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RESEARCH ARTICLE



Firms and innovation in the new industrial paradigm of the digital transformation

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ABSTRACT

The unfolding of the digital transformation, often associated with the advent of the Fourth Industrial Revolution, has been attracting increasing attention in diverse academic disciplines. The related research has already populated several special issues that represent important guideposts for future studies on the topic. However, a paper collection with an 'Industry and Innovation' perspective, dealing with how firms behave, innovate, and perform in the new industrial paradigm, is still missing. This special issue aims to fill this gap. The six research articles investigate how firms face digital transformation from three different angles, looking at its determinants, the patterns of its unfolding, and its techno-economic effects. The variety of the theoretical backgrounds, data sources, and empirical methodologies, along with the originality and managerial/policy relevance of their results, make the special issue a privileged point of view to investigate the new industrial paradigm.

KEYWORDS

Firm; innovation; digital transformation; industrial paradigm; industry 4.0

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O30; O31; O33

1. Introduction

The diffusion of new technologies such as robotics, artificial intelligence, machine learning, blockchain, additive manufacturing and the internet of things is having a massive impact on the organisation of production. Although each one of these new technologies is characterised by peculiar patterns of development, they all concur to engender a major technological breakthrough based mainly on machines characterised by flexibility, adaptability and learning. These new types of machines determine a structural change when compared to previous mechanisation waves. In particular, previous waves of technical change were typically impacting the segments of employment characterised by non-cognitive and repetitive routines, whose tasks could be automated relatively easily (Autor 2015). However, this new technological wave seems to be capable of impacting also (and especially) the upper tier of employment, characterised by high levels of cognitive and non-repetitive tasks.

Therefore, differently from previous changes in the prevailing industrial paradigm, the pairing of digitally controlled manufacturing with the capacity of autonomous control

and independent decision-making, made possible by AI, redefines the boundaries within which human control is essential to deliver a certain task. These patterns qualitatively modify the complementarity/substitutability areas, extending the substitutability area between machines and humans well beyond the traditional boundaries determined by the skill-bias technological change (Katz and Murphy 1992; Krueger 1993). As a consequence, as automation extends to cognitive and mental tasks, the balance between complementarity and/or substitutability between digitalisation and tasks (which determines the balance between job destruction and job creation) changes in a structural way.

The widespread availability of data, coupled with the exponentially-increasing power to deal with environmental complexity, in establishing non-controlled relationships with the environment, redefines in a quite radical way the nature of the informational problems that organisations face, within both stable and turbulent environments. In turn, this redefines the cost of processing the information in both inter- and intra-industry relationships.

As information becomes the centrepiece defining the firm's performance, the new digital paradigm is set to redesign from bottom to top the whole set of firms' characteristics: multidimensionality becomes the scale against which firms' and industry's performance is evaluated. Therefore, the new technologies (that span from industrial robots to artificial intelligence, from machine learning to data analytics, from 3d printing to I4.0) are not only likely to produce a major impact on labour markets (and especially on labour demand) but to extend the impact of digitalisation well beyond the narrow 'technological' domain. Hence, they extend their reach both horizontally (from innovative start-ups to mature industries) and vertically (from firms' organisations to firms' innovation, from decision-making processes to behavioural strategies, from strategic management to the creation of new managerial mental models).

The impact of these new digital technologies does also entail a rethinking of the basic idea of technological innovation itself, and of the standard analysis of the way firms compete and behave within new types of imperfect markets, as well as of how markets are defined, and industries evolve.¹

The problem identified by Ronald Coase in determining the 'nature of the firm' (Coase 1937) will be revisited, with the addition of locating firms within the I4.0 framework. Platform economies are transforming industrial dynamics into winner-takes-all dynamics characterised by increasing returns that can be activated by several factors such as network externalities, economies of scale, increasing returns to information, forms of learning (by using, by interacting, etc.), and technological complementarities.

Hence, the set of conditions required for firms to survive and prosper in a digitalised world implies radically new competencies. These new competencies build, in turn, the internal absorptive capacity, which is a form of relational capital that is much needed in situations in which the patterns of complementarities and/or substitutability are crucial to the development of new innovative knowledge.

The previous set of arguments is just a subset of the long list of theoretical and empirical issues that emerge in dealing with the firm and its innovation in front of the

¹For example, the mainstream theory of organisation is based on informational asymmetries, bounded rationality, limited span of control, and the like. However, new digital technologies will redefine the knowledge content of technologies, their balance between tacit and codified components, the way in which trust is distributed among agents (i.e. via the blockchains). This will redesign the whole set of asymmetries characterising the markets.

digital transformation. Their analysis has motivated the choice of the title of the 17th Workshop of the *European Network on the Economics of the Firm* (ENEF), which took place on-line (due to COVID-19 restrictions) in January 20–21, 2021, on the virtual premises of the University of Bergamo.² This special issue is in fact the outcome of a peer-review-based selection of the submissions received through the portal of *Industry and Innovation* soon after the Workshop. This occurred in response to a call for papers that was opened also to submitters that did not participate in the Workshop.

