



The digitalisation of manufacturing and blurring industry boundaries

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ABSTRACT

Numerous studies document the acceleration of technology and industry convergence and point out the role of digitalisation adding further impetus to these processes. However, the issue of how digitalisation engenders the blurring of industry boundaries has received little attention. This paper addresses this research gap and contributes to the conceptual understanding of blurring industry boundaries. We integrate previously disparate theories and constructs into a single conceptual framework to elucidate the mechanisms by which digital technologies make industry boundaries increasingly permeable. The proposed framework is illustrated with references to recent developments in the automotive industry.

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Introduction

Digital technologies have been hailed and feared as capable to disrupt the established structures of competition and value creation, compelling global value chain (GVC) actors to navigate in a radically new competitive environment [1] referred to as the 'next generation competition' [2]. Indeed, the current business environment is characterised by an unprecedented degree of volatility, uncertainty, complexity, and ambiguity (VUCA, [3]). VUCA is engendered by a growing speed, scale, and scope of changes in the business environment, in general, and by accelerating technological progress, in particular. Agile incumbents' and new entrants' bold strategic responses to these changes further enhance the VUCA properties of competition.

A prominent driver of VUCA is the phenomenon of blurring technology and industry boundaries, a development that exerts a strong impact on the structure of value creation [4]. One of the most conspicuous signs of blurred boundaries is digital disruption [5], when the prior dominant position of actors in established industries is challenged by technology companies arriving from outside the given industries. However, even if new entrants' digital offerings complement (and not displace) existing products, the distribution of value added and value capture may change substantially in GVCs [6,7].

One of the key developments by which digital technologies engender the aforementioned changes is the convergence of technologies and industries [2,8]. Adapting Agarwal and Brem's [9] definition, technology convergence occurs when the breadth and depth of interactions between two or more previously separate technologies increase, prompting the co-evolution of these technological systems toward performing similar tasks. A prominent example is the initially parallel development of manufacturing technology and information and communication technology. As elaborated upon in Monostori [10], technological interactions and the mutually inspiring developments in these fields have led to a convergence between these two technologies, culminating in the emergence of cyber-physical production systems.

Industry convergence refers to the gradual integration of previously distinct technological and/or market trajectories of two or more industries, driven by technological change, and by actors' innovations and strategy [11,12]. Curran and Leker [13] proposed a sequential model of this development. The first stage, involving convergence between two or more scientific fields, is followed by the convergent evolution of technologies. The next stage involves the convergence of markets, and the process culminates in the convergence of previously distinct industries.

Since the early discussions of technology and industry convergence [14,15], literature has been substantially enriched by new contributions discussing the evolution, measurement, and implications of this process [13,16,17]. Convergence has been operationalised with traditional indicators such as patents (analysis of the dynamics of industries' patenting outside their core technological fields), co-citations that show interdisciplinary knowledge

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flows, co-authorship of papers by scholars from different scientific disciplines, strategic collaborations among partners specialised in distant technological fields, and mergers and acquisitions [17]. Recent papers employ new, digitally enabled analytical methods to anticipate or assess convergence. For example, Kim et al. [18] used machine learning-powered text mining to capture the co-occurrence of firms in newspaper articles and identify collaboration of firms operating in different industries.

Irrespective of the indicators and methods employed, the reviewed studies found that the overall trends of technology and industry convergence are significantly upward and concluded that emerging digital technologies have added further impetus to the ongoing processes of convergence [13,16–19]. Increased average product complexity [20], specifically, the fact that products combine specialised knowledge from numerous technological fields [2,21], also points to an intensification of multi-industry collaboration.

Documenting the dynamics of convergence and discussing their types and implications, the reviewed papers do not adequately address the issue of how digitalisation engenders blurred industry boundaries. While studies intuitively accept the paramount role of digital technologies, and indeed, the acceleration of technology and industry convergence coincides with progressing digitalisation, the understanding of the mechanisms behind digitalisation-induced convergence is still underdeveloped.

Rather than producing another paper validating the acceleration of technology and industry convergence in the digital era, this paper turns this issue upside down to address this research gap. We aim to provide a better understanding of how digitalisation induces industry convergence.

Digitalisation is defined as using digital technologies, such as artificial intelligence, big data technology, cloud technology, Internet of Things (IoT), and robotics to (i) execute, control, and/or improve every tangible and intangible activity that together comprise the value chain, (ii) create smart products and services, and (iii) transform the business model.¹

The dissolution of traditional industry boundaries is propelled by two interrelated forces: by actors from outside, aka technology companies acting as digital disruptors and by incumbents' responses, embracing digital technologies.

This paper zooms in on manufacturing industries and discusses how incumbents' responses to the pervasive penetration of digital technologies make industry boundaries increasingly permeable. Accordingly, we discuss one specific type of industry boundary, the boundary between conventional manufacturing industries and industries from the digital technology sector.² For the purpose of this study, industry boundaries are defined in terms of activities and competencies: they circumscribe and at the same time delimit the scope of activities and competencies (knowledge and area of expertise) of firms operating in specific industries [22,23]. Accordingly, the blurring boundaries of an industry refer to the outcome of a process in which firms operating in specific industries extend their activity mix and include activities that were previously performed by actors in other industries. To do so, the firms in the focal industry need to extend their competence base, i.e., accumulate the

competences related to and necessary for performing the new kinds of activities.

We take a conceptual approach by building on and recombining existing concepts in a novel way to propose new relationships among them [24]. The main conceptual ingredient of this study is the resource-based theory (RBT) combined with the concept of dynamic capabilities. Three other constructs serve as the building blocks of our framework: open innovation, absorptive capacity, and technological diversification. Each of these theories and constructs has a long intellectual history. Notwithstanding, this paper is not intended to provide a review of the relevant threads of the literature. Rather, it discusses previously underexplored connections between these constructs, to explain how they lead to the outcome that is the focal phenomenon of this study: blurred industry boundaries. Our analysis of how the blurring of industry boundaries unfolds is illustrated with references to recent developments in the automotive industry.

Accordingly, this study contributes to the conceptual understanding of permeable industry boundaries by proposing a framework that elucidates the mechanisms triggered by digital technologies. In accordance with Hedström and Ylikovski [28], we define mechanism as a causal process in a system characterised by interacting entities whose activities bring about or prevent change in the system.

