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The Digital Transformation of Search and Recombination in the Innovation Function: Tensions and an Integrative Framework*

Gianvito Lanzolla, Danilo Pesce, and Christopher L. Tucci

Search and recombination are important mechanisms in the creativity phase of innovation. Digital transformation and the resulting pervasive digitalization of the innovation function have often been associated with increasing possibilities for search and recombination. In this paper, by systematically integrating the search and recombination literature with the literature on digitalization, we demonstrate that digitalization may engender new idiosyncratic tensions in the organizational antecedents of search and recombination and, by implication, in their likely outcomes. We propose that, depending on the interactions among the idiosyncratic tensions identified herein, knowledge recombination might spur very different outcomes, including knowledge layering, knowledge integration, knowledge grafting, or even no recombination at all (which we label "search for the sake of search"). These outcomes may not always be the initially planned desired outcomes. Finally, we provide implications of our integrative framework pertaining to product development and to organizing for innovation.

Practitioner Points

- Digitalization has no magical effects on creativity and innovation, and strategy and management should play a central role in designing and implementing digitalization.
- Innovation managers may want to pay close attention to the cognitive and emotional costs of adopting digital technologies.
- Digitalization may enable broader knowledge search and more effective knowledge recombination in the creativity phase of innovation if organizations implement digitalization by paying attention to blending subject matter expertise with digital skills.
- Digitalization can hamper innovation and creativity ("search for the sake of search") when digital technology is implemented by reinforcing existing knowledge networks, and subject matter experts and "digital champions" see each other as competitors.

Address correspondence to: Gianvito Lanzolla, The Business School, City, University of London, 106 Bunhill Row, London, EC1Y 8TZ, United Kingdom. E-mail: g.lanzolla@city.ac.uk

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Introduction

Digital technologies—for example, the Internet of Things, mobile connectivity, cloud services, artificial intelligence—are widely predicted to be pervasive within institutions, societies, and organizations, and it is not uncommon to see them linked to concepts such as "transformation," "paradigm shift," and the "4th Industrial Revolution." It is an excellent example of a technological change that has far-reaching impacts on firms across multiple sectors, a topic central to the field of innovation management for several decades (e.g., Abernathy and Clark, 1985; Afuah and Tucci, 2003; Henderson and Clark, 1990; Tushman and Anderson, 1986).

In the innovation management literature, digital technologies have been associated with new possibilities and opportunities for product and innovation management (e.g., Lyytinen, Yoo, and Boland, 2016; Tucci, Chesbrough, Piller, and West, 2016; Villarroel, 2013). For instance, Dougherty and Dunne (2012) analyze the generation of scientific knowledge that would not be possible without digital technologies, such as bioinformatics, metabolomics, or genomics. Other scholars have highlighted that digital technologies may enable new innovation management practices including boundary-spanning approaches (e.g., Levina and Vaast, 2005; Lindgren, Andersson, and Henfridsson, 2008), innovation from networks (e.g., Boland, Lyytinen, and Yoo, 2007; Powell, 1990; Tuomi, 2002; Van de Ven and Poole, 2005; Von Hippel, 2007) or from ecosystems (e.g., Basole, 2009; Selander, Henfridsson, and Svahn, 2013), rather than traditional organizational hierarchies. A sizeable body of literature has focused on the role of digital technologies in enabling Open Innovation and its more recent manifestation: crowdsourcing (e.g., Acar, 2019; Afuah and Tucci, 2012; Poetz and Schreier, 2012; Pollok, Lüttgens, and Piller, 2019; Tucci et al., 2016).

However, the debate on the impact of digital technology adoption for innovation management is still inconclusive. Digital technology adoption goes well beyond the technical processes of adopting, and involves, for instance, organizing new sociotechnical structures (e.g., Almirall and Casadesus-Masanell 2010; Bailey, Leonardi, and Barley, 2012; Yoo, 2012; Yoo, Henfridsson, and Lyytinen, 2010), bringing in new organizational skills (e.g., Troilo, De Luca, and Guenzi, 2017), and establishing new organizational structures (Brunswicker, Almirall, and Majchrzak, 2019; Viscusi and Tucci, 2018). Summarizing the current state of the debate, Appio, Frattini, Messeni Petruzzelli, and Neirotti (2018, p. 2) highlight that "how digital technologies sustain—and change—the foundations of organizational learning, absorptive capacity, combinative capabilities, dynamic capabilities, or shape open innovation and technological complementarities, remains underexplored."

Given the above, there are enormous possibilities for studying the role of digitalization on innovation and new product development in this world of expanded possibilities. In this paper, we are focusing on one important stream in the management literature related to innovation and product development: search and recombination of knowledge. As we argue in much more detail below, digitalization is already being demonstrated to having a profound impact on the search and recombination of knowledge (Austin, Devin, and Sullivan, 2012; Thomke, 2020). What is less obvious are the mechanisms by which digitalization influences knowledge search and recombination and how those filter down to innovation outcomes. In other words, prior research has not fully investigated the boundary conditions of when digitalization might enable different types of knowledge search and different types of knowledge recombination.

Knowledge search and recombination are thought to be of critical importance in the innovation process (Savino, Messeni Petruzzelli, and Albino, 2017), especially in the key early stages of creativity, ideation, and identifying new markets (Bonaccorsi, 2006; Sunley, Pinch, Reimer, and Macmillen, 2008).[1] We argue that in order to arrive at a more complete understanding of digitalization and innovation, we should, therefore, start with the most basic building blocks used early on in the chain (e.g., creativity, ideation, new product concepts). Even the later stages of the innovation chain, important in their own right as process innovations and making the product development process leaner, rely on knowledge search and recombination. To bear witness to the importance of the two innovation management mechanisms of search and recombination, since 2010, the *Journal of Product Innovation Management (JPIM)* alone counts more than 70 papers elucidating the role of search and recombination in innovation and new product development (NPD), based on a *JPIM* search on Google Scholar.

BIOGRAPHICAL SKETCHES

Dr. Gianvito Lanzolla is Professor of Corporate Strategy, Dean of the Faculty of Management, and Founding Director of the Digital Leadership Research Centre at the Business School, City, University of London. His research on technology strategy and digital transformation has been published in leading outlets including the *Academy of Management Journal*, *Academy of Management Review*, *Journal of Management*, *Journal of Management Studies* and *Harvard Business Review*. He contributes as an advisor to boards and executive leadership teams of leading global corporations and fast-growing companies.

Dr. Danilo Pesce is a postdoctoral research fellow at Politecnico di Torino and at the Business School, City, University of London. His research interests are mainly focused on the organizational and industry-level changes triggered by digital technologies adoption.

Dr. Christopher L. Tucci (Ph.D., Management of Technological Innovation, MIT Sloan School of Management) is Professor of Digital Strategy & Innovation at Imperial College Business School, where he directs the Centre for Digital Transformation. He was an industrial computer scientist in the 1980s involved in developing Internet protocols and applying artificial intelligence tools. Professor Tucci teaches courses in Design Thinking, Digital Strategy, and Innovation Management. His primary area of interest is in how firms make transitions to new business models, technologies, and organizational forms. He also studies crowdsourcing, Internetworking, and digital innovations. He is widely published, with over 250 papers and several books. His paper with Allan Afuah, "Crowdsourcing as solution to distant search," won the *Academy of Management Review*'s Best Paper Award in 2012 and the Best Practice Implications Award in 2019. He has served in leadership positions in the Academy of Management and the Strategic Management Society.

[1]Of course, digital technologies could also be extremely useful in all stages of the innovation process, for example, 3D printing and "digital twins" could help with experimentation and prototyping (Fixson and Marion, 2012; McAfee, 2019; Rayna and Striukova, 2016), and digital A/B testing, Augmented Reality (AR), and Virtual Reality (VR), could aid with testing (Luchs, Swan, and Creusen, 2015).

Thus, in this paper, we endeavor to develop a systematic and integrative framework on the joint consequences of digitization and connectivity—which hereafter we will call for simplicity *digitalization*—on search and recombination of knowledge, and thus the innovation function. We focus on digitization and connectivity rather than any specific digital technology (e.g., IoT, cloud computing, mobile connectivity) because digitization and connectivity are the bedrock of any digital transformation process (Adner, Puranam, and Zhu, 2019; Tilson, Lyytinen, and Sørensen, 2010; Yoo et al., 2010, 2012).

To accomplish our goal of understanding various tensions engendered by digitalization, first, we review recent developments in the literature of search and recombination to identify the organizational antecedents of different types of search and recombination. This leads us to identify three relevant categories: knowledge and organizational learning; resources and capabilities; and cognitive and emotional costs. Second, we perform a systematic review of the literature streams addressing the relationship between digitalization, organization, and organizing, from which we distill the most important idiosyncratic tensions triggered by digitalization and how they relate to the organizational antecedents of search and recombination.[2] Our analysis reveals that digitalization can engender new micro-foundations for search and recombination mechanisms and that the effects of such changes are not unidirectional and unambiguous; in fact, quite the contrary.