The appraisal and selection of the received submissions led us to assemble a special issue of 6 papers, whose common aspects, differentiating elements, and contents will be as usually illustrated in this introduction, in [Section 4](#). Before getting to that, in the following [Section 2](#) we will first try to set the stage in which the special issue collocates. In [Section 3](#) we will instead illustrate the ‘Industry and Innovation’ perspective that distinguishes it from other special issues on the digital transformation, which have been published in concomitant disciplines in the last years.

2. Setting the stage: “firms and innovation in the new industrial paradigm of the digital transformation”

Starting from the 1990s, the way to approach the world (and to interact with it) has been completely revolutionised by the progress of digital technologies, based on the co-evolution of the three complex systems constituted by hardware, software, and the connecting network. This co-evolution triggered an unprecedented structural change that, moving from the digital sphere, has eventually involved every aspect of our socio-economic life. This structural change has created a system-wide network of interconnections among sectors, together with the complete restructuring of its interdependencies, which has linked sectors originally very far from each other. And this process has travelled at an unprecedented speed.

To understand the impact of digital technologies, it is thus necessary to consider the various techno-economic sub-systems of which they are made, and their diffusion within the different sub-systems. Of particular importance is the fact that the interactions among the constitutive sub-systems are characterised by strong non-linearities that portray the patterns of diffusion within the economy of digital technologies. This systemic nature makes digital technologies ubiquitous, characterised by strong pervasiveness and complementarities. However, although these elements are common to the previous technological revolutions (e.g. steam, electricity, etc.), they totally differ in the unprecedented speed with which they are diffusing vertically and spreading horizontally. In their diffusion processes, they can thus contaminate the whole system, contributing in an exponential way to potential competitiveness and productivity growth in the sector within which they are directly applied and in the linked ones, both horizontally and vertically.

Economists are split into techno-pessimists and techno-optimists as for the impact of digitalisation on economic systems because of their horizontal and vertical pervasiveness. Besides involving a wide range of sectors, they develop essential linkages with other

²The mission and the activities of this network can be found at the following link: <https://sites.google.com/view/enef-webpage>.

(maybe distant) technologies. As such they are technologies that, beyond opening-up a whole set of techno-economic opportunities, are able to develop deep complementarities with other domains, such as social, legal, and political (Bresnahan and Trajtenberg 1995). Indeed, a wave of complementary innovations in a wide and ever-expanding range of sectors is called for, resulting in widespread economic disruption with winners and losers. The winners are predominantly at the forefront of the main applications connected directly to the technological wave, while the losers are laggards hit by what we might refer to as competence-destroying technical change (Tushman and Anderson 1986). These phenomena happen on top of the structural changes brought about by several waves of ‘creative destruction’ (Schumpeter 1934).

The impact of such technologies can be appreciated at different levels. For instance, digital technologies have been recognised as a strong set of elements determining the competitiveness and performance of the involved firms, both directly, through the creation of new opportunities for Schumpeterian-type of entrepreneurs, but also for follower-type of entrepreneurs throughout the linked channels created by the waves of innovative opportunities necessary to complement the diffusion of digital technologies. In particular, it seems that innovative activities (as proxied by patenting activities) in I4.0 fields are positively correlated to performance (as measured by either total factor or labour productivity), in particular for firms with deeper and longer than average experience in I4.0 technologies (e.g. Benassi et al. 2022). However, as already said, because of the ubiquitous complementarities of digital technologies, their dividends are widespread in a quite heterogeneous way, with a high and increasing dispersion in productivity performance across firms (Gal et al. 2019). Also, firms’ organisation is affected by the ubiquitous spreading of technologies allowing for real-time control of faraway production processes, for the reorganisation of production processes by means of virtual prototyping and 3D printing, for the processes of disintermediation allowed by these technologies (Bordeleau and Felden 2019). This new wave of digital technologies is completely reshaping the core functions, starting from manufacturing, to logistics, sales and even marketing: they are subject to a complete redesign and new forms of integration among them must be put in place. Moreover, new functions within firms are built. For instance, the new digital technologies are redefining the quantity (and the quality) of the data available that needs to be elaborated. The new additive manufacturing implies a complete rethinking of the design of the products. Furthermore, the virtualisation of design allows for a completely different management of the prototypes. All these (but not only) digital technologies will presumably force a very structural reshaping of the main functions within the firms’ organisation. Finally, what is probably the most hyped and analysed consequence of digital technologies is the implications for labour. In general, the literature seems to highlight a degree of substitution effect of robots for certain types of labour/tasks/routines, while, on the contrary, AI seems to engender a sort of complementary effect (e.g. Agrawal, Gans, and Goldfarb 2019).