The rest of this article is organised as follows. First, we briefly summarise the research context: the ubiquity of digital transformation (DT) and the different dimensions in which this ubiquity is manifested (Section 2.1) and two key manifestations of blurring industry boundaries: the process of servitization and the emergence of industrial product-service systems (Section 2.2). In the subsequent sections, we present and justify our research approach (Section 3) and develop a conceptual framework elucidating the mechanisms by which digitalisation blurs industry boundaries (Section 4). Section 5 presents illustrative examples from the automotive industry. In the concluding section, a short summary is provided, along with theoretical and managerial implications, and limitations (Section 6).

Research context

The ubiquity of digital technologies in manufacturing industries

The significance of DT has been analysed using a variety of disciplinary lenses [25,26,29–31]. While most analyses mention the ubiquity of digital technologies, scholarly efforts were made also to systematise the dimensions of this ubiquity [32,33]. For example, [33] distinguish a number of heterogeneous dimensions including among others, organisational, operational, managerial, legal, functional (e.g., security), and cultural ones. [34] perform a word co-occurrence analysis and present the multifaceted connections of DT with various dimensions of innovation (and innovation management).

Since this paper aims at explaining how digitalisation and firms' responses to the imperatives of a digitalising business environment stretch the boundaries of manufacturing industries, four dimensions of digital ubiquity are deemed particularly relevant (Fig. 1). The first one is the *industry dimension*, referring to the presence of digital technologies in all industries (and other non-manufacturing sectors). Since manufacturing activities are interconnected with numerous non-manufacturing ones that support both production and business strategy, a broader – value chain – perspective of digital ubiquity also needs to be considered. The *value chain dimension* includes both manufacturing and non-manufacturing actors connected through the value creation process of manufacturing industries.

At micro (firm) level, digital ubiquity is manifested also in terms of *resources*, since firms not only have to integrate new digital

¹ Adapted for the purpose of this study, this definition draws on an extensive literature concerned with the definition of digitalisation in general, and the digitalisation of industry in particular. However, the review of this stream of literature is beyond the scope of this paper (see [25,26]).

² Ever since the diffusion of the new paradigm-defining digital technologies has progressed beyond a tipping point, substantial efforts have been devoted to developing adequate methodologies to delineate and measure the digital technology sector (see review by Hooton [27]). Scholars are still far from reaching a shared view in this respect. For simplicity, this paper refers to digital technologies supplied to incumbent manufacturing companies by specialised technology providers as solutions originating in the 'digital technology sector'.

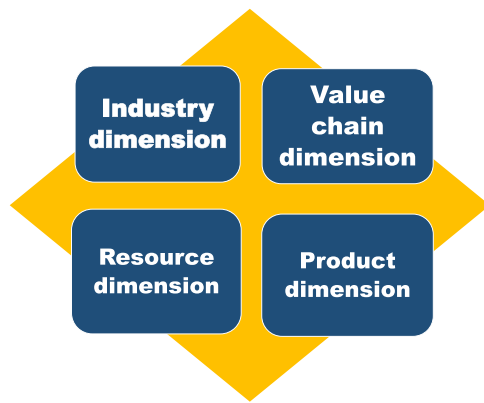


Fig. 1. Dimensions of digital ubiquity.

resources in their production and business systems, but they also have to digitalise their existing resources and digitally augment their capabilities. Finally, the fourth, the *product dimension* refers to digital technologies permeating into conventional products. The outcomes of this process have been discussed in terms of the ‘smartisation’ of products or emergence of (industrial) product-services systems (see section 2.2).

The industry dimension

To understand the importance of digitalisation for making industry boundaries increasingly permeable, it seems appropriate to depart from Lei’s [35] assertion stating that industry convergence occurs when technological innovations in one industry catalyse a series of process and product innovations in other industries. Digital technologies bear a particularly strong potential in this respect. Since they generate pervasive innovations and can be integrated with a wide range of diverse technologies, they are regarded as general-purpose technologies [36] or enabling technologies [37,38]. Accordingly, and consistently with Lei’s [35] conceptualisation, innovations emerging in the digital technology sector catalyse a series of process and product innovations in practically all industries (for a thought-provoking critique of this view, see [39]).

The value chain dimension

Digital technologies become integrated in each and every tangible and intangible activity that together comprise the value chain, from conception to production, end use, and beyond [40]. The *value chain dimension* highlights that the transformational impact of digital technologies applies to a cornucopia of processes and activities that support manufacturing production and manufacturing business [41]. The relevance of the value chain dimension of digital ubiquity to blurring boundaries is apparent if we consider that the digitalisation of operations, supply chain management, and other (pre-production, strategic management, and post-production) functions involves entry by an array of new non-manufacturing actors (technology providers) into manufacturing value chains.

The resource dimension

Regarding the resource dimension of digital ubiquity, we propose that except for human resources that are and remain the central constituents of companies’ resources [42,43] in the digital era, all resources are digital. Consider that strategic management literature emphasises that to build sustainable competitive advantage, firms have to accumulate digital resources, including digitally enhanced technological assets, digital infrastructure, platforms, data assets, and proprietary software applications – and improve their digital capabilities [2,25,26]. Digital capabilities refer to a collection of capabilities that enable organisations to integrate digital

technologies into their offerings, business processes, and organisational practices, and leverage digital data and technologies for achieving operational and/or strategic purposes [38,44–46].

Yet, in an increasingly digitised world, digital resources can hardly be treated separately from conventional manufacturing resources and capabilities, as reflected by concepts such as cyber-physical systems, digital twins, or virtual (as-a-service) assets. Moreover, both the ordinary and the dynamic capabilities of organisations are supported by embedded digital technologies (see section 4). Consequently, it can be concluded that in the digital era, the resource dimension of digital ubiquity makes the arguments regarding the imperative of accumulating ‘digital resources’ tautological.³

The product dimension

The product dimension of digital ubiquity is manifested in the infusion of digital technologies in an expanding range of conventional manufacturing products. The outcome of this latter type of integration between the ‘digital’ and the ‘conventional’ is the emergence of smart products. As argued in [47], smart products are not simply products with digitally enhanced technical features and functional capabilities [6] but there is qualitative difference between ‘smart’ and ‘conventional’ products’. Smart products accommodate internet-based services to exhibit features such as intelligence, connectedness, a wide range of associated services, and data drivenness (smart products generate, collect, and process data about the features of their use and their operational status).

