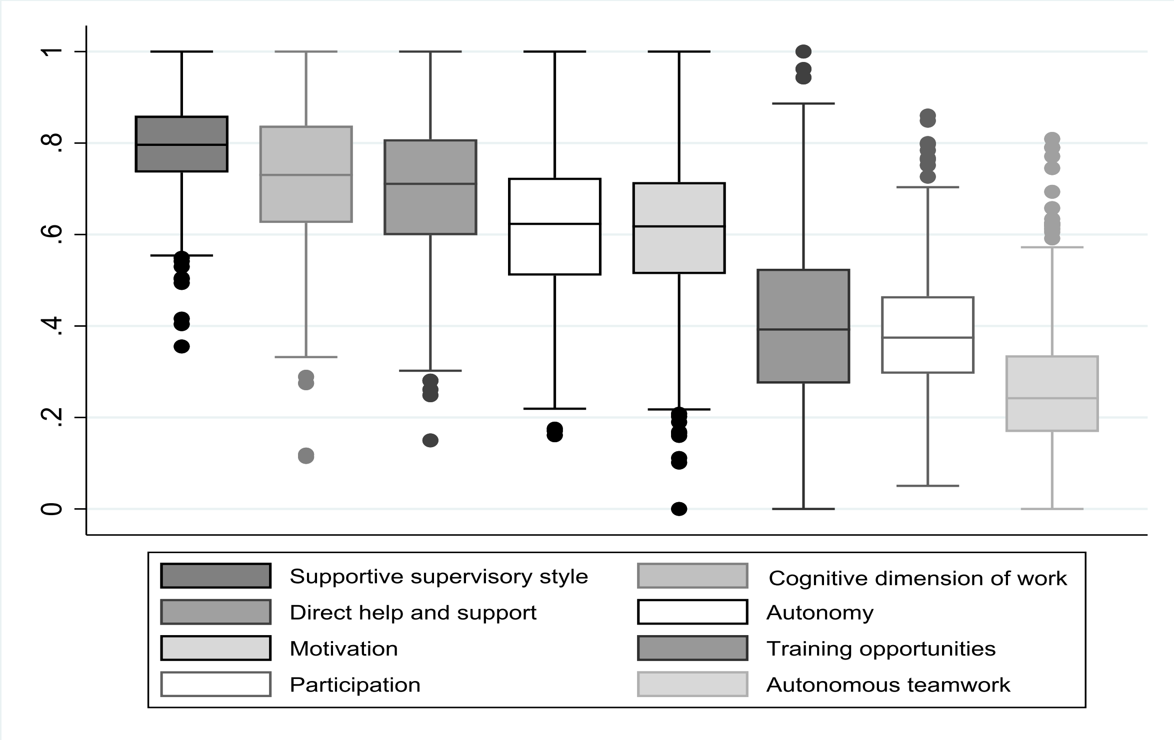
The *Learning capacity* indicator is constructed at the individual level, on the population of workers employed in organisations with more than 10 employees. Every variable that enter a sub-dimension is transformed (when necessary) in dummies[8]. The composite indicator equals the normalised sum of the 8 sub-dimensions, where each dimension has the same weight. The Cronbach's alpha coefficient among the sub-dimensions equals 0.80, suggesting that the items have relatively high internal consistency[9].

We then proceed with the aggregation of data at "common cell" level. As the EWCS provides two points in time, the 2010 and the 2015, we imputed the *Learning capacity* indicator's values for the 2012-2014 period as the midpoint between the two. The final *Learning capacity* indicator equals the average learning capacity in a specific country-

[8] Table A6 in appendix give the list of used variables and recodifications.
[9] See summary statistics and correlation matrix in tables A7 and A8 in the appendix.

sector-year level. Values vary from 29.62 to 88.89 (table A8 in the appendix) and figure 3 shows that there is great variation between different sector-country observations.

Figure 3: Distribution of the learning capacity sub-dimensions at the country-sector level