The case of Industry 4.0 deserves some deeper consideration, as it is probably the most disruptive manifestation of the diffusion of digital technologies (e.g. Mariani and Borghi 2019; Culot et al. 2020). In fact, I4.0 defines a process that, through deep processes of automation, encompasses several different levels in design, production, and distribution of products and processes. Based on the so-called Cyber-Physical Systems (CPS) production processes integrate heterogeneous data into the production of streams of knowledge,

which, in turn, should build a responsive dynamic environment able to confer both efficiency and effectiveness to industrial production. Generated by the profound technological transformations engendered by digital technologies, I4.0 is focused on automating and interconnecting all the phases of the productive processes in real-time: the resulting 'smart factory', thanks to the pervasive use of digital technologies, can monitor physical processes by means of sets of decentralised decisions. It is thus a firm that, through the concerted effort of production and services, is based on the self-organisation of efficient and flexible management resources to enhance productivity and competitiveness, through the realisation of a process of convergence between virtual and material sub-systems. I4.0 is mainly based on several major features (from digitisation to automation, from human machine interaction to automatic data exchange) that are highly dependent on the development of advanced internet technologies and their algorithms. In turn, they depend on the production and management of complex and multidimensional processes of knowledge generation, management, and exchange.

The impact of digital technologies on I4.0 is pervasive, as it emerges from the combination of several different enabling technologies (e.g. Martinelli, Mina, and Moggi 2021). In particular, I4.0 is a complex technology, made-up of the convergence within the CPS of several 'simple' technologies within the virtual space of Cloud computing/manufacturing that is made available to each firm, and within which the firm coordinates several technologies that are grouped under the headings of Internet of Things, of Robotics, of Additive Manufacturing. The coordinating devices are organised within the domain of two strictly linked technologies: Artificial Intelligence and Big Data. With such an arsenal of technologies, firms can operate with the aid of AI, which is made possible by the availability of huge quantities of data, used as (i) primary input of the AI algorithms to produce a prediction; (ii) training data to train the AI to learn how to make good enough productions; (iii) feedback data to improve ex-post the AI performance experience. The collection of data is made possible by the IoT that is connected to the production processes by a set of smart sensors. AI then drives both robots and additive manufacturing, by effectively reducing the number of steps necessary to the production of one unit of output.

The two major characteristics of the way I4.0 implements its peculiar production processes are integration and interoperability. Integrated hardware and software systems allow Industry 4.0 to operate seamlessly across organisational boundaries and favour the efficiency of inter-organisational networking. Interoperability builds on integration to confer the capacity to exchange and share information and knowledge across different systems in real-time. Within this framework, I4.0 is designed to use the CPS to supervise and monitor the production processes. Moreover, by replicating them in the virtual sphere, decentralised decision-making processes in real time are allowed through the integration of procedures as different and autonomous as those related to software components, production processes, and sectoral environment (for instance, by combining Enterprise Resource Planning, IoT, cloud-based manufacturing, 3D printing, etc).

CPS supervision allows communication and interaction between humans, between machines, and between humans and machines in a sort of seamless way. The delivery of in-presence medium to high knowledge-intensive jobs is thus made unnecessary by the use of some combinations of digital technologies: these types of services can be delivered either by 'telemigrants' working remotely by means of collaborative platforms or by

‘white-collar robots’ that are able to handle several previously only-human tasks (especially those needing face-to-face contact). This combination of new globalised teleworkers and new forms of robotics has been termed *globotics* (Baldwin 2019).

Participation in the value chain is therefore guaranteed in a secure, trustful, and effective way. What is particularly relevant and revolutionary with respect to previous waves of technological change is the fact that the addition of AI and Big Data allows the systems to operate in a quasi-autonomous way. As machines are now able to communicate among themselves, control each other without any human intervention, and adapt their behaviours and responses to changing environments, the system performance is then further modified (and possibly improved) in a qualitative way.

3. A special issue with an “Industry and Innovation” perspective

The unfolding of digital transformation and its implications and consequences have been attracting a lot of research attention. A simple google-scholar search of articles containing the words ‘digital transformation’³ in their title since 2019, returns as many as 9,730 articles, in whatever discipline. Of these, 520 (i.e. 5.3%) are review articles, denoting that the literature on the topic has been already exposed to an appreciable effort of systematisation and critical reflection.