However, the presence of these advanced features is not sufficient to account for a qualitative difference between conventional and smart products. What sets smart products apart is rather the fact, most important from the perspective of this study, that smart products are parts of complex business ecosystems. They connect and are connected to a variety of stakeholders that represent different industries: stakeholders from conventional industries (the traditional manufacturing value chain) and an array of stakeholders from the digital technology sector. These latter provide the digital technology infrastructure or account for the individual digital services delivered by smart products. Indeed, as argued by [47], smart products are, by definition, product-service systems. Since the emergence of mutually determined products and services [48,49] or in a broader perspective, the digital servitization of manufacturing [50] is a key manifestation of the dissolution of traditional industry boundaries, the next section presents a short summary of the related literature.

Key manifestations of blurred industry boundaries: digital servitization and industrial product-service systems

Servitization, refers to a shift to service-based strategies by manufacturing companies [41,53,54,55]. This shift is initially manifested in an increasing share of services in the offerings and total revenues of manufacturing firms. At higher levels of servitization, manufacturing companies transition to a service-oriented business model [54]. In this model, characterised by *integrated product and service offerings*, services not only add new functionalities to products but deliver value throughout the process when their customers use the products [48,49]. Customers pay for the usage and

³ In a similar vein, it seems obvious that in the digital era, every industry is technology-based. Previously, industry taxonomies (such as [137]) classified industries as low-tech or high-tech, based on the average R&D-intensity of firms in the given industries. This classification scheme was criticised from multiple angles [51,52], pointing out that innovation has multiple sources (not only research and development) and the knowledge generation and knowledge use patterns of firms classified as ‘low-tech’ are far from being negligible. Digitalisation has shed new light on these mature theses of innovation economics.

performance of the solutions that had been developed and tailored to their specific needs.

Although servitization has been going on for a long time [55], it has been significantly intensified by digitalisation [41,56]. On one hand, digitalisation allows for a rapid multiplication of product-embedded services and thus prompts the transformation of the product concept itself. Digitally enhanced products are conceived as modular systems in which modularly integrated digital subsystems account for specific functionalities or deliver specific services [4,57,58]. Since these digital subsystems are decomposable and can be integrated separately into the products, products become platforms for delivering services [59,60].

On the other hand, digitalisation empowers seamless interaction between manufacturers-services providers and their customers. These parties are linked throughout the lifecycle of the products (from design to disposal) through continuous information flows from the 'connected' product-service systems. Connectedness enables continuous services provision, such as remote control and troubleshooting, continuous performance optimisation, over-the-air upgrades, and integration of further custom-tailored service innovations [41].

In the context of this paper, *servitization is interpreted as a process of cross-sectoral convergence*, involving a convergence between digital technology-based services and conventional manufacturing products, and resulting in smart product-service systems.

Servitization-driven cross-sectoral convergence is manifested in terms of both processes and outcomes. 'Processes' concern the involvement of non-manufacturing actors (actors from the digital technology sector) in conventional manufacturing value chains. New and traditional actors align their competencies, combine their resources, collaborate, and co-create value – jointly with traditional manufacturing actors [53,61].

'Outcomes' refer to the emergence of new inter-industry segments between technology industries and conventional manufacturing industries. Consider, for example, the example of artificial intelligence-powered, voice-controlled personal assistant function. Developed originally by technology companies (e.g., Google, Amazon, Microsoft, and Apple) as a standalone solution, over time, voice control has become a common interface for an array of smart products (it is integrated among others in automotive OEMs' infotainment systems). *Voice control as a decomposable digital subsystem that can be disembodied from and integrated in physical products exemplifies that digitalisation gives rise to new inter-industry segments spanning digital and conventional industries.*

Drawing on this review of the research context, we introduce the following propositions. Digitalisation requires that incumbent manufacturing companies develop and/or access and integrate digital resources and capabilities. Since the required capabilities are often beyond the scope of the expertise of their industry, efforts to accumulate them should not be confined to the boundaries of single industries. Accordingly, firms⁴ seek to extend their technological and capability bases through developing and/or acquiring digital resources and capabilities. The latter option, resorting to actors outside their industries for the provision of the necessary resources, also necessitates internal capability development – for the effective integration of external knowledge [62]. Incumbent manufacturing firms are thus compelled to diversify in new technological directions that are outside their original technological core [63] and develop relational capabilities to integrate external knowledge effectively. These processes do not leave the boundaries of either firms or industries untouched.

⁴ Obviously, firms are heterogeneous in their willingness, speed, efficiency, and ability to develop/acquire digital resources and innovate [65].

Altogether, digital technologies boost the evolution of manufacturing industries and generate new trajectories for them [13,64]. A conspicuous manifestation of new trajectories is digital servitization [56,60] involving associated changes in the business model [25], and development of digital product-service systems [6,47].

Research design

To highlight the role of digitalisation in blurring the boundaries of manufacturing industries, we adopted a conceptual approach, building on four theoretical constructs that we consider parts of the explanation. The theories and constructs we draw on are as follows: (i) the resource-based theory and its extended evolutionary perspective, the theory of dynamic capabilities; (ii) open innovation; (iii) absorptive capacity, and (iv) technological diversification. We pull these lines of research together to propose a framework that illuminates – from the perspective of incumbents' reactions – the mechanisms by which digitalisation advances the blurring of industry boundaries (Fig. 2 and Fig. 3).

According to Whetten [66], two criteria exist for judging the scientific rigour of such a conceptual exercise: *comprehensiveness* (i.e., whether all relevant factors are included) and *parsimony*. This point makes us acknowledge a potential limitation right at the outset. Considering the complexity of DT manifested in the breadth and heterogeneity of its interconnections with other constructs, such as digital entrepreneurship, business model innovation, and servitization [34], and recognising that DT is still in a take-off phase as a field of scholarly interest for researchers from various disciplines, the requirement of comprehensiveness seems inconceivable. Therefore, we deliberately limit the ambition of this paper to opening the 'black box' of a particular set of mechanisms – out of several possible ones – that drive the blurring of industry boundaries.

Continuing along Whetten's [66] recommendations, the next step of the analysis is to answer the 'How' question, i.e., explain how the constructs are related. Accordingly, our arguments will be summarised in Fig. 2 and Fig. 3 visualising the interrelations among these theories that, in combination, account for the mechanisms in question.