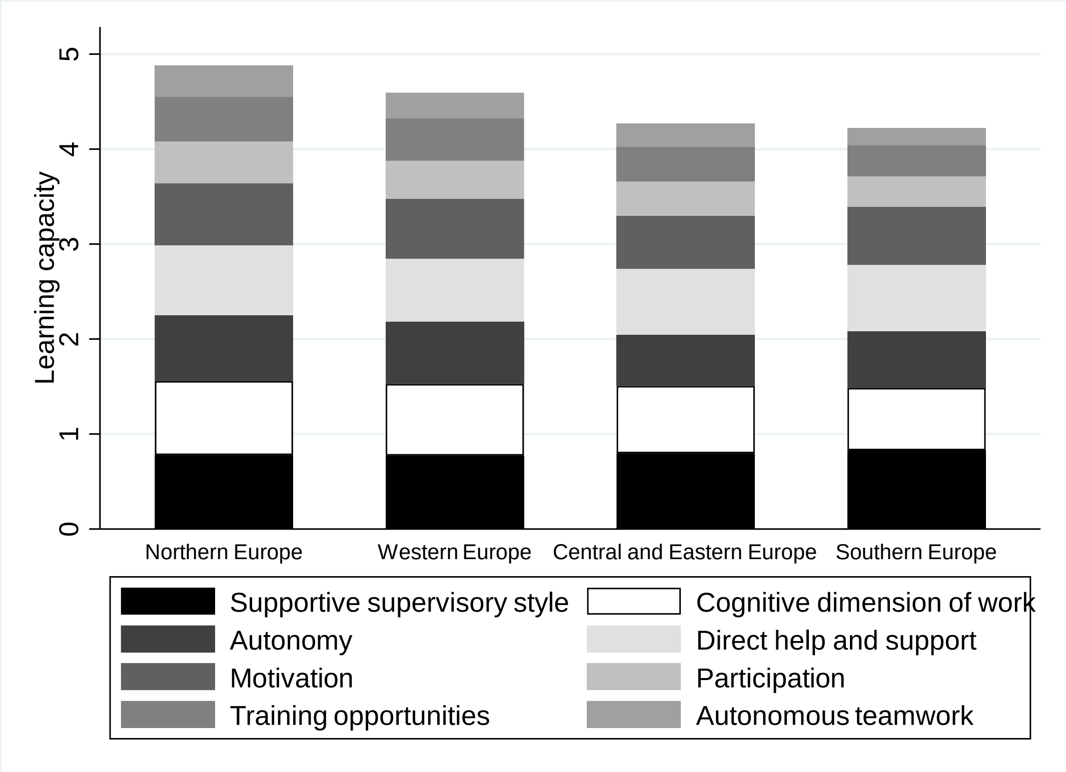


Source: Beyond 4.0 integrated database CIS-CICT-ECWS (2010, 2015)
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

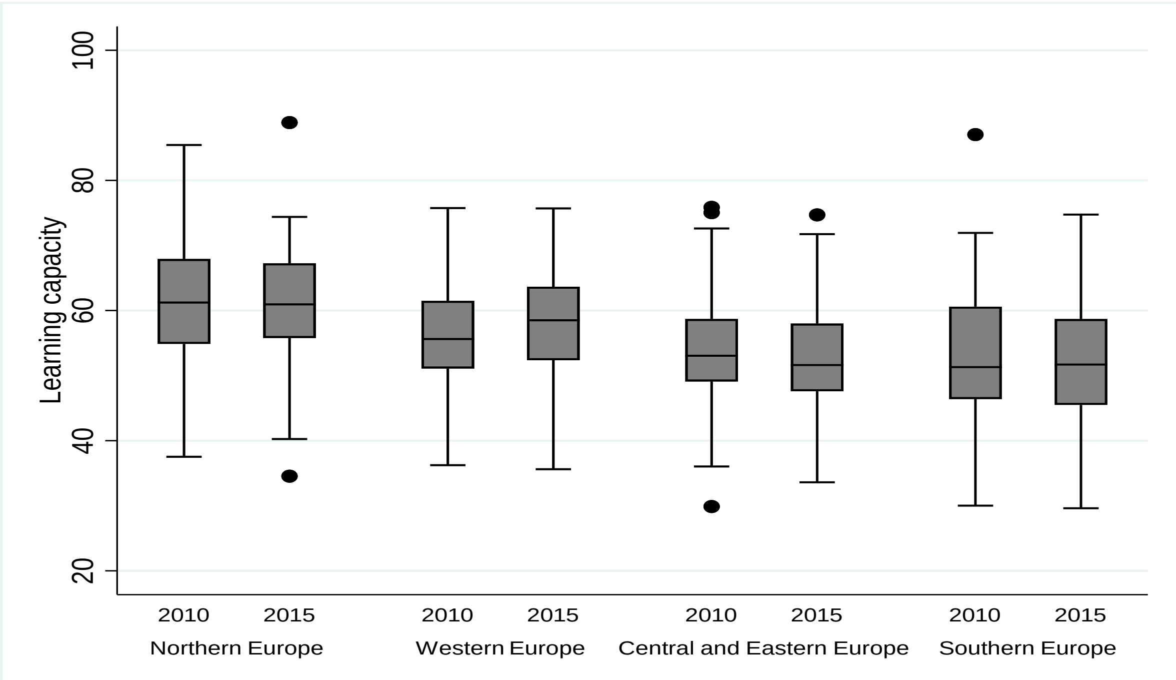
Figure 4 gives the distribution of the *Learning capacity* indicator between geographical groups. First, the ranking of the sub-dimensions is similar within the different groups; second, Northern and Western countries have higher average levels of *Learning capacity* than Central and Eastern and Southern countries. When looking at the evolution of the indicator between 2010 and 2015, we further note the stagnation of the average level of Learning capacity in the four geographical groups.

Figure 4: Average Learning capacity indicator …

… by geographical groups



… in time



Source: Beyond 4.0 integrated database CIS-CICT-ECWS (2010, 2015)
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

6.ECONOMETRIC ANALYSIS

We measure econometrically the determinants of innovation outputs, describing a knowledge production function where inputs determine innovation outputs.

The adopted specifications of the model are the following:

I. $Inno_{ijt} = \beta_0 + \beta_1 R\&D_{ijt-2} + \beta_2 Tech_{ijt-2} + \varepsilon_{ijt}$

II. $Inno_{ijt} = \beta_0 + \beta_1 R\&D_{ijt-2} + \beta_2 Tech_{ijt-2} + \beta_3 Learn_{ijt-2} + \varepsilon_{ijt}$

III. $Inno_{ijt} = \beta_0 + \beta_1 R\&D_{ijt-2} + \beta_2 Tech_{ijt-2} + \beta_3 Learn_{ijt-2} + \beta_6 X_{ijt} + \varepsilon_{ijt}$

IV. $Inno_{ijt} = \beta_0 + \beta_1 R\&D_{ijt-2} + \beta_2 Tech_{ijt-2} + \beta_3 Learn_{ijt-2} + \beta_4 Learn_{ijt-2} * Tech_{ijt-2} + \beta_5 R\&D_{ijt-2} * Tech_{ijt-2} + \beta_6 X_{ijt} + \varepsilon_{ijt}$

Where *i* are sectors according to the NACE Rev. 2 classification at 1-digit level, *j* are countries and *t* is time. In the first specification, we only include R&D and the Digital technology adoption and use indicator, while we augment the second one with the Learning capacity indicator which is original with respect to the literature about the determinants of innovation. In a third specification, we included some controls. In a fourth specification, we add the interaction terms between the Learning capacity and the Digital technology adoption and use indicators and between R&D and the Digital technology adoption and use indicator. All specifications include as controls country and time dummies as well as a dummy differentiating between the secondary (industry and construction) and tertiary (services) sectors.