Based on our analysis, we propose the following tensions to capture such implications: digitalization reinforcing versus overturning existing knowledge structures; digitalization substituting versus complementing existing competences; and digitalization increasing versus decreasing cognitive and emotional "costs." Finally, we systematically integrate our findings to develop a comprehensive framework that reveals the nonlinear and ambiguous implications of digitalization on knowledge search and knowledge recombination outcomes. We propose that, depending on the interactions among the idiosyncratic tensions identified herein, knowledge recombination might spur very different outcomes, including knowledge layering, knowledge integration, knowledge grafting, or even no recombination at all (which we label "search for the sake of search"). These outcomes may not always be the initially planned desired outcomes. Our integrative framework is then used for deriving implications for product innovation strategies and product innovation management in the Digital Age.

Our contribution is fourfold. First, we provide an updated and expanded classification of the organizational antecedents of search and recombination. Second, we identify the idiosyncratic tensions triggered by digitalization in the organizational antecedents of search and recombination. Third, we develop an integrative framework that can move us a step closer to gauge the likely outcomes of search and recombination mechanisms in the Digital Age. Finally, based on our framework, we provide insights into product innovation strategy and management in the Digital Age. Jointly, these contributions provide insights into the (interrelated) literatures of knowledge management, search and recombination, technology management, and innovation management.

Organizational Enablers and Outputs of Search and Recombination

There are many aspects of the innovation and new product development process that one can study. If we think of the entire process as a chain, with looping iterations at any point, some of the main categories are creativity/ideation, design, prototyping, and testing (Acklin, 2010; Cooper, 1990; Galanakis, 2006), followed by launch and post-sales service. As discussed above, in this paper, we focus on the more upstream part of the process, primarily creativity and knowledge creation. Creativity and knowledge creation are an essential part of this chain (Alves, Marques, Saur, and Marques, 2007; Amabile, 1988) and can range from incremental improvements to radical ideas for breakthrough new products, services or processes (George, 2007; Jung and Lee, 2016; Madjar, Greenberg, and Chen, 2011; Singh and Fleming, 2010).

There has been extensive work in different literature streams—including organizational learning, technological innovation, organizational adaptation, strategic management, innovation management, and organizational design—tying creativity and knowledge creation with the search and recombination of knowledge. Studies in these areas view search and recombination as problem-solving activities that involve the discovery and creation of knowledge

[2]We concentrate in this paper on the first-order effects of digitalization and connectivity. AI's idiosyncratic affordances might interact with our baseline model and we take up this point in the Discussion and Conclusions section.

(e.g., March, 1991; Nelson and Winter, 1982; Winter, 1984). Consequently, the literature has focused on analyzing the relationship between search, local search (also referred to as exploitation), distant search (also referred to as exploration) and the degree to which existing knowledge is re-combined, re-used or exploited (e.g., Huber, 1991; Rosenkopf and Nerkar, 2001; Stuart and Podolny, 1996). Recent studies have also proposed a variety of antecedents and some have proposed more complex relationships and potential moderating effects in how firms search and recombine knowledge to create new products (e.g., Fleming, 2001; Jansen, Van Den Bosch, and Volberda, 2006; Katila and Ahuja, 2002; Patel and Husairi, 2018).

Search, Recombination, and Innovation

Firms attempt to solve problems in ambiguous and uncertain environments (cf. Huber, 1991) in many cases by engaging in organizational learning through **search** processes. Organizations may undertake a wide variety of searches: for example, to develop new innovations (Von Hippel and Tyre, 1995), to create new methods for manufacturing (Jaikumar and Bohn, 1992), and to conceive of improved organizational designs (Bruderer and Singh, 1996). Winter (1984) defines real search activities as ones involved in the "manipulation and recombination of the actual technological and organizational ideas and skills associated with a particular economic context." In his seminal paper, Winter proposed that the search model gives firms two main possibilities. First, that the searching firm draws knowledge from other firms engaged in the same sort of activity, which several researchers characterize as *local search* (Cyert and March, 1963; Fleming and Sorenson, 2004; Hansen and Løvås, 2004; March and Simon, 1958; Nelson and Winter, 1982; Stuart and Podolny, 1996) or relatedly *exploitation* (March, 1991). Local search also implies that organizations address problems with their pre-existing knowledge bases, or knowledge that is highly related to it (cf. Helfat, 1994; Martin and Mitchell, 1998; Stuart and Podolny, 1996); in other words, organizations search incrementally (Fleming and Sorenson, 2004). This can also be referred to as searching more deeply or more narrowly.

In contrast, one major source of new knowledge might come from the firm's external environment, which is often referred to as *distant search or broad search* (Afuah and Tucci, 2012; Chesbrough, 2003; Fleming and Sorenson 2004; Gruber, MacMillan, and Thompson, 2012; Laursen, 2012; Rosenkopf and Nerkar, 2001) or what Heiner (1986) would characterize as knowledge beyond the normal experiences of the focal firm and March (1991) as *exploration*. Thus, distant or exploratory search behaviors may be the result of conscious or purposive efforts to expand one's knowledge base away from current knowledge and routines (March, 1991).[3] In what follows below, we briefly introduce each concept (search depth, search breadth, and recombination) before moving on to classifying the antecedents to search and recombination in the next section.

Search depth. Search depth is often defined as looking for new knowledge within current knowledge structures and areas of expertise, thereby "deepening" the knowledge base of an organization (cf. Winter, 1984). This has implications for problem-solving (cf. Ahuja and Lampert, 2001; Garriga, Von Krogh, and Spaeth, 2013; Helfat, 1997; Huber, 1991; Katila, 2002; Leonard-Barton, 1992; March, 1991; Winter, 2000) and product development (cf. Dougherty and Hardy, 1996). Katila and Ahuja (2002) propose that increasing search depth may have a positive impact on product innovation. These positive influences may be due to different kinds of "experience effects." Further, as discussed in more detail below, innovation and product development tasks subject to deep searches might be modularized and decomposed, breaking them into more manageable chunks that can be solved or optimized (cf. Eisenhardt and Tabrizi, 1995). However, the search depth may not always have a positive influence on innovation. There could be diminishing returns to the technology's performance with cumulative effort (Dosi, 1988; Foster, 1986). In addition, routines and constant reuse may lead to rigidities as old solutions (that worked well in the past) might be applied inappropriately to new situations (Argyris and Schon, 1978).

Search breadth. Search breadth is often defined as looking for new knowledge outside current knowledge structures and areas of expertise, thereby

[3]We realize that there are several nuances in the literature regarding these terms, but the overall grouping of deep/ narrow/ local/ exploitation versus broad/ distant/exploration is useful for exploring the effects of digitalization, so we will maintain this dichotomy in the manuscript employing the terms "search depth vs. search breadth," while acknowledging that reasonable people might disagree that these terms mean exactly the same thing or that they are polar opposites (cf. Katila and Ahuja, 2002 discussed further below).

"broadening" the knowledge base of an organization (cf. Winter, 1984). Evolutionary theories of organization suggest that broader search positively affects product innovation. Searching broadly may enhance the pool of knowledge through variation and novelty of knowledge employed by the external source (Teodoridis, Bikard, and Vakili, 2019). This variety and novelty are necessary for problem-solving (March, 1991). Evolutionary theorists label this the "selection effect of variation" (Katila and Ahuja 2002; Levinthal and March, 1981; Nelson and Winter, 1982).

Moreover, evolutionary theories of the organization also suggest negative consequences of broad search: the integration costs for the distant knowledge may be higher, the reliability of such distant knowledge might be lower (Katila and Ahuja, 2002) or a fast pace of knowledge change in specialized domains may reduce or eliminate the benefits of broad search (Teodoridis et al., 2019). Thus, as search scope broadens, the percentage of knowledge that needs to be integrated into the knowledge base of the organization also increases, and that might lead to challenges in both technological and organizational integration (Katila and Ahuja, 2002). The broader the search or higher the scope, the more difficult and complex the integration problems are (Grant, 1996). Taken to an extreme, at some point, the benefits of broader search and opportunities of new knowledge will be dwarfed by the costs of knowledge integration. Further, regarding the reliability of distant knowledge, attempting to incorporate distant knowledge into the firm may lead to the decreasing reliability of the firm's products (cf. Martin and Mitchell, 1998), or may make it more difficult for the firm to respond to new stimuli that require accurate decision-making (Heiner, 1986).

Recombination. Closely intertwined with the search literature are the works of literature on knowledge characteristics and recombination mechanisms that seek to shed light on the formal and informal mechanisms through which effective knowledge integration may happen. As far back as 1934, Schumpeter already broached the topics of economic development, innovation, and entrepreneurship as based on "new combinations" that could lead to new products, services, methods (processes), and markets (Schumpeter, 1934). Weick (1979) discussed the role of recombination in the creative process: "putting new things in old combinations and old things in new combinations" (p. 252).