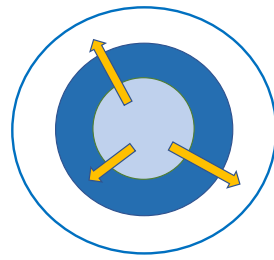
The resource-based theory and its extension: the dynamic capabilities perspective

RBT is a paradigmatic theory in the field of strategic management, explaining the relationship between firms' resources and their performance [23,67,68,69]. The RBT relates competitive advantage to the properties of the resources (valuable, rare, inimitable, and non-substitutable) that firms control.

Over time, the RBT has received criticism from multiple angles (reviewed by [70]) and has undergone multiple refinements and extensions [71,72]. One particular line of criticism and direction of refinement concerned the vague operationalisation of the core construct as to what constitutes a resource. Subsequent studies emphasised that resources can be both tangible and intangible. Intangible resources include competencies, knowledge, and capabilities or more generally: human capital [73,74] complemented with organisational practices (organisational capital) that enable a *better use of resources* [75,76]. The assumption underlying this latter argument, namely that it is not better resources per se that ensure sustainable competitive advantage but rather a better use of resources made the RBT, as a core theory, become the foundation of an important related strand of research, the dynamic capabilities theory [22,77,78].

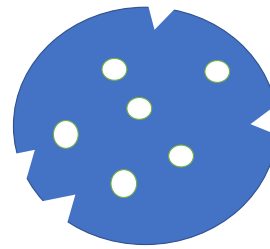
The concept of dynamic capabilities was proposed in response to a criticism, highly relevant in the context of this study, namely that in a dynamic business environment characterised by rapid

Digitalisation broadens the technological base of competitive advantage and requires new resources and capabilities



The firm as a bundle of resources and capabilities

Digitalisation reveals multiple resource and capability gaps for established firms



Some of the gaps are found in core functions, others in support or auxiliary functions

Fig. 2. Interpreting digitalisation from the perspective of the resource-based theory.

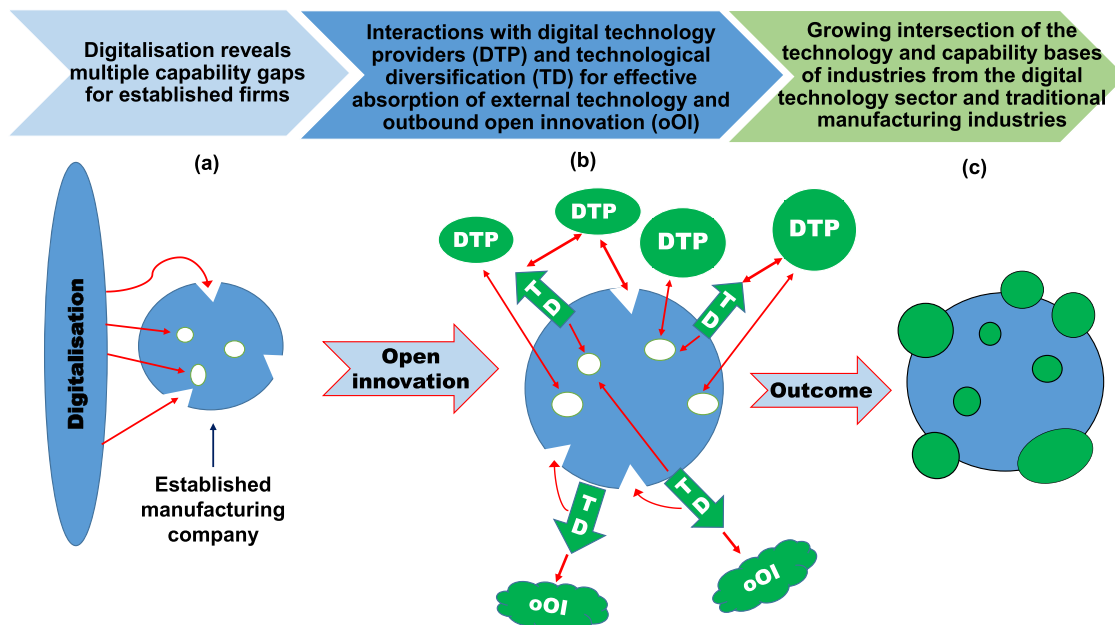


Fig. 3. The mechanisms by which digitalisation blurs industry boundaries.

technological change, the value of firms' resources might change as well. It is the actual market environment that determines the value of the resources [77,79]. Maintaining competitive advantage in a turbulent external environment requires 'higher-order capabilities' [22,80–82] that allow firms to create new resources and capabilities, and/or extend, recombine, and modify them.

Before moving on to the subsequent building blocks of our conceptual framework, a remark needs to be mentioned at this point.

Extant research discussing the impact of digitalisation from a resource-based perspective is concerned mainly with the ways digitalisation enables firms to *enhance* their capabilities and use their resources more effectively than previously [25,83–86]. We take a different direction, directing attention rather to the *capability gaps* revealed by the DT of the business environment.

The open innovation paradigm

The open innovation (OI) scholarship postulates that since firms rarely possess all the resources necessary for innovation, they need

to rely also on external ideas, specialised knowledge, technology, and other external resources [87,88]. The concept of OI was introduced as an academic response to the increasingly conspicuous trend of firms' outsourcing innovation and/or performing innovation activities in collaboration with other specialised organisations [89] and has rapidly become a highly influential paradigm of innovation management.

Enkel et al. [90] identified three archetypes of OI: (i) the inbound type, where firms access and integrate external ideas, knowledge, technology, and intellectual property; (ii) the outbound type, where firms, motivated by various strategic purposes, transfer their internal technological and knowledge assets to the external business environment, and (iii) the coupled or bidirectional type. This latter refers to the co-creation of innovation by complementary partners and is characterised by bidirectional flows of knowledge and technology.

The rapid diffusion of OI practices – a trend established by [91] more than a decade ago – 'from pioneers to mainstream', 'from high, to low-tech sectors', from large firms to smaller ones, and from

products to services [92], has gained momentum in the digital era [93]. There are, at least, two reasons accounting for OI becoming ubiquitous amidst digitalisation: (i) the significantly increased complexity of knowledge necessary for innovation and (ii) the improved efficiency and reduced transaction costs of accessing external knowledge sources – enabled by digital connectivity.

Another new or ‘enhanced-traditional’ aspect of current OI practices is the increased sectoral heterogeneity of knowledge and technology flows [94,95]. Firms – also in mature industries – progressively rely on distant and seemingly unrelated knowledge domains both for upgrading ordinary activities (e.g., production) and new product development.