The variable $Inno_{ijt}$ represents the sector level share of enterprises in a given country that introduced a new or significantly improved product, production process, organisational method, marketing concept or strategy between three different periods: 2010-2012, 2012-2014 and 2014-2016. It may stand as well for the share of enterprises which introduced a combination of different types of innovation outputs: product and/or process innovations regardless of organisational and marketing innovations; product and/or process innovations only; organisational and/or marketing innovations regardless of product and process innovation; organisational and/or marketing innovations only; product and/or process innovations AND organisational and/or marketing innovations. Basically these different aggregates allow to distinguish between enterprises introducing technological (product and/or process) and non-technological innovation (organisational and/or marketing innovations), as well as to identify enterprises implementing a combination of technological and non-technological innovations (OECD/Eurostat, 2005).

The explanatory variables are lagged of two years with respect to innovation outputs in order to characterise the date just before the start of the two years' innovation period. The R&D variable is the logarithm of the expenditure for research and development per employee, in thousands of euros, in the calendar year. The Tech variable is the Digital technology adoption and use indicator. The Learn variable stands for the Learning capacity indicator. X is a matrix of controls drawn from the CIS. The average size of enterprises takes into account the fact that larger enterprises may be able to invest more. The share of enterprises that receive public funding and the share of enterprises that cooperate on (product and/or process) innovation activities with other enterprises or organisations reflect the opportunities to share knowledge, to lower risks and costs and to benefit from knowledge spillovers (Mairesse and Mohnen, 2010).

We implement a Weighted Least Squares (WLS) estimator, where weights are the number of employees in the cell, in order to account for the differing sizes of industries within countries (Wooldridge, 2010). The WLS estimation improves the consistency of results. We can exclude endogeneity issue in our model as our dependent variables are two-years lagged with respect to the dependent variables. For example, when innovation refers to the period 2010-2012, inputs refer to 2010. This allows taking into account the path dependency between inputs and outputs: investments in tangible and intangible assets take time to lead to successful innovation. We can also exclude the presence of multicollinearity. The VIF (variance inflation factor) test over each regression is inferior to 10, which is the critical value for the VIF statistic in order to detect multicollinearity among independent variables (Kleinbaum et al., 1988). The Breush-Pagan test for heteroscedasticity rejects the null hypothesis for constant variance. This is why we estimate WLS with robust standard errors. The WLS results are robust across different model specifications including a number of control variables. We have also implemented an OLS baseline model with related diagnostic tests which results are reported in table A10 in the appendix. As well, we have tested the model for two different subsamples, the first one including only the secondary sectors and the second one including only the tertiary sectors. Estimations (not reported) show that our results are mostly driven by the tertiary sectors.

7.RESULTS

Table 3 shows the results of the specified models for what concerns the share of product, process, organisation and marketing innovative enterprises and in table 4 for what concern the share of enterprises that introduced combinations of technological and non-technological innovation outputs.

First, results show that R&D expenditures have a significant effect on all types of innovation outputs. This is in line with the previous literature that suggests that R&D efforts lead to successful innovation by generating new knowledge (Hall et al., 2010). In terms of magnitude, a 1 point rise in the R&D expenditure per employees increases by between 0.01 and 0.02 percentage points (pp) the share of innovative enterprises when only one type of innovation is considered (model III). Looking at the possible combinations of innovation outputs, the increase in R&D effort has a positive impact on the share of product and/or process innovative firms and on the share of organisation and/or marketing innovative firms by about 0.02 pp, independent of the introduction of other types of innovations. By contrast, it is less relevant, but still significant, for product and/or process innovative enterprises only, while it is not significant for organisation and/or marketing innovative enterprises only. Overall, a 1 point rise in R&D expenditure has a positive impact of 0.015 pp on the share of innovative enterprises introducing a combination of product and/or process innovations and organisational and/or marketing innovations (model III).

A rise of 1 point in the *Digital technologies adoption and use* index is particularly relevant for the share of product innovative enterprises, with an impact in the model III of 0.22 pp, while it is lower for the share of organisation (0.12 pp) and marketing (0.17 pp) innovative enterprises. Results are not stable across the different specified models for process innovative enterprises. Nonetheless, looking at combinations of innovations allows shedding more light in this regard: increased *Digital technology adoption and use* have positive and significant impact on the share of product and/or process innovative enterprises of 0.26 pp and on the share of organisation and/or marketing innovative enterprises of 0.19 pp, regardless any other types of innovations (model III). By contrast, for the share of product and/or process innovative enterprises only and for the share of organisation and/or marketing innovative enterprises only the effect is respectively small and non-significant. When technological and non-technological innovations are combined (as shown by the share of product and/or process innovative enterprises AND organisation and/or marketing innovative enterprises) a 1 point increase in *Digital technology adoption and use* has a positive impact of around 0.17 pp (model III). These results confirm that ICTs and digital technologies are important drivers of innovation as they enable and facilitate knowledge production.

What does the *Learning capacity* index add to this picture of the innovative activities of European enterprises? First, as one can see by comparing results of model I and II, the *Learning capacity* indicator adds information to the analysis, without considerably altering R&D and *Digital technology adoption and use* coefficients. The significant and positive effect of the *Learning capacity* indicator shows that innovation is not only a matter of having more highly qualified people dedicated to R&D activities. It also depends on having forms of work organisation favouring innovative work behaviour and creativity throughout the whole workforce.