Garud and Nayyar (1994) proposed the notion of "transformative capacity," which they claimed helps understand how firms can use, combine, and recombine existing and past knowledge (technologies "on the shelf"), as well as save current technologies and knowledge for later use. The concept was intended to be complementary to the notion of absorptive capacity, building on the resource-based view and developing an analogy with "pollination" with innovation recombination: "Knowledge is like pollen; it creates new knowledge by interacting with other knowledge vectors acting as stamen" (Garud and Nayyar, 1994, p. 372). As with the creation of hybrid plant varieties, creating new businesses is a probabilistic and path-dependent process. Therefore, consistent with the pollination analogy, time lags in knowledge and market development might open up opportunities for recombination based on the choice of knowledge vectors, the maintenance of knowledge vectors, and reactivation and synthesis of knowledge vectors.

Harvey (2014) articulates an interesting model for producing breakthrough ideas. Rather than assuming that each individual idea stands alone and that group creativity is about generating many ideas so that any one of them might be a good one (which one could conceive of as a pure enhanced search strategy), Harvey proposes that instead, the knowledge developed by the group could build upon the various ideas by connecting them or looking for commonalities among them, thus recombining "cognitive, social, and environmental resources" into better knowledge outcomes. Likewise, Hargadon (2002) explores the link between learning and innovation by examining the role of knowledge brokering in disassembling and recombining knowledge (ideas, artifacts, and even people) in organizations. Specifically, Hargadon studied how moving knowledge that is currently in use in one part of an organization via knowledge brokering to another part allows the opportunity to recombine the ideas to come up with innovations. Knowledge brokering thus involves spotting opportunities to apply existing knowledge to new situations: "In organizations, this process of linking existing knowledge to new situations, of creating new combinations of existing ideas, must occur across individuals and groups, and over time" (p. 45).

Recombination is also intimately bound up with search itself. With constant reuse and deep searching, the firm might develop a more nuanced understanding of (sub)problems and may be able to identify synergies and new combinations (Katila and Ahuja, 2002). In addition, broader search may increase the number of new products via the mechanism of recombination (Fleming and Sorenson, 2004; Nelson and Winter, 1982). The argument goes that given a certain baseline of knowledge elements, there is a limit to the number of novel ideas that can spring from them. Thus, broader search adds new knowledge elements to the baseline, which then can be recombined with the existing baseline to invent new products or to create new knowledge.

Classifying Search and Recombination

To conduct our analysis of the literature, we searched[4] in 30 leading journals[5] in several domains, such as general management, human resource management, information management, innovation, international business studies, marketing, management science, organization studies, and strategy. Our initial screening of the literature returned 607 journal papers. We downloaded the full papers in PDF format and saved their associated references into a bibliographic package. We carefully read the title, abstract, and, in some cases, the full text, before deciding on classifying each as "in" or "out." Papers that were included in our systematic review were the ones that focused on the antecedents of search and recombination, and their organizational outcomes. We then also included publications referenced by the authors of this first set of studies as seminal contributions in the adjacent stream of literature on "exploration and exploitation" (e.g., Levinthal and March, 1993; March, 1991). Overall, our final literature review of this topic is based on 171 papers.

The systematic analysis of these papers allows us to identify some key mechanisms and contingencies that are more likely to enable—or hinder—effective search and recombination. In what follows, we briefly synthesize such findings with the view to provide the background for the subsequent integration with the literature on digitization and connectivity.[6]Details on the literature review are available upon request from the Authors.

Knowledge and organizational learning. The different antecedents of search and recombination fall into three main themes.[6] First off, there is the theme of *knowledge and organizational learning*, which includes such topics as organizational knowledge, characteristics of knowledge, organizational learning, and absorptive capacity. In this theme, we find linkages in the literature between different ways of conceptualizing knowledge at the organizational level and search/recombination, for example, the role that modularity of knowledge plays in search behavior of firms, or how absorptive capacity might constrain search behavior of firms.

To explore one example further, the "tacitness" of knowledge and complexity of a problem (Kogut and Zander, 1992; Reed and DeFillippi, 1990; Winter, 1987) may limit the problem's delineation and transmission. Tacit knowledge cannot be described fully and cannot be codified (Polanyi, 1967; Winter, 1987), and is thought to be transferred from person to person in a labor-intensive fashion (Teece, 1977; Zander and Kogut, 1995). The tacit nature of certain kinds of knowledge might also make it difficult to evaluate, transfer, and (re)combine that kind of knowledge, especially when it is the result of distant or broad search processes (Afuah and Tucci, 2012; Kogut and Zander, 1992; Nonaka, 1994; Von Hippel, 2005). Along the same lines, knowledge complexity (interdependencies between knowledge elements) makes evaluation, transfer, and (re)combination of distant knowledge quite challenging. The high complexity of distant knowledge requires even more work for knowledge transfer, and higher tacitness of distant knowledge requires higher media richness for knowledge transfer (Teece, 1981), thus hindering the delineation and

[4]We used SCOPUS and searched for the terms (in titles, abstract and paper keywords, through 2019): search AND recombination, search AND knowledge, search AND innovation, recombination OR combination AND knowledge, recombination OR combination AND innovation, recombinant search, and recombinant innovation. The choice of SCOPUS was based on database access but since we were searching exclusively in 30 important journals, there should be no selection issues relative to other search engines.

[5]The journals included in the analyses are *Academy Of Management Annals, Academy of Management Discoveries, Academy Of Management Journal, Academy Of Management Perspectives, Academy of Management Perspectives, Academy Of Management Review, Administrative Science Quarterly, California Management Review, Harvard Business Review, Human Relations, Information Systems Research, Journal Of Consumer Research, Journal Of International Business Studies, Journal Of Management, Journal Of Management Studies, Journal Of Marketing, Journal Of Product Innovation Management, Journal Of Strategic Entrepreneurship, Journal Of Strategic Information Systems, Leadership Quarterly, Management Science, Marketing Science, Management Information Systems Quarterly (MISQ), MIT Sloan Management Review, Organization Science, Organization Studies, Research Policy, Strategic Entrepreneurship Journal, Strategic Management Journal, Strategy Science*.

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transmission process. Complex problems might need to be simplified to ease communication with external parties, but the simplification might lead to misunderstandings or incorrect/irrelevant solutions. This could be exacerbated by the focal firm's usage of their traditional cognitive frames and routines in transmitting or translating the problem (cf. Afuah and Tucci, 2012; Henderson and Clark, 1990).

Resources and capabilities. The second theme is on firm *resources and capabilities*, which includes topics such as core capabilities, dynamic capabilities, technological capabilities, combinative capabilities, process management, and resource endowments. This theme is less focused on knowledge per se, but rather on different kinds of capabilities that firms exhibit, such as how core capabilities might bias an organization toward local search, or how combinative capabilities are related to knowledge recombination.

As an example of insight in this literature, the higher levels of organizational slack, it is proposed that the more diverse the organization and the more widely distributed the skills are to solve a certain problem, the higher the likelihood that someone will have the correct knowledge to solve the problem, or at least that someone will be able to engage in local search to solve the problem (Nohria and Gulati, 1996; Troilo, De Luca, and Atuahene-Gima, 2014). In fact, in searching deeply or broadly, the firm can obtain a collection of "fragments of knowledge of possible usefulness in the improvement of its routines" (Winter, 1984, p. 293). As argued by Winter (1984), because such fragments may be quite limited relative to the firm's full routines, adoption, use, and recombination of the knowledge fragments also require efforts by the firm in problem-solving of a complementary nature. This is fully consistent with absorptive capacity arguments.[7] In the same light, technological recombination requires language and interface commonality to be able to be diffused within an organization and even to enter an organization (e.g., Forman and van Zeebroeck, 2019; Savino et al., 2017; Trantopoulos, von Krogh, Wallin, and Woerter, 2017; Vaccaro, Veloso, and Brusoni, 2009). The information processing needs of the different groups may require lateral information-processing mechanisms (Galbraith, 1973).

[7]Technically, absorptive capacity should be neutral regarding whether it promotes search depth or search breadth, since investments in knowledge could help broker new knowledge acquisition in either distant or local domains (cf. the discussion on horizontal vs vertical recombination in Teodoridis et al., 2019).