Notwithstanding the accelerated diffusion of OI practices, the empirical evidence of a positive relation between OI and performance (reviewed by [96]) is inconclusive. The absence of decisive evidence regarding the impact of OI on performance suggests that strong moderating factors are at play, such as complementary assets and (dynamic) capabilities, shaping the outcomes of OI efforts [97]. One of the most important moderating factors is absorptive capacity, a construct we turn to in the next sub-section.

Absorptive capacity

Open innovation, whether performed in the form of acquisitions, technological collaborations, open sourcing, or venture capital investments, requires broad and deep capabilities that together, are referred to as absorptive capacity [98]. Absorptive capacity is a dynamic capability of an organisation, enabling it to identify, evaluate, integrate, transform (by combining it with internal resources), and exploit external knowledge that is relevant to its business activities [99].

None of these components is trivial. To be able to recognise the value of external technology, firms have to understand its technical specifics and its applicability for firm-specific strategic purposes. This requires non-negligible internal expertise that is acquired usually through indigenous R&D [62,100,101]. Internal expertise and knowledge management capability are indispensable also for the effective integration of the acquired external knowledge [88,102] while dynamic capabilities, such as sensing the opportunities, seizing them and reconfiguring resources are indispensable for capturing value from OI [78,103].

Since digitalisation entailed a step change in the complexities of both the manufacturing systems and the products [104], and firms have to manage a growing number of technologies that are complementary to their core technologies [2], absorptive capacity and system integration capacity have become more important than ever. This begets a multiplication of technological learning paths that firms have to pursue to establish the groundwork for assimilating external technologies [98]. The resulting intensification of firms’ technological diversification is an issue we turn to in the next sub-section.

Technological diversification

To sustain their competitive position in industries shifting to a new trajectory marked by the infusion of emerging technologies, established firms have to extend the portfolio of their technological competencies. The concept of multi-technology firms reflecting that ‘firms know more than what they make’ [62] is by no means new [105,106]. However, emerging digital technologies have extended both the number of technologies and the diversity of technology domains to be integrated, as well as the technology-based opportunities firms might leverage. At the same time, rapidly intensifying global competition transformed the *opportunity* of taking up digital technologies into a *strategic imperative*, fuelling the expansion of firms’ technological base. Furthermore, digital ubiquity enhanced

the relatedness of digital and traditional manufacturing knowledge domains, improving thereby the chances of positive performance outcomes [63,107].

Consequently, technological diversification, defined as the degree to which firms diversify their R&D activities across distinct technological fields has been a conspicuous trend across industries. As Kook et al. ([108], p. 2) succinctly put it, referring to firms’ efforts to implement emerging technologies in combination with existing ones to find new growth engines, “as time goes on, a firm will prefer to evolve into multi-tech firm rather than hi-tech firm”.

Notable in this respect is that digitalisation is not only a driver but also an enabler of technological diversification, since it opens up new directions of exploring and exploiting business opportunities. However, similarly to the absence of a conclusive evidence for a positive impact of OI on performance, the impact of technological diversification on performance is not straightforward either.⁵ Performance outcomes were found to be moderated by the presence of complementary assets and dynamic capabilities [63]. These latter are indispensable for effectively integrating new technological resources and recombining them with existing ones in a synergistic manner.

Having provided the short summaries of the theoretical building blocks to be combined to address our research question, we now turn to the analytical exercise of integrating them into a framework.

The mechanisms by which digitalisation blurs industry boundaries

From a resource-based perspective, we interpret digitalisation as the integration of new (digital) resources into the corporate resource base, to improve the affordances of and the connections among existing resources and enable new activities that allow for new revenue sources.

Digitalisation substantially broadens the scope of competences established manufacturing firms have to acquire and master. Specifically, they have to build, master, and integrate a digital technology stack that automates or supports a wide variety of core processes and related business functions [57,110]. Developing, deploying, and integrating all these solutions requires new capabilities, including technological, R&D, and design capabilities [44]. Additionally, since digital technologies add to the complexity of everything they are integrated in, digitalisation magnifies the required system integration capabilities [111].

New competences are required for adding supplemental digital functionalities to products or developing *integrated offerings* in which digital functionalities and the associated services are organic parts of products [47,48,112].

Furthermore, firms need to build and master a technology stack that harmonises, integrates, and analyses product data and customer data for business insights [113]. They need to invest in Big Data infrastructure, hardware and software tools, and platforms that support Big Data applications, and develop Big Data management and data analytics capabilities [110,114].

The transformation of the value proposition through shifting from products to digitally enabled solutions also necessitates the extension of the scope of digital resources and capabilities. New business model-specific digital infrastructure is to be developed, knowledge management strategies reconfigured, and a bunch of applications implemented [115,116].

Taken together, *digitalisation* broadens the technological base of competitive advantage and *requires the expansion of manufacturing companies’ core resources, along with the accumulation of new*

⁵ Most studies found a curvilinear (an inverted U-shape) relation between technological diversification and performance (reviewed by [109]).

capabilities (Fig. 2). It is worth noting that most of the studies discussing the new capability requirements of the digital era focus on dynamic capabilities for sensing the new developments in the competitive environment and transforming the business model for seizing the opportunities of DT [2,45,117]. Nevertheless, firms' insufficient knowledge of how to digitalise ordinary (operational) capabilities [84,118] and develop new (digital) product capabilities [4,47,112] often proves to be an equally important capability gap.

In practice, as shown in Fig. 2, *digitalisation reveals numerous and diverse capability gaps for established manufacturing firms*. As a result of growing technological and product complexity and given the multidisciplinary nature of new product development, single firms hardly possess all the specialised knowledge components and capabilities required for maintaining their competitiveness. Moreover, with accelerated technological change and fierce global competition, firms have no time to close their capability gaps through internal capability building. Consequently, they need to complement their internal resource accumulation efforts with external sources and integrate the specialised knowledge and technological solutions of external providers to address the identified resource and capability gaps.

Note that access to and integration of external resources and capabilities also requires a (new) set of internal capabilities, specifically relational, knowledge integration and orchestration capabilities [31,97,117]. Firms are compelled to identify and evaluate collaboration partners, align the resources and capabilities of the parties in a synergistic manner, in short, to build and manage an innovation ecosystem [38,119].

Accordingly, *digitalisation adds impetus to firms' inbound open innovation practices*, that is, to their accessing, integrating, and internalising specialised knowledge beyond the scope of not only their own expertise but also beyond the expertise that resides within the boundaries of their industry.