This is further confirmed by the special issues that have been dedicated to the topic by academic journals in economics (of labour and innovation, in particular), organisation, and management and business studies, with which we came across in proposing our own and in writing this introduction.⁴ As we will see in the remaining part of this section, recent special issues in these fields have already contributed to distil important ‘blocks’ of research about the implications of digital transformation in which we are interested. However, we deem that a special issue with an ‘Industry and Innovation’ perspective is still missing and needed, and that the distinguishing features of our own, also illustrated in the following, could fill this gap.

The economics literature has obviously focused very interested eyes on digital transformation, as revealed by different special issues about its impact on firms, markets, and more in general, the economic system. A first example is a collection of papers published by *CESifo Forum* in 2020 about the impact of digital technologies on the labour market, dealing with the ‘classic’ and very debated question of ‘competing with the machine’ (see the introduction to the special issue in Englmaier and Falck 2020). The papers offer a panorama of how digital technologies change the landscape of the labour market by means of the new digital tools that are having a wide transformative impact in different respects, like in: allowing workers to work from home, creating a whole new ‘gig economy’, triggering new opportunities for collaborative software projects, and destroying certain jobs and/or tasks while forcing some others to change. Another theme that has stimulated the call for a special issue is that of the role of digital technologies in

³Unlike ‘digitalisation’, the term ‘digital transformation’ evokes more directly the paradigmatic kind of change that digitalisation has had, and on which this special issue focuses.

⁴In the light of that, these special issues, which we will briefly review in the following, do not represent an exhaustive list of those that have been published in academic journals, and neither a representative sample of them. They are rather examples of paper collections that we have encountered in our research on the topic at the firm and industry level in the latest years. Because of that, special issues about the digital transformation at other levels of analysis, like for example, the regional one, will not be considered in the following.

reconfiguring the supply chains that are (were?) the core of the current global production processes. Such a special issue has been published in 2021 on the *International Labour Review* (see Gereffi, Posthuma, and Rossi 2021) and focuses on the evolution of buyer-driven global value chains, and, again not surprisingly, on the impacts of their reconfiguration on labour conditions and workers' rights. Related to the previous topic is that of the way in which digital technologies impact on firms' internationalisation strategies. Its analysis has stimulated a research stream in international business, which has also spurred the launch of a special issue, published in 2022 by the *Journal of International Management* (see Strange, Chen, and Fleury 2022). The special issue highlights a twofold impact of digital technologies. On the one hand, they allow firms to benefit from brand new international strategies, by means of a set of completely new digital tools, thus creating, developing and maintaining value for the firm. On the other hand, digital technologies also create unprecedented challenges to the internationalisation strategies of firms, for instance because digital technologies can lead to the reorganisation of global value chains, or of multinational enterprises.

Special issues have also recently appeared in journals in the economics and management of innovation. In general, the topics of how to conceptualise digital transformation and which theoretical framework to use in order to understand it have been their main concern. In their introduction to the special issue that *Research Policy* published in 2019, Nambisan, Wright, and Feldman (2019) first emphasise the need to incorporate in its investigation, a multiple and cross-level kind of analysis because digitalisation holds implications at different levels of analysis (individual, organisation, ecosystem/community, regional/society) and across levels too. Second, the guest editors suggest that in dealing with the digital transformation, it is essential to adopt an interdisciplinary perspective, drawing and combining concepts and methodologies from multiple scientific domains. Third, the role of digital technologies in transforming organisations and social relationships is urged to be explicitly acknowledged in understanding the implications of digital transformation for creating and capturing value. Three themes – openness, affordances and generativity (taken from diverse disciplines) – are proposed to serve as a common conceptual platform to allow for connections to be made between issues at different levels of analysis as well as the integration of ideas from different disciplines. In other subsequent special issues in the field of innovation studies, the attention has been posed to the antecedents, the drivers, and the consequences of digital transformation on innovation. For example, in 2021, the *Journal of Product Innovation Management* published a special issue that concentrates on the effects of digital transformation on the structure and governance of ecosystems, and on the way industries and firms compete in the new digital paradigm (see Appio et al. 2021). The special issue interestingly collects articles that investigate digital transformation at three levels of analysis – macro, meso and micro – dedicating special attention to its effects on the organisation of innovation activities inside the firm and on the process of developing new products and services. A focus on the micro level of analysis, instead, characterises the special issue that *Information and Management* published in 2022 on the 'digital business transformation' of innovation and entrepreneurship (see Sedera, Tan, and Xu 2022). The collection includes articles that deal with topical research issues in innovation studies – like, how firms try to resort to digital technologies in addressing the trade-off between knowledge exploration and exploitation – together with other relevant questions that, as

we will see, diffuse in management studies – like, how do firms transform their business model to cope with digital changes in their business environment. Unlike in the previous one, the focus is at the country and regional level, in the special issue that the *Journal of Technology Transfer* published in 2022 (see Amoroso et al. 2022). This includes articles that investigate how the evolution of digital technologies combines with other critical ones – like green technologies – and how such an evolution affects national and regional performances, passing through the role of knowledge spillovers and knowledge relatedness in their development.