Cognitive and emotional costs. The third theme that we found in our literature review is that of *cognitive and emotional costs* and includes such elements as cognitive and behavioral inclinations, cognitive and behavioral structures, socio-emotional and behavioral inclinations, and organizational behavior and culture. These papers focus on for example, how culture might shape search behavior, the role of leadership and managerial attention in search and recombination, and how decentralization and autonomy of smaller units might bias toward or away from search and recombination. More recently, the literature has started complementing the structural (e.g., Henderson and Clark, 1990) and cognitive perspectives (e.g., Gavetti and Levinthal, 2000; Gavetti and Rivkin, 2007; Gavetti, Greve, Levinthal, and Ocasio, 2012; March and Simon, 1958; Pisano, 1994) with individual and collective emotions (Huy, 1999, 2011; Vuori and Huy, 2016). For instance, Vuori and Huy (2016) show that emotions influence people's choices and behaviors (e.g., Izard, 2009; Phelps, Lempert, and Sokol-Hessner, 2014), social processes (e.g., Hareli and Rafaeli 2008; Niedenthal and Brauer, 2012), and organization members' thinking and behavior related to strategy implementation (Huy, 2002, 2011; Huy, Corley, and Kraatz, 2014) and—by implication—the scope for wider search and recombination. We group these together under the rubric "cognitive and emotional costs" as antecedents to search and recombination and will come back to these themes later in this paper as we develop an integrative framework for the role that digitalization might play in search, recombination, and innovation outcomes.

The Digital Transformation of Search and Recombination: New Tensions

Earlier in this paper, we have proposed that knowledge and organizational learning; resources and capabilities; and cognitive and emotional costs are major antecedents of the scope of search and recombination behaviors related to the innovation function. To build our framework on the impact of digitalization on search and recombination, we now turn to a systematic analysis of the impact of digitalization on those three major antecedents. To identify such an impact, we searched the same online database and leading journals used for reviewing the search and recombination literature above using several keywords related to

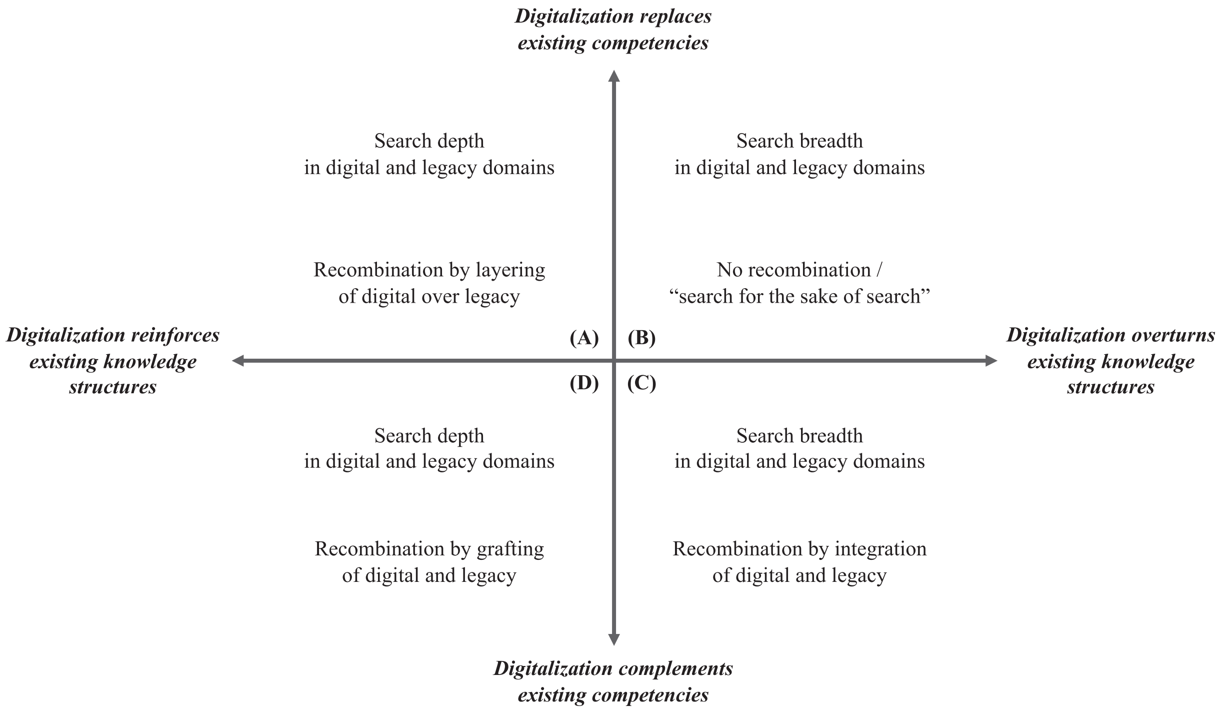

Figure 1. The Digitalization of Search and Recombination: Toward an Integrative Framework

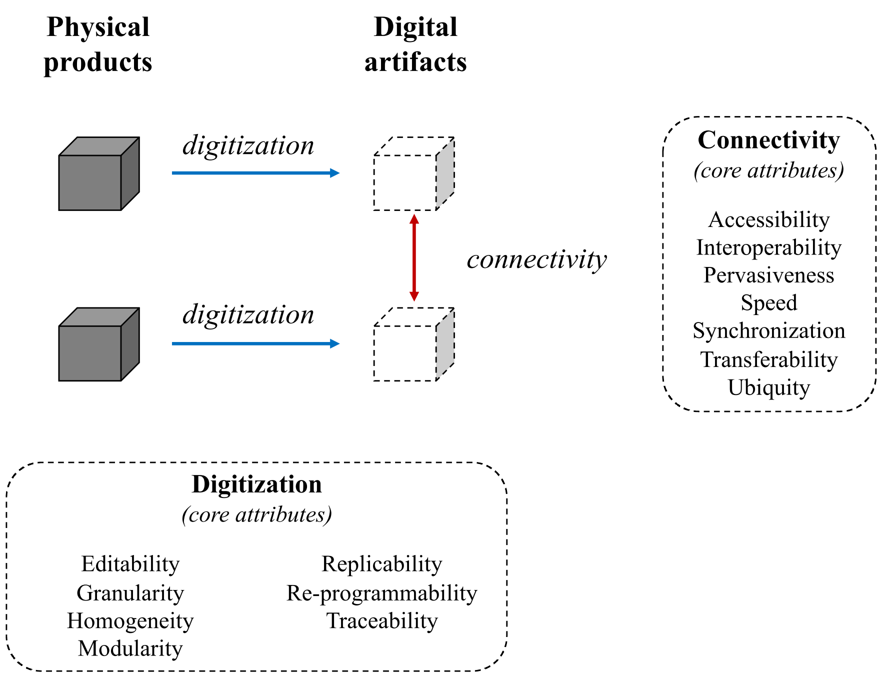

Figure 2. The Impact of Digitization and Connectivity on the "Digital Transformation" of Physical Products

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digitization and connectivity.[8] Our initial screening of the literature returned 649 journal papers. Using the same process and bibliographic software as we did for the antecedents, we selected papers that focused on organizational changes triggered by such technologies. Overall, our final literature review underpinning the development of this framework is based on 169 papers.

In what follows, we systematically review these papers, often rooted in partially overlapping literature streams, to identify possible impacts of digital technology adoption on the antecedents of search and recombination. Our focus here is on the identification of *idiosyncratic* impacts of digitalization, that is, the impact directly related to digital technology adoption. For the sake of clarity, we represent the idiosyncratic tensions we identified in Figure 1. What follows below is an extensive discussion, starting with digitalization and knowledge and organizational learning (the X-axis), digitalization and resources and capabilities (the Y-axis), and digitalization and cognitive and emotional costs (the third dimension of our framework that we will discuss further below).

Digitalization and Knowledge and Organizational Learning

This section builds up to the X-axis in Figure 1. Digitization and connectivity are not neutral vis-à-vis the information being digitized (Tilson et al., 2010; Yoo et al., 2010, 2012). Let us start with digitization (converting physical to digital) and then move on to connectivity. Digitized artifacts exhibit some new attributes such as being *editable*, *replicable*, *granular*, *re-programmable*, *homogeneous*, *traceable*, and *modular* (e.g., Bahrami and Evans, 2011; Barrett, Davidson, and Vargo, 2015; Kallinikos, Aaltonen, and Marton, 2013; Lusch and Nambisan, 2015; Yoo et al., 2012).[6]

Likewise, connectivity enables new attributes and these include *interoperability* (e.g., Bharadwaj, El Sawy, Pavlou, and Venkatraman, 2013; Kallinikos et al., 2013; Porter and Heppelmann, 2014, 2015; Yoo et al., 2012), *pervasiveness* (e.g., Kolb, 2008; Kolb, Caza, and Collins, 2012; Wajcman and Rose, 2011), *speed* (e.g., Bharadwaj et al., 2013; Lazer and Friedman, 2007; Siggelkow and Rivkin, 2005; Svahn and Henfridsson, 2012), *synchronization* (e.g., Angwin and Vaara, 2005; Chatterjee, Segars, and Watson, 2006; Overby, 2008; Porter and Heppelmann, 2014), *accessibility/transferability* (e.g., Cross, Laseter, Parker, and Velasquez, 2006; Kallinikos et al., 2013; Lee and Berente, 2012; Leonardi and Bailey, 2008; Matusik and Mickel, 2011; Mazmanian, 2013; Mazmanian, Orlikowski, and Yates, 2013; Zittrain, 2006, 2008; Zhang, Yoo, Wattal, Zhang, and Kulathinal, 2014), and *ubiquity* (e.g., Iansiti and Lakhani, 2014; Kolb, 2008; Mardon and Belk, 2018; Sørensen and Landau, 2015; Wajcman and Rose, 2011).[6] Figure 2 provides a succinct visual representation of these properties in a holistic fashion.