The *Learning capacity* of the organisation is significant for all types of innovative enterprises, but it is especially relevant for the share of organisation innovative enterprises, with an impact of around 0.26 pp for a 1 point increase (model III). It also favours combinations of innovations: a 1 point increase in *Learning capacity* has a significant and positive impact of around 0.15 pp on product and/or process innovative enterprises and of 0.26 pp on organisation and/or marketing innovative enterprises (regardless any other form of innovation). It also shows a significant effect of 0.17 pp when technological and non-technological innovations are combined. By contrast, it has a minor effect on the share of non-technological innovative enterprises only (0.07 pp) while it is not significant for the share of technological innovative enterprises only (model III).

When we introduce the interaction term between *Digital technologies* and *Learning capacity* investments (Model IV), results in table 3 show that, for all types of innovative enterprises, the coefficient of the interaction term is significant. Thus scaling up the *Learning capacity* of organisations while investing in ICTs and digital technology is highly relevant for developing the innovativeness of industries. The results on the interaction terms in table 4 further confirm that a mix of technological and non-technological innovations rests on joint investments in *Digital technology adoption and use* and *Learning capacity*.

The interaction term between R&D and *Digital technology adoption and use* is also highly significant for all types of innovative enterprises, except for process innovative enterprises. It is significant and positive for technological and non-technological innovative enterprises (regardless any other type of innovation) or for a mix of them. By contrast, the coefficient is negative for non-technological enterprises only.

With respect to the controls introduced in the models, the size of enterprises has a significant and positive effect on the share of process and organisation innovative enterprises as well as on the share of enterprises introducing a mix of technological and non-technological innovations. The estimates for the share of enterprises receiving public funding is significant and positive only for the share of technological innovative enterprises and for the share of product and/or process innovative enterprises. It is instead significant but negative for the share of organisation and/or marketing innovative enterprises only. The share of enterprises engaged in cooperation for innovation activities has a positive influence on the shares of organisation innovative enterprises in table 3, while it has a negative effect on the share of product and/or process innovative enterprises in table 4. Finally, tertiary industries are characterised by higher shares of product, organisation and marketing innovative enterprises (table 3) and of non-technological innovative enterprises (table 4), but by lower share of technological innovative enterprises only (table 4).

Table 3. WLS with robust standard errors and number of employees as weights

	Share of Product innovative enterprises				Share of Process innovative enterprises				Share of Organisation innovative enterprises				Share of Marketing innovative enterprises			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
R&D exp. per employee (ln, th. euro)	2.705***	2.398***	2.203***	2.118***	1.655***	1.470***	1.259***	1.278***	1.463***	0.886***	1.184***	1.060***	1.507***	1.240***	1.300***	1.250***
	(13.01)	(11.04)	(7.82)	(7.73)	(11.03)	(9.07)	(5.66)	(5.64)	(8.55)	(5.58)	(5.49)	(5.08)	(7.59)	(6.11)	(4.96)	(4.71)
Technology adoption and use	0.265***	0.246***	0.224***	0.229***	0.079**	0.063*	0.054	0.048	0.083**	0.048	0.118***	0.122***	0.148***	0.129***	0.169***	0.170***
	(5.24)	(4.96)	(3.79)	(4.10)	(2.10)	(1.67)	(1.13)	(1.07)	(2.03)	(1.29)	(3.12)	(3.35)	(3.25)	(2.87)	(3.13)	(3.19)
Learning capacity		0.203***	0.148**	0.145**		0.164***	0.120**	0.109**		0.414***	0.262***	0.276***		0.187***	0.150***	0.147**
		(3.73)	(2.44)	(2.41)		(3.83)	(2.41)	(2.20)		(9.54)	(5.77)	(6.21)		(3.84)	(2.65)	(2.56)
Learning capacity:Technology				0.009**				0.008***				0.006**				0.006*
				(2.57)				(2.91)				(2.53)				(1.84)
R&D:Technology				0.041***				0.009				0.018**				0.022**
				(3.52)				(1.14)				(2.38)				(2.17)
Average size of enterprises			0.011	0.011			0.022***	0.023***			0.028***	0.027***			0.011*	0.011
			(1.50)	(1.46)			(3.21)	(3.23)			(3.72)	(3.69)			(1.66)	(1.62)
Share of enterprises receiving public funding			0.159***	0.104**			0.103***	0.081**			-0.001	-0.019			0.014	-0.017
			(3.41)	(2.35)			(2.80)	(2.25)			(-0.03)	(-0.56)			(0.32)	(-0.41)
Share of enterprises engaged in cooperation for innovation activities			-0.006	0.013			0.049	0.057			0.098**	0.120***			-0.014	-0.002
			(-0.11)	(0.27)			(1.13)	(1.33)			(2.40)	(3.10)			(-0.30)	(-0.05)
Tertiary sectors (ref: secondary sectors)	2.851***	2.354***	4.169***	3.309***	-1.846***	-2.433***	-0.744	-1.054	3.233***	1.813***	2.487***	1.990***	5.026***	4.449***	4.458***	4.025***
	(3.38)	(2.72)	(4.10)	(3.41)	(-2.62)	(-3.48)	(-0.90)	(-1.30)	(4.42)	(2.65)	(3.52)	(2.94)	(6.52)	(5.80)	(4.77)	(4.43)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant																
Observations	578	578	486	486	581	581	486	486	581	581	486	486	581	581	486	486
Adjusted R^2	0.600	0.600	0.623	0.651	0.731	0.757	0.742	0.736	0.665	0.696	0.770	0.760	0.592	0.598	0.551	0.560

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4. WLS with robust standard errors and number of employees as weights