Some special issues have focussed on the impact of digital technologies on organisations. Indeed, this appears to be a major area of research, both empirical and theoretical. Technology and organisation have always been strictly intertwined, and also the previous industrial revolutions have been characterised by major changes in both technology and organisation. However, there is little controversy that the organisational impact of digitalisation, AI, machine learning, etc. is likely to prove unprecedented. These technologies are adopted at all levels of the organisation, especially at those coordination roles that were typically the exclusive domain of decisions, rules, habits, routines, etc. constructed and performed mostly by human agents. New technologies are increasingly pushing the domain of mechanisation to these higher-level coordination tasks. Theoretical implications are far-reaching and profound. For instance, many economic theories of organisation (e.g. transaction cost economics, evolutionary and behavioural theories, etc.) are grounded on a boundedly rationality assumption which is fully justified for human decision makers but less so for decisions taken by intelligent machines or by machine aided humans.

The recent special issue of *Organization Science* (see Bailey et al. 2022), discusses these topics by taking a relational perspective, which treats digital technologies not as stable entities, but as a set of evolving relations. The special issue asks for organisational scientists to turn into technology scholars and vice versa as the two can no longer be considered separately. The special issue of *Information and Organization* (see Aroles et al. 2021) focuses on the impact on labour, analysing the processes of flexibilization, virtualisation and mediation of work practices and addressing the ‘big question’ on the future of labour in the age of intelligent machines. Such a big question is also addressed in the special issue published by *Organization* in 2021 (see Trittin-Ulbrich et al. 2021) which further enlarges the perspective to a societal one and discusses the ‘dark side’ of the digitalisation of work and organisational processes, particularly for workers, employees, and for the society as a whole.

Digital transformation has also attracted the attention of management and business journals, which over the last years have hosted interesting special issues, usually in the aftermath of dedicated workshops and conferences, like in the case of the current one, sometimes also open to stakeholders and practitioners. Some of these special issues focus on how digitalisation has been transforming the conceptual and theoretical pillars of the respective disciplines, urging a substantial re-thought of their application also in empirical analyses. This is for example the case of the special issue published in 2021 by the *Journal of Management Studies*, focusing on the way in which the theory of the firm is challenged by the impending revolution carried out by digital technologies (see Menz et al. 2021). In particular, the special issue stresses the digital implications for the firms’ corporate strategy, with a particular focus on how competitive advantage is reshaped

within the new digital technologies paradigm, on the way in which firm's scale, scope and boundaries are affected by it, and on how the possibility for decentralised decision structures affects the internal structure of firms. Along the same line of analysis of the impact of digital transformation on 'the fundamentals' is another special issue, published in 2020 by the *California Management Review*, about how the modalities of value (co-) generation and delivery have been changing in the new industrial paradigm (see Cennamo et al. 2020). Mainly on the basis of new case-based evidence at the company level, the collection addresses new modalities in the use of data for value creation, in the employment of digital technologies for the implementation of new business strategies and new business models, in the creation of digital mindsets and of digital relational and managerial practices, and in the organisational design of tasks and interdependencies within the firm.

In addition to the previous ones, other special issues in business studies have been dedicated to quite specific, though important and 'complex', topics. For example, in 2021, the *Journal of Business Research* (see Broekhuizen et al. 2021) and the *Review of Managerial Science* (see Bouncken, Kraus, and Roig-Tierno 2021) have both published special issues on how the digital transformation has been changing the firms' 'business models'. The focus has thus been posed on how the new wave of digital technologies is turning these models into digital too – like in the case of cloud computing business models – and on the new digital leverages – like crowdsourcing and data analytics – through which firms can create and appropriate value. Another example of a specific focus is that on the 'digital servitisation', meant as the crossing of digitalisation and servitisation of business practices, to which the journal *Industrial Marketing Management* (see Gebauer et al. 2021) has dedicated a special issue in 2021. As the articles of this collection document, this is another complex research issue, susceptible to be investigated through heterogeneous theoretical approaches (e.g. dynamic capabilities, discovery-oriented, affordance, and relational view theories) and from various angles (drivers, impacts, processes and organisational shifts), but within delimited research boundaries in the broader analysis of the digital transformation. A certain focalisation also characterises other special issues in the field of business, which however have an apparent broader approach to the digital transformation. In that about 'Digital or not – The future of entrepreneurship and innovation' (see Berger et al. 2021), still published by the *Journal of Business Research* in 2021, the selected 11 studies address and extend the state of research on digital entrepreneurship and digital innovation in different respects. Digitalisation is addressed as a 'context', as a moderator/mediator, rather than independent/dependent variable. Still, consistently with the objective of the journal, a focus remains on specific digital applications – like on-line innovation communities, or digital networks – or on specific business-related issues – like digital ventures, entrepreneurial earnings, and value creation.