While the list of new attributes is fairly uncontroversial, our analysis of the literature shows that the implications of these new attributes on knowledge and organizational learning are ambiguous. On one hand, digitalization—by allowing the decomposition/atomization of the elements by which digital artifacts are made, and by re-shuffling these elements to new configurations (Kallinikos, Aaltonen, and Marton, 2010)—might enable possibilities of gaining access to previously distant knowledge. Lessig (2002) argues that digital technologies "could enable an extraordinary range of ordinary people to become part of a creative process" (Lessig, 2002, p. 9) and von Hippel (2005) emphasizes that "even individual hobbyists have access to sophisticated design tools […] With relatively little training and practice, they enable users to design new products and services" (Von Hippel, 2005, p. 13).

On the other hand, digitalization may create new connections and enhance existing connections among objects, individuals, and organizations (e.g., Siggelkow and Terwiesch, 2019) and this might lead to higher levels of complexity. In this line of research, some researchers find that connectivity may create a new type of knowledge that is "more tacit and more difficult to convert into words" (Vaccaro et al., 2009, p. 1284). This new form of digital knowledge provides essential complementary insights for complex innovation that cannot exist otherwise (Dougherty and Dunne, 2012). As digital technologies may increase knowledge exchange in the face of geographical distance, this will not necessarily be productive without careful examination of human resource management processes (Mabey and Zhao, 2017). Mabey and Zhao (2017)

[8]Keywords used in the SCOPUS search (in titles, abstract and paper keywords, through 2018): *digit*, digiti?ation, digitali?ation, dat?fication, digital transformation, digital artifact, digital twin, digital copy, and digital materiality*.

show that the more pervasive the technologies for knowledge exchange, the more isolated knowledge specialists can become, as discussed further below.

The analysis of the literature points to rather conflicting potential outcomes of digitalization on information flows as well. On one hand, digitalization might eliminate silos (Cross et al., 2006) by increasing internal interfaces among the different organizational units (Antonelli, 2017), which we call "overturning existing knowledge structures." The improved quality of internal interactions might favor the better use of internal information and capabilities that were dispersed, thus, for instance, favoring a higher quality of alignment of research activities with corporate strategies (Antonelli, 2017). In this line of research, scholars show that internal governance costs, such as information processing costs, monitoring costs, and opportunity costs due to poor information, etc., might be reduced by digitization. For example, Gong, Nault, and Rahman (2016) find that in-house operations become more efficient, and firms prefer the internal provision of solutions to external ones.

On the other hand, digitalization may inhibit knowledge exchange. Newell, Scarbrough, and Swan (2001, p. 97), studying a global bank, note that: "ironically, the outcome of intranet adoption was that, rather than integrate individuals across this particular organization, the intranet actually helped to reinforce the existing functional and national boundaries with 'electronic fences.'" Mabey and Zhao (2017) and Howells (2012) propose explanations or enablers of these new electronic fences, which we say help "reinforce existing knowledge structures." First, they observe that the knowledge economy may narrow the scope of peers with whom knowledge workers interact, possibly further away geographically, as knowledge becomes more specialized. This may lead to "relational isolation" and is, therefore, a social explanation. Second, the different paths of knowledge evolution and the specialization of knowledge may make it difficult for experts in one certain area of knowledge to meaningfully interact with experts in different areas. This might be classified as a technical explanation. Third, cognitive limitations may make it difficult or undesirable to engage with people in different knowledge domains, as discussed further below.

Based on the above literature review, we argue that the range of impact of digitalization on the knowledge and organizational dynamics of an innovation function could be captured by the following tension: digitalization reinforcing existing knowledge structures versus digitalization overturning existing knowledge structures. We represent this potential range of outcomes on the horizontal (X) axis in Figure 1. We say that digitalization reinforces knowledge structures when digitalization mirrors the interdependencies among pieces of knowledge underpinning the product/service components. We say that digitalization overturns knowledge structures when digitalization enables organization members to go beyond their normal knowledge boundaries.

Digitalization and Resources and Capabilities

This section leads to a justification of the Y-axis in Figure 1. The analysis of the literature points to potential specific effects of digitalization on resources and capabilities in the innovation function as well. Pisano (2006) suggests that many digital technologies were implemented simply as tools at first, not as new knowledge that needed to be integrated with other knowledge. Digital technology as a technological resource has been discussed in the information systems literature (e.g., Tilson et al., 2010). The second stream of literature has focused on the implications of digital technology adoption on organizational resources, focusing on skills and competences. For example, Acemoglu and Autor (2011) show that the demand for skilled labor is closely correlated with advances in digital technologies. Troilo et al. (2017) estimate that the demand for data scientists and advanced analysts will increase significantly over the next several years. Many of these new jobs are in domains that did not exist a mere decade ago (Henke et al., 2016). For example, LinkedIn reported in 2020 that the top emerging job of the prior five years was Machine Learning Engineer, which saw a 9.8x growth rate. Coming in second, Data Science saw a 6.5x growth rate. Further, as digital 3D visualizations of complex designs became standard for large projects in the construction sector, one firm consolidated software engineers and "digital" construction engineers throughout and created a unit for internal consulting that provides capabilities in 3D visualization and simulation (Yoo et al., 2012). Troilo et al. (2017) demonstrate the dual nature of data scientists: "socially skilled, analytical professionals" that combine analytics expertise with knowledge of the business, versus "number crunchers," with "an old-fashioned siloed view of the organization."

According to this second view, data scientists may act without sharing their competences. They may also be unwilling to help build a clearly understood common view of the business issues that analytics could resolve in an effective manner. This raises the question as to the extent to which the balance between digital skills and "legacy" skills might influence innovation outcomes.

Dougherty and Dunne (2012) note that when digital skills were introduced to replace, not complement, legacy skills, it generated several new "fault lines" and innovation outputs were not the ones expected or hoped. Lanzolla and Giudici (2017) discuss how Axel-Springer in the period 2003–2013 replaced several existing competences in journalism, marketing, and advertising with digital skills, and the company's innovation was reduced by the conflicts arising between digital and legacy skills. At the extreme end of the replacement/complement continuum, when companies pursue full replacement of legacy skills, Ferner, Edwards, and Tempel (2012) show that this might reduce organizational conflicts but also diversity in knowledge and knowledge exchange through codes of practice and standard operating procedures. Digitization may also decrease the diversity of programmable organizational functions through digitalized forms of standardized routines, leaving humans to handle the nonprogrammable tasks, especially those involving interpersonal communication and judgment (Bailey et al., 2012). As an example, Bailey, Leonardi, and Chong (2010) discuss how ERP systems pose the greatest threat to the persistence of diversity in many knowledge occupations since they replace independent applications—unique to each function—with interrelated and standardized programs in functional modules. This is another example of compatibility between digital and legacy skills.

It follows from the discussion above that to capture the idiosyncratic implications of digitalization on the resources and capabilities of the innovation function, we should focus on the extent to which new digital skills are introduced to ***complement*** versus ***replace existing competences***. We represent these potential outcomes on the vertical (Y) axis in Figure 1.

Digitalization and Cognition and Emotions

In this section, we derive and provide justification for a third tension in our framework. A relatively small but emerging literature on the impact of digitization on cognition and emotion points to contrasting outcomes. We start with cognition and the cognitive costs of digitalization. On one hand, digitalization might allow a reduction in cognitive load by minimizing the effects of stress and time pressure, while bringing the multitude of variables outside employees' control under management (Bailey et al., 2012). Faraj, Pachidi, and Sayegh (2018) point out that intelligent technological actors can reduce the cognitive load of resources by performing work such as collecting and processing information, integrating tasks, and making decisions. Brynjolfsson and McAfee (2014) show how industrial robots, by advanced vision systems, can both enhance abilities and reduce cognitive load for different actors in different sectors. Marescaux and Rubino (2004) show that doctors can operate on patients using digital video images and real-time data collected by sensors that—by arming them with the best possible information—put their full attention into the surgery.

On the other hand, there is significant evidence that operating in the physical world through digital interfaces prompts changes in the organization of work, alters the way people make sense of—and come to trust—the objects with which they work, and can increase cognitive load. In this vein, Zuboff (1988) shows that in paper mills, before the digitalization processes, workers relied on their senses to get information about the production process. With digitalization, workers were relocated to analyze information displayed on digital interfaces as indicators of the production process and had to learn (and to trust) information instead of their senses. Blohm, Riedl, Füller, and Leimeister (2016), argue that when the total cognitive load imposed by a digital representation of a task exceeds the capacity of an individual's cognitive system, the consequence is cognitive overload and, consequently, the problem-solving effectiveness and the decision quality decrease (cf. Mayer and Moreno, 2003). Several other studies show that cognitive load can also increase because team members must work across time zones and cultures and because the digital communication technologies they use may foster incomplete messages, misunderstandings, and conflict (Hinds and Bailey, 2003; Maznevski and Chudoba, 2000; Shaft and Vessey, 2006). Overall, Brunswicker et al. (2019) show through formal analytical models the interplay between digital architectures and innovation performance, and they conclude that the outcomes are nonlinear and unpredictable if "socio-dynamic" factors are not factored in.