It needs to be pointed out that external collaborations envisaging access to specialised knowledge do not preclude efforts to develop in-house technological and R&D capabilities to manage digitalisation. On the contrary, internal capability development is paramount for the absorption of collaboration partners' knowledge [98]. Hence, besides resorting to external technology providers, established manufacturing companies also develop their own digital capabilities (as depicted both by the double arrows linking the technology providers and the established manufacturing firm and the arrows representing the focal firm's technological diversification efforts – Fig. 3, section b).

Diversification in new technological directions outside their original technological core reinforces the absorptive capacity of established manufacturing companies and strengthens their innovation capability. It enables them to custom-tailor the digital solutions implemented by digital technology providers, and more importantly, develop new, digitally enhanced products, and/or shift to digitally enabled business models.

Considered from the perspective of the resource-based theory and departing from the claim that firms belonging to the same industry possess similar resources and competences [120], it is obvious that *if firms start to integrate the resources of other industries into their own competence base, this blurs industry boundaries*. As disparate knowledge fields are combined and recombined in the course of firms' digital transformation processes, a growing set of previously unrelated industries become related (Fig. 3, section c).

Two remarks need to be made here. First, over and beyond commercialising their new digitally enhanced products, established incumbents draw on their new capabilities and expand the scope of their businesses by engaging in the external commercialisation of the digital technologies that they developed originally to serve internal competitive purposes. Drawing on *outbound open innovation* [121], the agile representatives of conventional industries engender

new competition dynamics outside their industries. Accordingly, penetration into established industries by technology companies is not the single direction of crossing industry boundaries. The opposite direction is also pertinent, when the representatives of conventional manufacturing industries engage in head-to-head competition with digital players in market segments that are 'normally' the targets of companies of the digital technology sector (as depicted in the bottom part of Fig. 3, section b). Industrial Internet of Things cloud platforms developed by manufacturing companies and opened up to provide services to third parties, such as Predix (GE), Mindsphere (Siemens), Volkswagen Industrial Cloud (VW), and Ecostruxure (Schneider Electric) are salient examples.

Second, when discussing, in the context of digitalisation, the paramount importance of internal R&D efforts that enable firms to leverage the external sources of innovation through combining external knowledge inputs with internal resources, studies usually refer to manufacturing firms' efforts to incorporate and utilise knowledge generated by firms in the digital technology sector [122]. However, scarce attention is devoted to the flipside of the same coin, to external knowledge providers' learning and incorporating manufacturing-specific knowledge. To improve the fit and performance of their solutions, external knowledge providers also need to broaden their knowledge bases: beyond the boundaries of their specialised knowledge. Technology providers must build complementary competences through learning about the specifics of their manufacturing customers' or collaboration partners' core technologies which is indispensable for the effective integration of their own solutions. In the context of this study, when developing digital solutions for manufacturing companies, digital technology providers need to develop manufacturing domain-specific knowledge (as depicted by the double arrows linking the technology providers and their customer, the established manufacturing firm – Fig. 3, section b).

The eventual outcome of these processes, when manufacturing firms and technology providers adventure outside their own technology domains to assimilate part of each other's competencies, is a *growing intersection of the knowledge, technology, and capability bases of manufacturing industries and industries in the digital technology sector*, aka the digitalisation-driven blurring of the boundaries of traditional manufacturing industries. Fig. 3 summarises the conceptual framework depicting the afore-discussed mechanisms.

The red arrows in section (b) indicate that established firms' technological diversification serves three purposes: (i) closing the capability gaps through internal capability development; (ii) improving absorptive capacity and thus enabling an effective collaboration with and coordination of digital technology providers; (iii) outbound open innovation (oOI).

Section (c) portrays (from the perspective of the focal firm) the outcome of a process in which both the focal firm, representing a traditional industry, and firms from the digital technology sector move beyond their traditional industry boundaries through integrating the resources of other industries into their own competence base.

Discussing the permeability of the boundaries of conventional manufacturing industries, incorporating the competencies and activities associated with the digital technology industries, the above analysis considers the blurring of industry boundaries in a specific and thus, somewhat limited context. However, considering the industry dimension of digital ubiquity, a broader context is also pertinent. Since digitalisation applies to and induces similar mechanisms in all industries, the number of common technological domains among different manufacturing industries will also increase – together with the bundles of resources that are common in different manufacturing industries. Consequently, the technological distance – the extent to which industries differ in their technological knowledge [123] – among manufacturing industries will diminish.

Illustrative examples from the automotive industry

This section presents examples from the automotive industry to illustrate the proposed framework. Epitomising digital disruption, blurred industry boundaries, and incumbent firms' successful adaptation, this industry is considered an appropriate setting for presenting illustrative examples [111,124]. Both digital and non-digital transformative technologies have been reshaping the automotive industry along its whole value chain [125], as well as the automotive value chains themselves. Addressing the challenges posed by new entrants, who compete on the basis of novel business models and try to disrupt established structures [124], incumbent lead companies also embrace digital technologies,⁶ engage in digital servitization through collaborations with technology firms, and experiment with new business models [111,126]. Consequently, today's end-product of the automotive industry epitomises the 'smart connected product' [6,112] or the smart product-service system [47] of the digital era, where the physical products are converted into platforms for software-based services provision [41,59,60].

Reporting on recent developments in the automotive industry, the business press abounds with examples of key actors' (original equipment manufacturers (OEMs) and Tier 1 suppliers) collaborations with digital technology providers. Table 1 lists some salient examples of such collaborations, illustrating that incumbent OEMs resort to third party technology providers who help them close their capability gaps in developing digitally enhanced products, digitalising manufacturing processes and business functions, and/or engaging in digital servitization and business model innovation. The selection of the cases was based on the principle of purposeful sampling [127]: we intended to select illuminative cases from the point of view of incumbent automotive companies' collaborations with digital technology providers.

Examples of digitalisation-induced outward open innovation are similarly abundant. Incumbents may not only roll out internally the digital solution they have developed for their own purposes but also commercialise it externally. One example is Volkswagen's above-mentioned collaborative project with AWS and Siemens. The resulting industrial cloud is designed as an open platform for third party firms who want to use it as an IoT platform in their facilities. The industrial cloud has become a community and marketplace for cloud-based processes connecting industrial equipment providers (e.g., ABB and Dürr) who contribute use cases that work best with their technologies, and industrial software providers and systems integrators who can co-develop solutions [131].