	Share of Product and/or process innovative enterprises				Share of Product and/or process innovative enterprises only				Share of Organisation and/or marketing innovative enterprises				Share of Organisation and/or marketing innovative enterprises only				Share of Product and/or process AND organisation and/or marketing innovative enterprises			
	I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
R&D exp per employee (ln, th. euro)	3.072***	2.749***	2.462***	2.428***	0.856***	0.893***	0.715***	0.713***	1.874***	1.407***	1.677***	1.644***	-0.160	-0.309***	-0.133	-0.113	2.132***	1.776***	1.575***	1.523***
	(14.59)	(12.44)	(9.84)	(9.76)	(10.29)	(10.00)	(6.57)	(6.54)	(8.16)	(6.44)	(6.32)	(6.03)	(-1.58)	(-2.89)	(-1.13)	(-0.97)	(11.42)	(9.79)	(7.11)	(6.98)
Technology adoption and use	0.269***	0.248***	0.264***	0.260***	0.061***	0.064***	0.036*	0.036*	0.146***	0.087*	0.192***	0.191***	-0.0335	-0.0437*	0.0172	0.015	0.166***	0.152***	0.170***	0.175***
	(5.49)	(5.23)	(5.04)	(5.05)	(3.62)	(3.72)	(1.78)	(1.74)	(3.01)	(1.90)	(3.83)	(3.84)	(-1.50)	(-2.01)	(0.93)	(0.87)	(3.91)	(3.67)	(3.48)	(3.72)
Learning capacity		0.209***	0.151***	0.147***		-0.025	-0.021	-0.020		0.369***	0.260***	0.256***		0.100***	0.066**	0.067**		0.247***	0.172***	0.168***
		(3.94)	(2.82)	(2.72)		(-1.04)	(-0.78)	(-0.75)		(6.99)	(4.52)	(4.40)		(3.68)	(2.15)	(2.19)		(5.38)	(3.43)	(3.35)
Learning capacity:Tech.				0.007**				0.000				0.008***				-0.002				0.005*
				(2.41)				(0.27)				(2.74)				(-1.20)				(1.76)
R&D:Tech.				0.025***				0.002				0.016*				-0.009***				0.026***
				(2.87)				(0.57)				(1.67)				(-2.73)				(2.85)
Average size of enterprises			0.030***	0.030***			0.002	0.002			0.025***	0.025***			0.004	0.004			0.017**	0.017**
			(5.11)	(5.07)			(0.55)	(0.55)			(3.33)	(3.30)			(1.56)	(1.57)			(2.26)	(2.22)
Share of ent. receiving public funding			0.189***	0.153***			0.117***	0.114***			-0.021	-0.048			-0.075***	-0.063***			0.077*	0.041
			(5.43)	(4.39)			(6.00)	(5.57)			(-0.47)	(-1.14)			(-4.15)	(-3.38)			(1.95)	(1.06)
Share of ent. engaged in cooperation for innovation activities			-0.085**	-0.072**			-0.033	-0.033			0.033	0.046			0.036	0.032			0.052	0.064
			(-2.27)	(-1.97)			(-1.61)	(-1.59)			(0.70)	(0.98)			(1.57)	(1.40)			(1.26)	(1.59)
Tertiary sectors (ref: secondary sectors)	-0.886	-1.456*	1.157	0.560	-2.608***	-2.536***	-1.607**	-1.650***	3.795***	2.700***	2.625***	2.182**	1.655***	1.372***	0.557	0.746*	1.756**	1.055	2.080**	1.504*
	(-1.10)	(-1.78)	(1.20)	(0.60)	(-7.04)	(-6.76)	(-3.75)	(-3.87)	(4.41)	(3.30)	(2.78)	(2.32)	(4.25)	(3.45)	(1.38)	(1.83)	(2.57)	(1.56)	(2.52)	(1.88)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	558	558	478	478	575	575	483	483	584	584	486	486	578	578	486	486	574	574	479	479
Adjusted R^2	0.802	0.805	0.836	0.844	0.610	0.610	0.692	0.692	0.821	0.830	0.852	0.856	0.435	0.450	0.441	0.449	0.798	0.714	0.699	0.716

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

8.CONCLUSIONS

In this paper, we investigate the determinants of the innovativeness of industries across countries in a context of technological revolution based on ICTs and digital technologies. We focus on a knowledge production function - inspired by the first equation in the CDM model (Crépon et al., 1998) - to measure the effects on innovation outputs of different innovation inputs able to increase the stock of knowledge within companies. Apart from R&D and *Digital technologies adoption and use*, we introduce a new argument, the *Learning capacity* of the organisation, which proves to be a distinct and impactful dimension of the knowledge production function. We consider that this augmented knowledge production function gives a comprehensive description of the technological transformation in the digital age.

We built a unique dataset at EU-wide level to provide some first empirical evidence about the main components of this technological transformation over 2010-2016. It combines through a "common cell" which is an industry in a country in a given year, three main data sources: two employer level data sources, the Community innovation survey and the Community ICT usage and e-commerce in enterprises survey (Eurostat), and an employee level one, the European Working Conditions Survey (Eurofound). This dataset allows us to develop an enriched measurement frame of the ongoing technological transformation with three novelties: first, a synthetic indicator of *Digital technology adoption and use* that takes into account the diversity of ICTs and digital technologies as well as their innovativeness; second, a composite indicator of the *Learning capacity* of the organisation based on information gathered at the employee level; third, combined measures of technological and non-technological innovations within industries.

Data access and harmonisation issues have raised a number of problems. Nevertheless, using different sources in an integrated way represents a huge opportunity to examine simultaneously the behaviour of firms in terms of tangible and intangible investments, work and organisational practices, and their impacts on innovation.

In line with the CDM research tradition, we find that across European industries, investments in R&D are powerful drivers of all forms of innovation but are especially impactful for the share of product innovative enterprises and for the share of product and/or process innovative enterprises regardless the introduction of other types of innovations. Industries that invest in ICTs and digital technologies also show more innovativeness with one exception: the share of process innovative enterprises. Looking at combinations of innovations, ICTs and digital technologies seem impactful except for the share of product and process innovative enterprises only and for the share of organisation and/or marketing innovative enterprises only.