Moving from cognition to emotions, in Zuboff's seminal study of paper mills (1988), she proposes that the implementation of the new control system triggered in some workers emotions such as anger and fear, while others documented the presence of emotions such as happiness, joy, relief, frustration, irritation, and annoyance. Rafaeli and Vilnai-Yavetz (2004) point out that digital artifacts may trigger emotional reactions from individuals when they interrupt routines. Specifically, emotions play a large role in the period between the moment the routine is interrupted, and the time new routines are established (or old routines are reestablished). Lerner and Keltner (2000) explore the effects of emotions occurring prior to the deployment of a new digital technology. They suggest that emotions are triggered based on the users' expectations of how the new technology will affect them, their work, their performance, and their coping mechanisms.

It is important to note that in all cases, it is not the digital artifact per se that triggers emotions, but the psychological assessment of the artifact by an individual. In light of this, Beaudry and Pinsonneault (2010) studied the direct and indirect relationship between emotions and technology use among bank account managers. On one hand, they show that positive emotions—such as excitement and happiness—are positively related to technology use through task adaptation. Specifically, excitement is *indirectly* positively related to technology use through task adaptation. Happiness is *directly* positively related to technology use and is negatively related to task adaptation—which is a facilitator of technology use (cf. Brown, Fuller, and Vician, 2004; Kim, Chan, Chan, and Gupta, 2004; Venkatesh, Morris, Davis, and Davis, 2003). On the other hand, negative emotions—such as anger and anxiety—are negatively related to technology use thorough psychological distancing (cf. Compeau and Higgins, 1995; Compeau, Higgins, and Huff, 1999; Venkatesh, 2000).

The analysis above demonstrates that the idiosyncratic impact of digitalization on cognition and emotion is multifaceted: digitalization may increase cognitive and emotional (both individual and collective) costs, or decrease them.

The Digital Transformation of the Antecedents of Search and Recombination: Toward an Integrative Framework

Our earlier analysis of the tensions engendered by digitalization on the antecedents of search and recombination is summarized in Figure 1 and leads to four quadrants, labeled A to D in a clockwise fashion, which captures four potential technology implementation scenarios. Our analysis above has also revealed that cognitive and emotional costs increase or decrease based on the contingencies under which digital technology implementation takes place. This gives us a roadmap for systematically integrating cognitive and emotional costs as a third element that might have an additional impact on search and recombination outcomes. Below, we develop our integrative framework quadrant by quadrant. In each quadrant, we discuss how the identified tensions interact with one another to influence the outcome of search and recombination, respectively.

Quadrant A (Pre-existing Knowledge Structure Reinforced and Digital Skills Replace Legacy Skills)

Quadrant A describes a case in which the existing knowledge flows mirroring the interdependencies among pieces of knowledge underpinning the product/service components are further reinforced by the digital infrastructure. This situation in and of itself is likely to allow deep search due to the fact that knowledge can remain in "silos" and knowledge workers can use digital means to engage in local search in their own silos (this would hold true for both Quadrants A and D). For instance, Howells (2012) shows that despite the increasing diffusion of digital technologies, knowledge can often remain "stubbornly localized around the comparatively small number of highly skilled knowledge workers engaged in high orientation networks…we still live and work in narrow social networks" (p. 1014).

At the same time, in the case of Quadrant A, the innovation function also sees a robust injection of new digital skills that replace (some of) the legacy ones. It follows from our discussion above that the addition of digital competences to the organization might have a mixed impact on search. On one hand, it might add to the diversity of the innovation function and allow increasing search breadth (e.g., Katila and Ahuja, 2002; Laursen and Salter, 2006). On the other hand, if digital skills and legacy skills do not complement one other, the conflicts arising between digital and legacy skills might increase the emotional barriers for search across domains even more, once again leading to search depth over breadth (e.g., Katila and Ahuja, 2002; Laursen and Salter, 2006). Thus, far we have shown that the impact of digitalization on search is nonlinear and ambiguous. In this case, the prevailing presence of negative emotions emerging from the conflicts between digital and legacy skills act as a further barrier toward broadening search (e.g., Eggers and Kaplan, 2013; Vuori and Huy, 2016). It follows that the most likely search outcome here is **a prevalence of search depth in the legacy and digital domains, separately.**

Regarding knowledge recombination under the contingencies described here, Martin and Mitchell (1998) demonstrate that incumbent firms in the magnetic resonance imaging (MRI) machine market failed to combine new knowledge with at the time dominant (legacy) technology for their siloed organizational structure. Huy (2002) shows in a large service-providing company in the information technology industry, that low emotional commitment to change led to organizational inertia and hindered the development of new knowledge. Bailey et al. (2010) find that efforts to substitute existing capabilities with digital ones without considering organizational goals disrupted the development of products or organizational knowledge. And Dougherty and Dunne (2012) find that drug discovery is hindered by "fault lines" between digital and legacy skills in three knowledge dimensions: defining the product, building the product, and projecting the future.

Overall, we argue that given the high individual and collective emotional costs that might often be prevalent in this quadrant, there will be limited propensity to exchange knowledge across digital and legacy domains and that, when knowledge recombination happens, **it is more likely to take the form of a "layering" of the digital knowledge domain upon the legacy one**, consistent with what Gavetti and Levinthal (2000) call *backward-looking experiential learning* and Lopez-Vega, Tell, and Vanhaverbeke (2016) call *situated paths*.

Quadrant B (Pre-Existing Knowledge Structure Overturned and Digital Skills Replace Legacy Skills)

In Quadrant B, the innovation function is modified in a way whereby the digital infrastructure is potentially conducive to discovering new interactions among knowledge components, which we label as *overturning existing knowledge structures*. This situation might enable broader search (Afuah and Tucci, 2012; Fleming and Sorenson, 2004; Lopez-Vega et al., 2016; Piezunka and Dahlander, 2015). At the same time, there is also a robust introduction of new digital skills to substitute the legacy ones and this, as discussed in Quadrant A, has an ambivalent potential outcome: it can be linked to increase in broader search (because of more skill diversity) versus an increase in deeper search (because of the negative individual and collective emotions triggered in the organization by the skill replacement dynamics). In this case, we argue that the breaking down of knowledge structures and the addition of diversity to the organization **is likely to lead to a prevalence of search breadth,** and that the presence of prevailing negative emotional costs will negatively moderate this outcome.

Regarding recombination, in Quadrant B, knowledge recombination dynamics are influenced by two forces that reinforce one another. First, as discussed in Quadrant A, high individual and collective emotional costs might reduce the propensity to exchange information. Second, the scope for knowledge recombination in Quadrant B is further decreased because the digital infrastructure might also lead to increased knowledge complexity (Dougherty and Dunne, 2012; Fleming and Sorenson, 2001, 2004). The rugged landscape metaphor of *NK* fitness models has been used as a theoretical device for representing knowledge complexity in this case (Levinthal, 1997; Rivkin, 2000; Winter, Cattani, and Dorsch, 2007). In this model, N represents the number of knowledge attributes and K the number of interactions among knowledge attributes. When the value of K is low and there is little interaction among the attributes, then the fitness landscape is smooth. In contrast, with a high K value, the fitness landscape becomes more rugged or multipeaked (Lazer and Friedman, 2007; Levinthal and Warglien, 1999) and, ultimately, more complex (Baumann and Siggelkow, 2013; Kim and Anand, 2018; Lazer and Friedman, 2007; Levinthal and Warglien, 1999; Siggelkow and Rivkin, 2005). Overall, in this Quadrant, the potential for broader search may come at the expense of high(er) cognitive costs. Gavetti and Levinthal (2000) find that the role of cognition is accentuated when the "fitness landscape" is more complex, or rugged. Specifically, cognitive processes allow a broader examination of the fitness landscape, but unless an actor is endowed with the omniscience sometimes assumed in economic analyses (Milgrom and Roberts, 1990), there is no reason to presume that the global peak will be identified.

In the empirical literature, Appio, Martini, and Fantoni (2017) analyzed different levels of knowledge search and recombination of scientific and technological knowledge in the bioinformatics sector, and found that a wide range of diversity was not linked to successful ("impactful") recombination of scientific and technological knowledge. Similarly, through a formal simulation model, Almirall and Casadesus-Masanell (2010) show that when search breadth is high and "partners" have divergent goals, innovation efforts often lead to the incorporation in products of narrow "technological trajectories." Fleming and Sorenson (2001) show that the interdependence and size of the search space do influence the likelihood of successful search, yet inventors might face a "complexity catastrophe" when they attempt to recombine highly interdependent technologies.