With respect to the extant special issues, the current one presents a set of distinguishing features that make it an important value added in augmenting our knowledge of digital transformation in constituting a new industrial paradigm in which firms operate and innovate. First, our special issue overcomes the knowledge fragmentation that inevitably descends from being the previous ones mainly focused, either on the drivers and obstacles of the extent to which firms adapt and/or contribute to the digital transformation or on the effects that the same transformation has been having on their

techno-economic performances. The coverage of the collection that we have assembled is more systematic. While it encompasses papers about both digitalisation drivers (Andersson, Kusetogullari, and Wernberg 2023; Lopez-Vega and Moodysson, 2023) and outcomes (Antonietti et al. 2023; Cirillo et al. 2023; Forgione and Migliardo 2023), it also comprehends analyses of the technological choices, strategies, organisational, and cognitive models through which firms transform in facing the last digitalisation wave (Lopez-Vega and Moodysson forthcoming; de Paula et al. 2023). In so doing, our special issue provides the reader with a privileged 360° observation viewpoint of the different angles along which the digital transformation can be addressed.

Second, while the firm is the main unit of analysis of our special issue, the collected papers investigate its role in digital transformation by referring to the multiple conceptual and theoretical dimensions along which such a firm role can substantiate, and to which different disciplines (e.g. labour economics, industrial organisation, organisation studies, and innovation geography) typically dedicate. These dimensions comprehend and distinguish the role of the *structural features* of the digitalising firms – spanning from their size and age (Cirillo et al. 2023) to their ownership structure and internationalisation degree (Andersson, Kusetogullari, and Wernberg 2023) – and their *behavioural strategies* (e.g. building internal capabilities or nurturing experimentation) in creating a managerial mental model for digitalisation (de Paula et al. 2023). Some papers do also deal with the contexts in which firms face their digitalisation, focusing on both their *geographical location* – like the local labour market (Antonietti et al. 2023) and regional areas (Forgione and Migliardo, 2023) – and their *industrial setting* – like automotive (Lopez-Vega and Moodysson, 2023), and chemistry, banking, and insurance (de Paula et al. 2023). This multidimensional analysis of the firm digitalisation represents an important multidisciplinary added value of the special issue, whose contents could be relevant for different research communities and contribute to enriching and bridging their focal perspectives.

Third, the papers of the special issue deal with digital transformation by means of a nice variety of application domains, methodological approaches, and analytical instruments in their empirical analyses. The used data sources span from brand new secondary data of both administrative and official statistical nature (Andersson, Kusetogullari, and Wernberg 2023; Antonietti et al. 2023; Cirillo et al. 2023; Forgione and Migliardo, 2023) to primary data collected through on-purpose dedicated surveys and field interviews (de Paula et al. 2023; Lopez-Vega and Moodysson, 2023). The period, which the temporal windows of these different datasets cover, extends from 2008 to 2019 (going back to 1970 in one case) and thus provides a picture of the digital transformation that encapsulates the consequences of the ‘double-dip recession’ that firms have suffered, but stops before and excludes those of the pandemic and post-pandemic crises. Given the still unascertained effects that the latter have been having, also and above all on the extent to which firms resort to digitalisation (Xiong et al. 2021), this makes the special issue a novel point of departure with which to benchmark its more recent evolution.

Also in geographical terms, the special issue provides the reader with an alternative point of view with respect to that emerging from the thick stream of studies about firm automation and digitalisation in the US (e.g. Zolas et al. 2021; Leigh, Lee, and Kraft 2022), with which the results of our collected papers, mainly referring to Europe, are amenable to be compared.

Finally, the special issue does also contain a variegated portfolio of empirical methodologies that combine frontier quantitative and qualitative methods. This original combination enables the special issue to offer an interesting complementary set of synthetic systematic results and analytical case-based evidence, which is as usual of great benefit in getting a full-fledged understanding of the phenomenon at stake.