The *Learning capacity* of the organisation, built on the creative capabilities of the whole workforce, appears as a third vital force of the innovativeness of industries, with a stronger direct influence on organisational innovation and non-technological forms of innovation (regardless any other type of innovation).

The paper also provides evidence of synergetic effects between investments in ICTs and digital technologies and in the learning capacity of organisations. Indeed, interaction effects between these two domains of investment are significant across all forms of innovation. It is also particularly impactful for the non-restricted combined forms of technological, non-technological and both technological and non-technological innovations, which are likely to be the most innovative ones in the digital age.

Complementarities are also found between R&D and ICTs and digital technologies adoption and use, for all types of innovative enterprises with the exception of process innovations. Also in this case, results points to the fact that a mix of technological and non-technological innovations rests on joint investments for R&D and digital technologies.

However, the descriptive evidence provides a cautionary tale with policy implications. While the adoption of ICTs and digital technologies has steadily increased in European industries between 2010 and 2016, the average learning capacity of European organisations has remained stagnant. To meet the upcoming challenges of enhancing social foundations of nations in the boundaries of the ecological ceiling (Raworth, 2017), public authorities should be concerned with the means to give a new impetus to the learning capacity of organisations.

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10.APPENDIX

Table A1: Surveys' coverage and common cells

Survey	Editions/years	Country coverage	Sectoral coverage
Community survey on ICT usage and e-commerce in enterprises (aggregated data, Eurostat)	2010 - 2016	EU-27, UK, Norway, Serbia, Turkey, Iceland, North Macedonia.	NACE Rev. 2 sections C to N, plus S, at 1-digit level. Sub-aggregates are available for section C (C10-12, C10-18, C10-33, C13-15, C16-18, C19-22, C19-23, C23-25, C24-25, C26, C26-33, C27-28, C29-30, C31-33), G (G45, 46 and 47); J (I55 and 56; J58-69, J61, J62-63); and K (K64, 65 and 66). From 2014, the financial sector (K) is not covered anymore. Data about sectors D and E are provided only coupled. For some sectors (section C, G, I, J), data are finer grained in sub-aggregates.
Community Innovation Survey (aggregated data, Eurostat)	2010, 2012, 2014, 2016	EU 27, UK, Norway, Serbia, Turkey, Iceland, Switzerland, North Macedonia and, from 2016, Montenegro	NACE Rev. 2 sections A to N, 2-digit level
European Working Condition Survey (EWCS, Eurofound)	2010, 2015	EU27, UK, Albania, North North Macedonia, Montenegro, Serbia, Turkey, Norway and Switzerland	NACE Rev. 2 all sections, 2-digit level

Note: The common coverage among the three dataset is of 32 countries (the 28 Member States plus North Macedonia, Norway, Serbia, Turkey and UK); 11 sectors (the NACE Rev. 2 at 1-digit level, sections C to N, but with sections D and E aggregated), and 3 time periods (2010-2012, 2012-2014, 2014-2016). North Macedonia has only 2 time periods, since CIS data was first collected in 2014. Sector L is missing in some countries and for some years. Because of these missing cells, the actual number of observations in the final dataset is of 1.056.

Table A2: List of countries by geographical groups

NORTHERN EUROPE	WESTERN EUROPE	CENTRAL AND EASTERN EUROPE	SOUTHERN EUROPE
Denmark Estonia Finland Lithuania Latvia Norway Sweden	Austria Belgium Germany France Ireland Luxembourg Netherlands United Kingdom	Bulgaria Czech Republic Croatia Hungary Poland Romania Serbia Slovenia Slovakia North Macedonia	Cyprus Greece Spain Italy Malta Portugal Turkey

Table A3: Summary statistics of selected variables

Variable	Number of observations	Mean	Std. Dev.	Min	Max
Share of product innovative enterprises	715	21.07	13.25	0.20	66.10
Share of process innovative enterprises	718	22.20	11.35	1.50	75.65
Share of organisation innovative enterprises	718	27.02	12.10	0.00	66.65
Share of marketing innovative enterprises	718	22.91	11.61	0.00	61.55
Share of product and/or process innovative enterprises	687	35.24	16.83	1.55	80.30
Share of product and/or process innovative enterprises only	709	10.31	6.13	0.00	34.70
Share of organisation and/or marketing innovative enterprises	721	34.69	14.00	0.00	73.60
Share of organisation and/or marketing innovative enterprises only	712	12.36	5.48	0.00	29.70
Share of product and/or process AND organisation and/or marketing innovative enterprises	697	21.64	11.85	0.00	67.95
R&D exp. per employee (ln, th. euro)	651	2.00	3.49	0.00	23.10
Technology adoption and use	947	46.39	16.54	0.41	95.22
Learning capacity	981	55.72	9.09	29.62	88.89
Enterprise size	708	85.42	77.31	13.96	1012.61
Share of enterprises receiving public funding	613	23.11	14.66	0.00	65.00
Share of enterprises engaged in cooperation for innovation activities	712	35.39	16.44	0.00	82.50

Source: Beyond 4.0 integrated database CIS-CICT-ECWS (2010, 2012 and 2014)
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

Table A4: Digital technology adoption and use: summary statistics

Variable	Number of observations	Mean	Std. Dev.	Min	Max
Digital technology adoption and use synthetic indicator	***947***	***46.39***	***16.54***	***0.41***	***95.22***
E-commerce	842	27.55	15.55	0	74.86
Connection	907	71.74	16.62	4.68	100
Web and social media	925	43.61	16.35	0	92.44
E-business	897	24.93	13.67	1.50	76.00
Cloud computing	867	13.52	14.88	1.55	89.46

Source: Beyond 4.0 integrated database CIS-CICT-ECWS (2010, 2012 and 2014)
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