It follows from our discussion above that in Quadrant B, where high individual and collective emotional costs compound with high cognitive cost due to higher complexity, **there is an increased likelihood of "search for the sake of search"—that is, search that does not lead directly to any knowledge recombination**.

Quadrant C (Knowledge Structure Overturned and Digital Skills Complement Legacy Skills)

In Quadrant C, the digital infrastructure unleashes knowledge search dynamics similar to the ones described in Quadrant B—that is, the potential for an increase in search breadth. The addition of digital competences is now considered complementary to existing competences. Differently from Quadrants A and B, where we observe both more skills diversity and negative individual and collective emotions, in Quadrant C skill diversity co-exists with positive individual and collective emotions. **It follows that all forces in Quadrant C point toward search breadth as the more likely outcome.**

Recombination dynamics here depend on the balance between two forces which have opposite effects. On one hand, as in Quadrant B, more complexity increases cognitive costs for knowledge recombination. On the other hand, differently from Quadrant B, emotional costs are lower in this case because digital and legacy skills perceive each other as complementary. Lanzolla and Giudici (2017) show that when Axel-Springer (in 2013) changed its digital transformation strategy from the substitution of journalists with digital experts to complementarity between them, the company effectively integrated content and digital "capabilities." Gruber, Harhoff, and Hoisl (2013) propose that inventors with a science background and inventors with higher educational attainment are more likely to combine knowledge across technological boundaries when they perceive each other as complementary. Karim and Kaul (2015) show that in the US medical sector, recombination has a positive impact on innovation where the firm has significant complementarities between its knowledge resources, where it has high-quality knowledge resources, and where path dependence is low. Almirall and Casadesus-Masanell (2010) propose that when search breadth is high and "partners" have converging goals, innovation efforts enable firms to discover new combinations of product features, which would be hard to uncover in the presence of conflicts among "partners."

In the conditions described in Quadrant C, **recombination is more likely to happen in the form of knowledge integration** (cf. Karim and Kaul, 2015), even if high cognitive costs make the likelihood of effective recombination slimmer.

Quadrant D (Knowledge Structure Reinforced and Digital Skills Complement Legacy Skills)

In innovation functions in Quadrant D, the structure of the technological and skill setup as well as the resulting cognitive and emotional costs fall in between cases A and C, a situation that we have argued above **raises the likelihood of search depth in both legacy and digital knowledge domains**, most likely independently. Similarly, in terms of knowledge recombination, the cognitive and emotional structure here is also in between Quadrants A and C—that is, between layering knowledge versus knowledge integration—a case that following Nag, Corley, Gioia (2007) can be called *knowledge grafting*. Nag et al. (2007) show that knowledge grafting, arguably a more desirable outcome than layering knowledge, is more likely to happen when identity and knowledge that manifested itself in organization members' collective practices that characterized how they used knowledge in accomplishing their work are not massively changed, a situation similar to the contingency described in Quadrant D. Thus, we argue that the conditions of Quadrant D will lead to **a higher likelihood of knowledge recombination via knowledge grafting** from the digital to the legacy domains, or vice versa.

Discussion and Conclusions

Summary and Theoretical Implications

In this paper, we have accomplished three main goals. First, we have provided an updated classification of

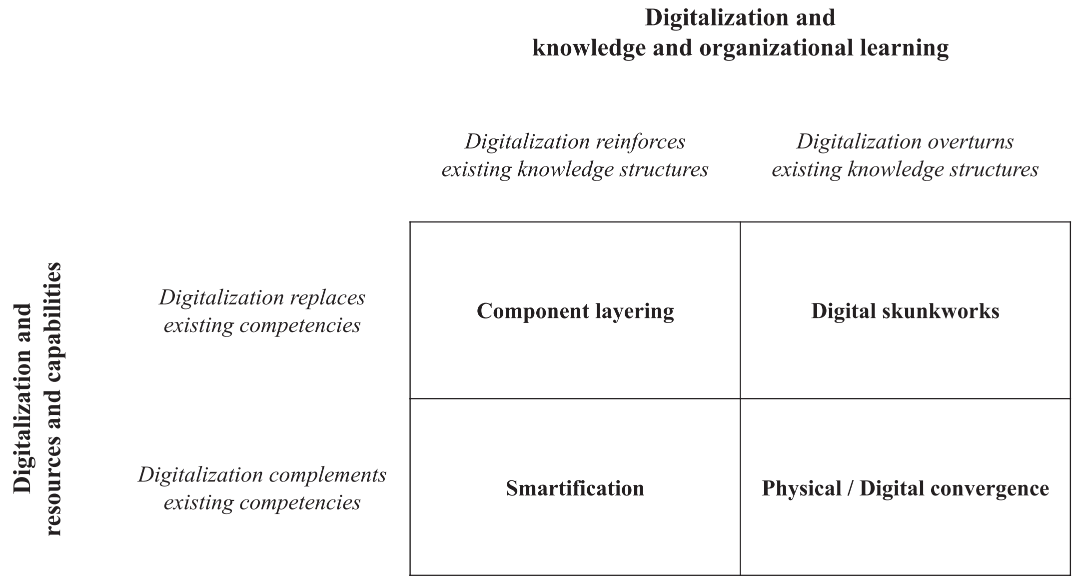

Figure 3. A Framework for Product Innovation Management in the Digital Age

the organizational antecedents of search and recombination, two important processes, especially in the creativity phase of innovation. By reviewing the voluminous recent literature on search and recombination and their antecedents, we have provided a novel classification of such antecedents. This classification complements and expands on existing ones (e.g., Gibson and Birkinshaw, 2004; Jansen et al., 2006; Katila and Ahuja, 2002; Raisch and Birkinshaw, 2008) by providing an updated analysis of the role of knowledge characteristics and organizational learning dynamics and of the roles of competencies, and, crucially, by systematically integrating cognitive and emotional costs, a hitherto less prominent dimension in the extant search and recombination literature.

Second, we have identified the idiosyncratic tensions triggered by digitalization in the organizational antecedents of search and recombination. We have shown that the potential effects of digitalization on such antecedents are not unequivocal, nor always positive. Specifically, we have shown that digitalization can enable the discovery of new knowledge, but it can also reinforce extant knowledge structures by creating new technological barriers to knowledge discovery. We have further shown that digitalization triggers a new distribution of competencies in the innovation function and that new digital competencies and existing competencies, depending on the extent to which they complement versus substitute one another, can create synergic or dysfunctional organizational outcomes. Finally, we have shown that digitalization has mixed effects on cognition and emotions, and that these effects are positive or negative depending on the conditions under which digital technology adoption and implementation takes place. These findings contribute directly to the emerging literature of knowledge dynamics in the early phases of the innovation process (e.g., Teodoridis et al., 2019; Yoo et al., 2012). Taken together, our tensions provide a fresh lens to analyze the seemingly contradictory empirical findings on digitalization and innovation (e.g., Bharadwaj and Noble, 2017; Nambisan, Wright, and Feldman, 2019; Teece, 2018) and we provide support to the idea that digitalization cannot just be "dumped" (Appio et al., 2018; Dougherty and Dunne, 2012) in the innovation function, assuming that the underlying structure of the innovation function will remain the same.

Third, we have developed an integrative framework (described in Figure 1) that predicts the likely outcomes of search and recombination in the innovation function. Depending on the relative balance of the tensions discussed in this paper, the outcome of search and recombination vis-à-vis digitalization might lead firms to more or less search breadth relative to depth. We also show that the likely outcome of knowledge recombination can range from knowledge layering, knowledge integration, knowledge grafting or even little recombination at all. By providing specific scenarios that link the idiosyncratic changes in digitalization to knowledge search and recombination dynamics, we contribute to the literature on knowledge management and innovation management in the Digital Age (e.g., Bharadwaj and Noble, 2017; Biemans and Langerak, 2015; Caridi-Zahavi, Carmeli, and Arazy, 2016; Mauerhoefer, Strese, and Brettel, 2017; Patel and Husairi, 2018; Pollok et al., 2019; Spanjol, Qualls, and Rosa, 2011; Tucci et al., 2016; West and Bogers, 2014). Our framework also represents one of the first attempts to integrate the different literature streams that have addressed the impact of digitalization at the micro and macro organizational level of analysis in a systematic way, and by doing so, we also contribute insights into the broader technology in organization literature (e.g., Almirall and Casadesus-Masanell, 2010; Bailey et al., 2010, 2012, 2019; Brunswicker et al., 2019; Leonardi and Barley, 2010; Mazmanian et al., 2013; Orlikowski and Scott, 2008; Yoo et al., 2012).

Overall, in this paper, we have shown that digitalization may, indeed, change the structure of the innovation function and as such may also require new managerial frameworks for guiding product innovation strategies and product innovation management. Below we provide the managerial implications of our findings and integrative framework.