Because of the previous distinguishing features, the papers of the current special issues represent an original point of view from which to investigate how digital transformation has been creating a new industrial paradigm for firms and their innovation. As we will illustrate in the next section, this originality extends to the results that the papers have obtained and to their strategic and policy implications.

4. Synopsis of the special issue and its main contents

As we have remarked in the previous Section, the 6 papers of the special issue investigate how firms face digital transformation from three different angles, looking at its determinants, the patterns of its unfolding, and its techno-economic effects.

As far as the *determinants* of digitalisation are concerned, Andersson, Kusetogullari, and Wernberg (2023) investigate how the firms' decision to develop the software required to digitalise their operations, depends on their structural characteristics (e.g. ownership structure and economic assets), the composition of their employment, and the extent to which they are internationalised and innovative. In particular, the authors theoretically argue that these features could be responsible for the way software is developed – i.e. internally, outsourced, or in a mixed way – and for the purpose for which it is developed – spanning from the objective of making it an independent service or product, to that of using it for specific business functions (e.g. product distribution or sale, rather than service consultancy). Based on a unique firm-level survey about software development in Sweden during 2019, combined with the other three firm-level datasets at previous points in time (2016–2018), the analysis reveals interesting and original results. As for the way of software development, for example, the resort to an internal vs. external model appears to vary with the share of STEM firms' employees. As for the function of software development, its orientation towards embedded software and towards distribution and sales, appear predominant in multinational firms. Drawing on these and other results, important policy implications are drawn about educational training programmes and about internationalisation and innovation-supporting actions that could help firms to tailor the strategy of software development that better suits their distinguishing profile and can better serve their digitalisation.

Coming to the *implementation* of digital transformation within the firm, de Paula et al. (2023) investigate which are the behavioural strategies that companies' top managers should implement to harness the creativity of their employees and reinforce their contribution to a managerial (mental) model suitable to deal with the Industry 4.0 paradigm. Following an original combination of the design-thinking approach and of the paradigm-mindset-mental model from cognition theory, these behavioural strategies are searched for by the authors through 45 field interviews carried out between 2016 and 2018 with two kinds of stakeholders: practitioners and informants of key industries in the Industry 4.0 paradigm (healthcare, automotive, chemistry, banking, and insurance) in some European countries (Finland, UK, Switzerland, Denmark, the Netherlands and

especially Germany), and academic experts of design-thinking training from Germany and the US, identified starting from the Stanford D-school (benchmark, <https://dschool.stanford.edu>). By inspecting and coding the outcomes of the interviews, and by validating their importance against the adopted theoretical frameworks and with the selected practitioners, the authors identify twenty behavioural strategies, which they interestingly map into different application areas of the firm. These strategies thus span from the area of 'Strategy and Vision' (like 'focusing on long-term internal capability building'), to the area of 'Data and Structure' (like 'augmenting design thinking with data analytics'), passing through the areas of 'Culture and Environment' (like 'nurturing a culture of experimentation, failure and feedback') and 'Employees and Competencies' (like 'providing blended learning and training on design thinking'). This portfolio of mapped strategies, which contributes to an organisational kind of analysis of the digital transformation, is finally suggested to provide managers with a 'novel set of survival conditions' through which their companies can align to the new industrial paradigm of Industry 4.0.

The *unfolding* of digitalisation is also the focus of the paper by Lopez-Vega and Moodysson (2023), who investigate the degree of novelty (radical vs. incremental) and breadth (within vs. across sectors) marking innovations in the 'digital technology topics' that are transforming the autonomous vehicle sector. Identified by the authors as the most inventive of the trajectories that characterise the automotive industry – in comparison to electrification, car sharing and connected vehicles, and power plants – the autonomous vehicle sector in fact represents an ideal field to investigate how innovation occurs at the times of digital transformation. By applying a topic modelling research approach to a selection of 455 patents filed from 1970 to 2019 by firms operating in Sweden and confirming the search outcomes through a survey with the relative inventors, the authors identify as many as 26 digital technology topics, spanning from autonomous speed control assistance to smart navigation systems. Looking at the relative patents and distributing them across four categories in terms of novelty and breadth – i.e. augmenting, spanning, transforming and disrupting – Lopez-Vega and Moodysson find an extremely important result, which is worthwhile verifying also beyond the autonomous vehicle sector. Incremental innovations in mature applications are crucial for the development of more radical digital technologies, as they often condition their disruptive power in transforming the industry. Managers and policymakers are thus alerted to work carefully in supporting an innovative digitalisation of the automotive industry, by retaining the complementarities that characterise its digital technology topics.