Table A5: Digital technology adoption and use: correlation matrix

	Technology adoption and use	**E-commerce**	**Connection**	**Web and social media**	**E-business**	**Cloud computing**
Technology adoption and use	1.00					
E-commerce	0.72	1.00				
Connection	0.88	0.47	1.00			
Web and social media	0.89	0.58	0.72	1.00		
E-business	0.78	0.55	0.60	0.59	1.00	
Cloud computing	0.75	0.35	0.59	0.73	0.47	1.00

Source: Beyond 4.0 integrated database CIS-CICT-ECWS (2010, 2012 and 2014)
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

Table A6: Learning capacity indicator composition

SUB-DIMENSION	SURVEY QUESTIONNAIRE (2015's version)	ORIGINAL VARIABLES	RECODIFICATION CRITERIA
Cognitive dimension of work	Q53c - Generally, does your main paid job involve ...? **C - solving unforeseen problems on your own**	variable Q49C for 2010 and variable Q53C for 2015	Yes =1 No =0
	Q53e- Generally, does your main paid job involve ...? **E - complex tasks**	variable Q49E for 2010 and variable Q53E for 2015	Yes =1 No =0
	Q53f - Generally, does your main paid job involve ...? **F - learning new things**	variable Q49F for 2010 and variable Q53F for 2015	Yes =1 No =0
Training opportunities	Q65a - Over the past 12 months, have you undergone any of the following types of training to improve your skills? **A - Training paid for or provided by your employer**	variable Q61A for 2010 and variable Q65A for 2015	Yes =1 No =0
	Q65c - Over the past 12 months, have you undergone any of the following types of training to improve your skills? **C - On-the-job training (co-workers, supervisors)**	variable Q61C for 2010 and variable Q65C for 2015	Yes =1 No =0
Autonomy	Q61i - For each of the following statements, please select the response which best describes your work situation. **I - You are able to apply your own ideas in your work**	variable Q51I for 2010 and variable Q61I for 2015	Always =1 Most of the time =1 Sometimes =0 Rarely =0 Never =0
	Q53b - Generally, does your main paid job involve ...? **B - assessing yourself the quality of your own work**	variable Q49B for 2010 and variable Q53B for 2015	Yes =1 No =0
Motivation	Q89e - To what extent do you agree or disagree with the following statements about your job? **E - The organisation I work for motivates me to give my best job performance**	variable Q77Gfor 2010 and variable Q89E for 2015	Strongly agree =1 Tend to agree =1 Neither agree nor disagree =0 Tend to disagree =0 Strongly disagree =0
Autonomous teamwork	Q58 - Do you work in a group or team that has common tasks and can plan its work?	variable Q56 for 2010 and variable Q58 for 2015	Yes =1 No =0 In 2010, Yes, always in the same one =1 Yes, in several =1 I do not work in such a team or group =0
	Q60b - For the team in which you work mostly, do the members decide by themselves…? **B - … who will be head of the team**	variable Q57B for 2010 and variable Q60B for 2015	Yes =1 No =0
	Q60a - For the team in which you work mostly, do the members decide by themselves…? **A - … on the division of tasks**	variable Q57A for 2010 and variable Q60A for 2015	Yes =1 No =0
	Q60c - For the team in which you work mostly, do the members decide by themselves…? **C - … the timetable of the work**	variable Q57C for 2010 and variable Q60C for 2015	Yes =1 No =0

Table A6: Learning capacity indicator composition (continued)

SUB-DIMENSION	SURVEY QUESTIONNAIRE (2015's version)	ORIGINAL VARIABLES	RECODIFICATION CRITERIA
Direct help and support	Q61a - For each of the following statements, please select the response which best describes your work situation. **A -Your colleagues help and support you**	variable Q51A for 2010 and variable Q61A for 2015	Always =1 Most of the time =1 Sometimes =0 Rarely =0 Never =0
	Q61b - For each of the following statements, please select the response which best describes your work situation. **B - Your manager helps and supports you**	variable Q51B for 2010 and variable Q61B for 2015	Always =1 Most of the time =1 Sometimes =0 Rarely =0 Never =0
Supportive supervisory style	Q63E - Your immediate boss… **E - provides useful feedback on your work**	variable Q58A for 2010 and variable Q63E for 2015	Strongly agree =1 Tend to agree =1 Neither agree nor disagree =0 Tend to disagree =0 Strongly disagree =0 In 2010, Yes=1, No=0
	Q63A - To what extent do you agree or disagree with the following statements? Your immediate boss… **A - respects you as a person**	variable Q58B for 2010 and variable Q63A for 2015	Strongly agree =1 Tend to agree =1 Neither agree nor disagree =0 Tend to disagree =0 Strongly disagree =0 In 2010, Yes=1, No=0
	Q63c - Your immediate boss… **C - is successful in getting people to work together** In 2010, In general, your immediate manager / supervisor …. **Is good at resolving conflicts**	variable Q58C for 2010 and variable Q63C for 2015	Strongly agree =1 Tend to agree =1 Neither agree nor disagree =0 Tend to disagree =0 Strongly disagree =0 In 2010, Yes=1, No=0
Participation	Q61e - For each of the following statements, please select the response which best describes your work situation. **E - You have a say in the choice of your work colleagues**	variable Q51E for 2010 and variable Q61E for 2015	Always =1 Most of the time =1 Sometimes =0 Rarely =0 Never =0
	Q61c - For each of the following statements, please select the response which best describes your work situation. **C - You are consulted before objectives are set for your work-**	variable Q51C for 2010 and variable Q61C for 2015	Always =1 Most of the time =1 Sometimes =0 Rarely =0 Never =0
	Q61d - For each of the following statements, please select the response which best describes your work situation. **D - You are involved in improving the work organisation or work processes of your department or organisation**	variable Q51D for 2010 and variable Q61D for 2015	Always =1 Most of the time =1 Sometimes =0 Rarely =0 Never =0
	Q61n - For each of the following statements, please select the response which best describes your work situation. **N - You can influence decisions that are important for your work**	variable Q51O for 2010 and variable Q61N for 2015	Always =1 Most of the time =1 Sometimes =0 Rarely =0 Never =0