Another example is BMW's spin-off and wholly-owned subsidiary IDEALworks GmbH. The purpose of the – originally internal – project, carried out by BMW's logistics team, was the digitalisation and automation of BMW's production logistics. The outcome was an autonomous robotic system that relies on BMW's cloud-based management software. Since these robots are versatile enough to be used following some customisation in several different industries, BMW established a subsidiary to commercialise the solution externally. BMW's industrial cloud was also opened to third parties, providing digital infrastructure and management software for logistics solutions (Source: websites of BMW and IDEALworks).

Moving beyond the illustrative examples of individual companies, the multiplication of corporate venture capital funding by incumbent OEMs is a phenomenon that provides a broader perspective, since it integrates several building blocks of the framework proposed in this paper: specifically, cross-industry collaborations to close internal capability gaps and integrate the technologies and

expertise of digital technology providers, and incumbents' technology diversification and outward open innovation.

According to Statista, the global amount of funding invested annually in automotive technology start-up companies increased from USD 2 billion in 2013 to USD 27.5 billion in 2018 [132]. Established OEMs figure high among the top investors [133]. Their venture capital units identify start-ups to acquire or collaborate with in areas including autonomous vehicle and mobility-as-a-service technologies, robotics, industrial IoT, data analytics, cyber security, and so forth. Externally oriented venture capital units are complemented with a global network of internal innovation labs and centres of excellence specialised in the same focus areas. For example, Volkswagen has a globally distributed ecosystem consisting of venture capital units, corporate accelerators, incubators, and internal units: innovation and engineering centres, research labs, centres of excellence, and units specialised in launching open innovation challenges and linking internal and external actors to collaborate in specific projects [134].

The afore-discussed examples indicate a growing weight of digital output embedded both in the inputs and the output of traditional manufacturing firms. In terms of output, this development refers to manufacturing companies' shifting focus from physical products to smart product-service systems. These developments also demonstrate the multiplication of non-manufacturing actors in the value chains of traditional manufacturing companies, which is one manifestation of blurring industry boundaries. The flipside of the same coin – also illustrated by these examples – is that firms in established manufacturing industries increasingly integrate digital resources and capabilities into the portfolio of their core competences and turn to generating digital technologies themselves. Altogether, as indicated in section (c) of Fig. 3, actors in conventional manufacturing industries expand their technology and capability boundaries through open innovation and technological diversification, aligning external technology and knowledge acquisition with internal R&D and technological capability accumulation. Consequently, the intersection between the technology and capability bases of the digital technology sector and the traditional manufacturing industries becomes larger, which indicates the blurring of industry boundaries.

Concluding remarks, implications, and limitations

Digitalisation has transformed the structure of industries and the nature of competition therein. Drawing on new sources of competitive advantage, external-to-industry competitors penetrate traditional industries and disrupt established structures. In response to these threats, incumbents seek to extend their resources and capabilities by resorting to actors outside their industries for the provision of the necessary resources (open innovation) – a strategy they combine with internal capability building, in order to improve their absorptive capacity. Over time, incumbent actors' technological diversification efforts may culminate in their transformation from a traditional manufacturing company into a service-oriented digital company. Accordingly, incumbents in traditional industries will not only become self-sufficient in addressing specific digitalisation use cases but will also be able to compete with digital natives in the market for digital technologies. These developments intensify a long ongoing process: the blurring of industry boundaries.

In a nutshell, we analysed a particular outcome of two inter-related developments: the pervasive infusion of general-purpose digital technologies into the resources, products, processes, value chains, and business models of conventional manufacturing industries on one hand, and incumbent actors' above-summarised strategic adaption on the other hand. The ultimate outcome of these intertwined processes is an immersion of industry-external technology and knowledge into the core knowledge and capability bases

⁶ The automotive industry figures high in industry rankings (e.g., Boston Consulting Group, McKinsey, Deloitte), where digital maturity is assessed by the extent to which particular digital technologies are used in specific industries.

Table 1

Collaboration between automotive companies and digital technology providers.

Purpose of collaboration	Description of the collaboration
Development of integrated product-service offerings; digitally enhanced products	According to industry analyses, the magnitude of technical challenges associated with autonomous vehicle technology development requires broad-based collaborations involving a large number of technology providers and resulting in highly complex webs of collaborating partners [128,129]. For example, BMW has partnered with Inrix, a mobility analytics and connected car services provider, and embedded Inrix' parking-influenced routing solution in the navigation head units of its vehicles. (Source: ATZ Electronics, 12/2020 p. 27.) BMW also collaborates with Qualcomm Technologies and integrates Qualcomm's driver assistance technologies (e.g., vision system-on-chip, perception, and localisation) into its driving technology stack (Source: Qualcomm website). Another key technology company whose cameras, chips, and software are present in 80 per cent of vehicles with advanced driver assistance systems is Intel who acquired the autonomous driving technology company Mobileye [130].
Digitalising manufacturing processes	A typical production-oriented collaboration between automotive companies and digital technology providers envisages the implementation of smart autonomous logistics solutions. For example, BMW relies on Nvidia's autonomous logistics robots, running on Nvidia's robotics software platform, for parts and material transportation and sorting. (Source: Nvidia). Since connectedness, i.e., the integration and interoperability of information constitutes the very essence of digital transformation [85], implementing cyber-physical production systems and accomplishing horizontal and vertical connectedness of business functions and activities within business units and across the global value chain is the key overarching purpose of cross-industry collaborations. For example, Volkswagen AG established partnership with Amazon Web Services (AWS) and Siemens to jointly develop an industrial cloud, integrating Volkswagen's fragmented IT landscape into a digital production platform and running analytics on the data of all the machines, plants, and systems of Volkswagen's geographically dispersed facilities. Use cases include digital shopfloor management, predictive maintenance, smart quality management, energy management, and track and trace solutions. Individual sites can develop their site-specific solutions and roll them out to other sites via app store-like standardised processes. Siemens contributes expertise as an integration partner, responsible for connectivity of shopfloor equipment (e.g., through edge computing) and for specific service applications (Source: corporate websites). Another high-profile, albeit more-specific example of collaborations associated with the digitalisation of manufacturing processes, is Volkswagen's pilot 5 G project at its Wolfsburg plant, launched in collaboration with Nokia. Nokia deployed a private 5 G wireless network to support various smart factory applications. (Source: www.automotivemanufacturingsolutions.com, 06/12/2021).
Development of digitally enhanced business functions	In response to the radical transformation of car buying practices, OEMs collaborate with digital technology providers in a quest to control user touchpoints. For example, OEMs including Audi, Volkswagen, and Mitsubishi established partnerships with the British technology company ZeroLight. This company developed a cloud-based 3D visualisation solution for automotive marketing and sales. The technology permits potential customers to configure the required model virtually. Car buyers can test the functions of the car online via a virtual immersive experience. ZeroLight has sold the custom-tailored versions of its technology to. Multi-party collaborations involving traditional automotive companies, ZeroLight, and the digital giants: Amazon and Facebook permit OEMs to engage in more radical business model innovations. Disintermediating (or complementing) car dealerships, OEMs can stream directly their ZeroLight-powered content to potential customers' mobile phones (using the platforms of Amazon and Facebook) and thus, shift to a direct to customers (D2C) business model or employ multiple sales channels (Source: corporate websites).
Servitization, business model innovation	In accordance with industry trends characterised by OEMs' embracing platform-based strategies, BMW introduced an onboard app platform, offering several functionalities of the car as apps (e.g., parking lot finder, music streaming, digital key, personal assistant, traffic information, 'connected charging services'). This transition required collaboration with technology providers. For example, collaboration with Apple powers BMW's digital key, and collaboration with Amazon permitted the integration of Amazon's Alexa in BMW's app store (Source: BMW website). According to rumours in the business press (e.g., Bloomberg), negotiations on strategic partnership with Apple are going on about designing jointly a smart car. Another industry trend prompting OEMs' adaption is the increasing demand for mobility as a service. The magnitude and diversity of technical challenges associated with OEMs' transition into mobility services providers requires collaborations with or acquisition of technology companies – to be financed by consortia of multiple OEMs. For example, Daimler and BMW developed their portfolios of urban mobility services through both internal R&D and acquisitions of start-ups specialised in mobility services. In 2019, these two global players decided to unify their mobility services and invest €1 billion respectively to enhance and integrate these solutions into an all-electric, self-driving fleet of vehicles that charge and park autonomously and interconnect with other modes of transport. Meanwhile these two companies continue establishing partnerships with mobility services related technology providers. For example, BMW established partnership with Approov to integrate Approov's authentication software solution in its car sharing platform (Source: corporate websites).