The remaining three papers deal with the *effects* that digital transformation is having on the firms' economic behaviours and performances, once more, from different angles. Antonietti et al. (2023) focus on the six technologies (micro and nanoelectronics, nanotechnology, industrial biotechnology, advanced materials, photonics, and advanced manufacturing technologies) that the European Commission has recently recommended firms to prioritise for their 'Key-Enabling' role in creating advanced and sustainable economies in the new digital era. By following an interesting regional perspective, the authors extend to these Key Enabling Technologies (KETs) the debate about the displacement vs. reinstatement effect of automation technologies. They then investigate how the availability of KETs, in the local labour market areas (LLMA) where firms are based, affects their labour demand in terms of workers' education, skills, and tasks. Combining administrative (Linked Employers-Employee), occupational survey-based, and

secondary patent data for 39 LLMA in the Emilia-Romagna region (Italy), the authors build up three novel indicators of the complexity that marks workers' occupations, tasks, and skills and find that, over the period 2008–2016, their demand is actually affected by the local availability of KETs. Quite interestingly, not only do KETs make firms demand more (tertiary) educated workers and for accomplishing less routinary tasks, but they also correlate with a higher demand for more complex (wider and more exclusive) occupations, tasks and skills. These results are shown to have interesting implications on the local-specific efforts that higher education and regional/national institutions should put in fostering the portfolio of tasks and skills of the workforce in facing digital transformation.

A regional perspective in addressing the effects of firms' digitalisation is also incorporated in the paper by Forgione and Migliardo (2023), who focus this time on the operational efficiency gains (i.e. added value imputable to resources) that could descend from firms' investments in the 'advanced digital technologies' that characterise the Industry 4.0. Using a sample of 2,609 firms from the Bank of Italy Remote Dataset (BIRD), the authors estimate the technical efficiency scores of this sample over the period 2016–2019, by applying a stochastic frontier analysis that enables them to relate their operating performance simultaneously, to both their share of digital investments and their location in administrative regions. The obtained results are interesting in both respects. On the one hand, irrespectively of their location, by investing in Industry 4.0 technologies, firms gain a premium with respect to non-investing ones in reducing their technical inefficiency: a premium, which grows in size with the share of the digital investment. On the other hand, while firms located in the most developed Italian regions (in the Northwest) are closer to their optimal frontier, the greatest reduction of inefficiency allowed by digital investments is experienced by firms in backward regions (e.g. Southern ones), in spite of their lower shares of these investments. The implications of these results are quite strong, as they talk directly to the regional efficiency gaps that structurally mark the Italian economic system. In the authors' words: 'the fourth industrial revolution brings about an efficiency improvement for the lagged regions that [could] partially bridge the distance between Southern Italy and the rest of Italy'.

The effect that digital transformation has been having on the firms' performance is also investigated by the paper by Cirillo et al. (2023), who, however, focus on a different dimension than technical efficiency, looking at the impact that firms' investments in Industry 4.0 technologies (Internet of things (IoT), Robotics, Big Data Analytics, Augmented Reality, and Cybersecurity) have on their labour productivity, sales growth, and average wages. By positioning in, and contributing to the consolidating literature about the labour implications of firm automation, the authors search for evidence of a relation between Industry 4.0 investments and the variables at stake with respect to a large representative sample of Italian firms observed along the three years 2010, 2014, and 2018. More precisely, by exploiting the last three waves of the survey carried out by the Italian National Institute for the Analysis of Public Policies (INAPP) with respect to those years, and merging the relative data with Orbis ones, the authors integrate their baseline estimates with a Diff-in-Diff methodology, which is capable to reassure them about the robustness of very interesting results. As expected, investing in the technologies at stake guarantees firms higher productivity and higher sales growth, as well as an expected increase in their average wages. However, the former effect appears to be only

partially transferred by firms on the latter, being twice as large in its economic size. These results are characterised by some puzzling nuances with respect to different typologies of firms, showing a higher impact of Industry 4.0 investments on SMEs, but a lower one with respect to younger firms. Also, in the case of this paper, the obtained results are charged with important policy implications. They span from the need of targeting policy support to Industry 4.0, by retaining the firms' distance from the technological frontier, to the need of addressing the wage-productivity decoupling that has been occurring in several national contexts over the last ten years.

As the previous synopsis of their contents reveals, the papers of the special issue combine interesting elements of differentiation with useful aspects of complementarity. Accordingly, the reader could approach the special issue either in a 'modular' – focusing on selected and obviously self-contained papers – or in a 'transversal' way – grouping papers that share different kinds of aspects, like perspectives, methodologies, and domains of the empirical application. One way or the other, we are confident that the special issue will enrich the reader with new and useful knowledge about the topic.

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