Table A8: Learning capacity indicator sub-dimensions: summary statistics

Variable	**Number of observations**	**Mean**	**Std. Dev.**	**Min**	**Max**
Learning capacity composite indicator	***656***	***55.75***	***9.43***	***29.62***	***88.89***
Cognitive dimension of work	656	72.56	14.59	11.37	100
Training opportunities	656	40.17	17.66	0	100
Autonomy	656	61.75	15.01	16.11	100
Motivation	656	60.84	16.37	0	100
Autonomous teamwork	656	25.64	13.34	0	80.91
Direct help and support	656	69.74	14.62	14.99	100
Supportive supervisory style	656	79.37	9.99	35.53	100
Participation	656	38.10	13.20	5.05	86.01

Source: Beyond 4.0 integrated database CIS-CICT-ECWS, 2010 and 2015
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

Table A9: Learning capacity indicator sub-dimensions: summary statistics

	Learning capacity	**Cognitive dim. of work**	**Training opp.**	**Auton.**	**Motiv.**	**Auton. Teamwork**	**Direct help & support**	**Supportive sup. style**	**Particip.**
Learning capacity	***1.00***								
Cognitive dimension of work	***0.70***	1.00							
Training opportunities	***0.63***	0.53	1.00						
Autonomy	***0.76***	0.55	0.38	1.00					
Motivation	***0.65***	0.24	0.26	0.40	1.00				
Autonomous teamwork	***0.58***	0.43	0.27	0.44	0.14	1.00			
Direct help and support	***0.61***	0.22	0.18	0.30	0.43	0.27	1.00		
Supportive supervisory style	***0.42***	0.07	0.06	0.18	0.46	0.05	0.39	1.00	
Participation	***0.80***	0.55	0.39	0.68	0.44	0.46	0.43	0.23	1.00

Source: Beyond 4.0 integrated database CIS-CICT-ECWS, 2010 and 2015
Coverage: EU27 plus North Macedonia, Norway, Serbia, Turkey and UK, enterprises with more than 10 employees in NACE Rev. 2 1-digit sectors C to N, D-E aggregated.

Table A10: OLS baseline model specification

	Share of Product innovative enterprises		Share of Process innovative enterprises		Share of Organisation innovative enterprises		Share of Marketing innovative enterprises	
R&D exp per employee (ln, th. euro)	2.550*** (11.11)	2.341*** (10.31)	1.965*** (8.71)	1.336*** (7.43)	1.752*** (7.99)	0.989*** (5.50)	1.586*** (7.13)	1.226*** (6.16)
Technology adoption and use	0.205*** (5.88)	0.250*** (6.30)	0.0721** (2.10)	0.0726** (2.29)	0.070** (2.11)	0.066** (2.09)	0.119*** (3.53)	0.134*** (3.83)
Learning capacity	0.141** (2.51)	0.210*** (3.56)	0.0443 (0.80)	0.172*** (3.67)	0.249*** (4.64)	0.400*** (8.51)	0.142*** (2.61)	0.185*** (3.56)
Tertiary sectors		2.716*** (3.25)		-2.118*** (-3.18)		1.767*** (2.66)		4.761*** (6.47)
Country dummies		Yes		Yes		Yes		Yes
Time dummies		Yes		Yes		Yes		Yes
Constant	5.642* (1.65)	5.349 (1.27)	18.34*** (5.45)	21.12*** (6.32)	10.84*** (3.31)	15.35*** (4.59)	10.37*** (3.12)	13.40*** (3.63)
Observations	578	581	581	581	581	581	581	578
Adjusted R^2	0.588	0.201	0.649	0.255	0.654	0.216	0.567	0.588

	Share of Product and/or process innovative enterprises		Share of Product and/or process innovative enterprises only		Share of Organisation and/or marketing innovative enterprises		Share of Organisation and/or marketing innovative enterprises only		Share of Product and/or process AND organisation and/or marketing innovative enterprises	
R&D exp per employee (ln, th. euro)	3.987*** (13.42)	2.672*** (12.88)	1.130*** (10.25)	0.890*** (9.07)	2.359*** (9.41)	1.474*** (7.22)	0.054 (0.47)	-0.280*** (-2.70)	2.080*** (9.73)	3.987*** (13.42)
Technology adoption and use	0.092** (2.06)	0.253*** (7.07)	0.046*** (2.72)	0.066*** (3.84)	0.104*** (2.75)	0.102*** (2.85)	-0.029* (-1.69)	-0.046** (-2.53)	0.123*** (3.81)	0.092** (2.06)
Learning capacity	0.189** (2.58)	0.213*** (3.91)	-0.052* (-1.93)	-0.025 (-0.99)	0.239*** (3.90)	0.377*** (7.08)	0.058** (2.07)	0.102*** (3.77)	0.198*** (3.80)	0.189** (2.58)
Tertiary sectors		-1.201 (-1.60)		-2.498*** (-6.88)		2.824*** (3.75)		1.215*** (3.18)		1.369** (2.08)
Country dummies		Yes		Yes		Yes		Yes		Yes
Time dummies		Yes		Yes		Yes		Yes		Yes
Constant	24.38*** (5.54)	23.76*** (6.25)	12.31*** (7.50)	7.97*** (4.40)	18.16*** (4.86)	23.67*** (6.26)	10.30*** (6.08)	11.27*** (5.88)	6.685** (2.11)	13.14*** (3.95)
Observations	558	558	575	575	584	584	578	578	574	574
Adjusted R^2	0.389	0.798	0.229	0.580	0.294	0.676	0.006	0.434	0.326	0.670

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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