of traditional industries (together with some knowledge spillover in the opposite direction) and thus, an increase in the common technological domains of technology industries and conventional industries.

This study contributes both to the scholarship on technology and industry convergence and to the expanding literature discussing incumbent companies' adaptation to the transformational pressures of digitalisation [34,41,45,65,111,117]. Its main contribution is that it provides a parsimonious framework explaining the mechanisms by which digitalisation advances the blurring of industry boundaries in manufacturing. This framework was derived from a conceptual approach involving the integration of four theories – (i) the RBT and the theory of dynamic capabilities; (ii) open innovation; (iii) absorptive capacity, and (iv) technological diversification – into a single

theoretical framework. We showed that these theories complement each other: together, they provide a more complete framework for understanding the mechanisms by which digitalisation blurs industry boundaries.

We pointed out that crossing the boundaries of established industries by technology companies is not the single expression of blurred industry boundaries. Building on their newly accumulated technological capabilities, incumbent manufacturing companies cross the boundaries of their industries in the opposite direction and commercialise their solutions outside their industries.

An important theoretical implication of our findings and a key direction of future research is that blurring industry boundaries call for revisiting a number of traditional theories where the underlying assumption is that industry boundaries are stable. Therefore, future

research should address the theoretical implications of digital convergence, for example, explore the convergence-induced evolution of the structure of industries and value chains.

Another theoretical lesson is connected to the performance impact of corporate and technological diversification [109,135,136]. The blurring of industry boundaries sheds new light on the commonly accepted assumption that (too much) unrelated diversification is detrimental to performance. Recently, [136] found that the relationship between unrelated corporate diversification and firm performance has improved significantly over the past two decades. This is understandable from the perspective of our assertion that with blurring industry boundaries, a growing set of unrelated industries become 'related' in terms of common technological segments, functionalities, and capability requirements. Future research should investigate whether the curvilinear relation between technological diversification and performance, established in prior studies (e.g., [109]), still holds, or rather, how the changes in this relationship modify the shape of the curve.

Our findings have several important managerial implications. First, managers have to recognise that in an era when digitalisation makes it increasingly difficult to delimit industry boundaries, the statement that competitors may 'arrive from every corner', i.e., from outside the industry boundaries, is also true the other way round. As the range of applications for digital technology keeps growing, leveraging newly acquired digital expertise across new business areas offers exceptional opportunities. As a flipside, firms need to monitor a broader variety of markets and identify how to embed new technologies into their own processes and/or offerings.

At the same time, even when venturing outside the narrow boundaries of their industries, managers in established manufacturing industries need to understand the value of their domain-specific capabilities and devise a digital growth strategy that aligns new capabilities with the ones that have been accumulated and perfected for decades.

As for the accumulation of a new set of capabilities, an important message of this study is that in an era when firms cannot possess all the required capabilities for maintaining and improving their competitiveness, their resource-based strategies need to focus on developing *key enabling competences* such as knowledge integration and recombination, and relational and resource orchestration capabilities.

Since our focus was limited one specific type of industry boundary, which is an important limitation, this study should be considered a steppingstone for further research that considers additional sectors, industries, and technologies. Furthermore, incorporation of additional theoretical building blocks in the framework may add further nuance and clarity. An additional theoretical strand that is closely related to the question how digitalisation advances the blurring of industry boundaries is the transaction cost theory elaborating on factors moderating firms' 'make, buy, or collaborate' decisions. Relatedly, the scholarship discussing ecosystems (organisational forms of value creation among partners aligning resources and complementary competences) is similarly germane, since it clearly expresses that digitalisation exerts an impact on actors' constellation (number, heterogeneity, position, and linkages) in value chains. Therefore, another avenue for future research is to incorporate also these theoretical perspectives in the framework introduced in section 4.

Another important limitation of this study is that we used one single industry as illustration, sidestepping the fact that there are non-negligible inter-industry differences in terms of the permeability of their boundaries. Consequently, a possible direction of future research is to examine whether the boundaries of digital frontrunner industries are more permeable than the ones of digital laggards and how the permeability of industry boundaries relates to performance.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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