Implications for Product Innovation Management in the Digital Age

How can a company make digital technologies work for them and not against them when it comes to search and recombination? We emphasize that there is no one “optimal” solution or place to be, as different quadrants will be suited to different situations. However, what is important is to realize where one’s organization is in this continuum and what the purpose of the digital transformation exercise is. We discuss the implications of each quadrant for product innovation management in the Digital Age below. Our considerations are summarized in Figure 3.

It follows from our discussion for Quadrant A that innovation in this quadrant is likely to happen in different product components and then layered. As discussed earlier in this paper, this case may not always be ideal in terms of developing products vis-à-vis a technological discontinuity, although it might be adequate in situations of relative stability in which process improvements can improve efficiency. In the case of a digital discontinuity, this approach might bring forward incremental innovation which might even give the impression that the company is keeping up. Yet this might be misleading. Vuori and Huy (2016) reveal that Nokia’s failure to produce a next-generation smartphone in response to Apple’s iPhone was related to the individual and collective negative emotions triggered by abrupt technological and organizational changes, something similar to conditions that may occur in Quadrant A. Likewise, Boland et al. (2007) discuss how at Volvo Cars, there were tensions evident between employees who sought to bring about digital change and those whose existing capabilities were challenged by such changes and that these tensions brought innovation to a halt.

This may have also been the case for Kodak, which was criticized for “missing” the transition to digital cameras, but in fact, was one of the first firms to think about digital cameras (Lucas and Goh, 2009) and developed one of the first analog/digital hybrid cameras, the Advanced Photo System (Tucci, 2000). However, this innovation was not intended to replace the entire system; rather, the digitalization process involved allowing what is now known as metadata to be stored along with a new (analog) film cartridge, thus allowing “communication” between the film, the camera, and the film processors. Yet, the results ended up being mostly dysfunctional, with digital innovation mostly layered on legacy products.

A more recent example is General Electric (GE), which in the early phase of its digital transformation process, onboarded several digital skills and kept digital and legacy skills in “silos” (GE Digital vs. the other GE’s verticals). These resulted in knowledge layering that led to suboptimal results and a subsequent broader re-organization (Lohr, 2018). Finally, this may also be the case in incumbents facing biotech, medtech, fintech, etc. innovations, in which the increased diversity has in many cases borne fruit but where the digital components prevail over the legacy ones. For example, one important change in the business environment has been open banking, with application programming interfaces (APIs) that allow third party access to what were formerly proprietary interfaces (Zachariadis and Ozcan, 2017), with incumbents finding themselves often in Quadrant A and wondering about the best way to respond to “challenger banks,” usually with a layered solution that does not

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integrate digital solutions but rather rings them to minimize changes to the current portfolio (Blakstad and Allen, 2018).

In the case described in Quadrant B, we believe that innovation functions might form "digital skunkworks" (cf. Ahuja, Lampert, and Tandon, 2008). The term *skunkworks* typically refers to technology projects developed in semi-secrecy—such as Google X, Microsoft Research, Boeing Phantom Works, Amazon's Labs, Nike's Innovation Kitchen and Sports Research Lab, Walmart Labs, IBM's Thomas J. Watson Research Center (at the time)—with the understanding that if the development is successful, the product/service will be developed further following usual processes. Skunkworks solutions, in some cases called innovation spinoffs, facilitate exploration, and in the best of cases, they can come up with breakthroughs unencumbered by the "traditional" ways of product development in the parent organization. Moreover, they are risky and might, indeed, develop ideas that are difficult to recombine or reintegrate into the parent. A case in point here is the early Google Labs. The set-up of the Lab was conducive to a very broad search with the hope of extensive knowledge recombination. Yet it was discontinued in 2011 for lack of results and for putting "more wood behind fewer arrows" (Coughran, 2011). This is what we were referring to as "search for the sake of search."

Moving along to Quadrant C, here innovation functions might spur "physical/digital product convergence" effectively integrating digital components in their legacy products. For instance, the so-called quad play (combining broadband internet, phone, TV services and apps in mobile internet) has resulted in the convergence of media content, storage, and distribution mechanisms, and has generated significant digital product innovations such as smartphone services for YouTube or Netflix (Lyytinen, Yoo, and Boland, 2016). Netflix has further exploited its complementarities between digital and existing competencies to arrive at original shows, demonstrating the dynamic capabilities required for digital business innovation in entertainment. By creating new links among once disconnected units of knowledge, we argue that in this quadrant, the convergence of digital and legacy knowledge components might create a space for new types of *digital business innovation* in what had been a stable, traditional set of legacy industries.

As highlighted in the auto, media, and home appliances industry, most legacy products are now increasingly composed of digital components, which also enable them to interact with other digital products or to use the Internet to service them (Jonsson, Holmström, and Lyytinen, 2009; Lee and Berente, 2012). Magnusson and Berggren (2011) show that in the car manufacturing industry the coupling of legacy skills with digital expertise enabled the "connected car" as a viable innovation platform for participants in the traditional automotive industry.

Many brands are converging on seamlessly blending the physical and digital worlds. For example, Bonobos, which was born purely digital, now uses physical stores to let customers try on clothes. Galleries Lafayette—despite intense competition from online stores—recognizes the importance of physical proximity to build an emotional relationship with the customer, while using digital channels to better understand customers' needs using, for example, AI (Furr and Shipilov, 2019). Finally, Kelion (2014) discusses how Google's Nest is partnering with businesses such as Mercedes, Jawbone, LIFX, Logitech, and Whirlpool to develop increasingly blended physical/digital experiences.

Moving to Quadrant D, deeper search behavior combined with complementary competencies leading to knowledge recombination are likely to lead to keeping the core products more or less the same, but bringing them into the digital world by adding digital features to them. In these cases, the core knowledge remains the same, but the digital part is grafted onto the core product to add value to the customer by demonstrating some extra capabilities. In the context of digital, this is often also called *smartification*—that is, the incorporation of digital sensors into objects that previously had purely physical materiality (Porter and Heppelmann, 2014, 2015). Sensors allow objects to provide information about their environment, context, and location (Alemdar and Ersoy, 2010). For instance, Disney invested $1 billion to develop a smart wrist band to improve and personalize the customer experience in Disney World resorts (Barnes, 2014). Carnival Cruise provides every guest with an "Ocean Medallion" to wear onboard. It serves not only as a room key and credit card, but is also a sensor and Internet-connected transmitter that keeps passengers connected wherever they go on the ship. The data streams into Carnival's servers, analysis occurs in real-time revealing each guest's preferences, and artificial intelligence analysis informs crew members so that guests enjoy a personalized experience tailored to their preferences in activities, dining, and so on (Wilson and Daugherty, 2018). In all these cases, the core product (e.g., shoes, cruise, theme park) remains the same, but the digital part is integrated with the core product to add value to the customer (e.g., step tracking, diagnostics for running, mechanical tightening and loosening depending on activity level, adapting the shoe to the shape of the foot, and so on).

One final implication of our research is that the digital transformation of the innovation function may allow product development team members to quickly form into "flash matrix organizations" (the cases depicted in Quadrant B and C) that have the possibility to cohere and form more permanent bonds. This sounds like a positive development, but quick team formation should also be managed purposefully since the teams might become siloed or isolated, or there might be so many of them that membership becomes distracting for the team members. Thus, there is a practical question of how does one keep the flash matrix organization aligned with the rest of the company? It is difficult enough to align one permanent matrix structure (Katz and Allen, 1985), but when multiple matrix structures can be created digitally, how can one align their product development and innovation work with corporate strategy? Thus, the more negative consequences of flash matrixes need to be actively monitored and teams managed in such a way as to take full advantage of the positive consequences.

Limitations and Future Research

As it is often the case, there could be other effects beyond changes in knowledge structure and competences triggered by the adoption of digital technologies in the innovation function. As such, it would be important to continue our line of theorizing by identifying other such idiosyncratic changes and developing propositions on their impact on innovation outputs, independently and alongside the ones we have developed. For instance, our literature review shows that digitalization might also have an idiosyncratic impact on innovation governance: digitalization may enact even more formal and centralized governance mechanisms (cf. Seshadri, Shapira, and Tucci, 2019), or it may trigger even more informal/horizontal and decentralized governance mechanisms (Carnabuci and Operti 2013; Lavie, Stettner, and Tushman, 2010; Piezunka and Dahlander, 2015, 2019). Some extensions of our model might investigate the interactions among digitalization, governance, knowledge, and competences.

In the interest of building a solid baseline model and to keep the paper tractable, we have not fully integrated all the possible effects of artificial intelligence (AI). AI, while obviously useful for making predictions based on large amounts of data, such as IoT sensor data, and therefore helpful in integrating digital and legacy products and services in the ways described above, might also have multiple direct influences on both search/recombination through its technical affordances (e.g., speed, "black boxing") and by impacting the cognitive/emotional dynamics of the innovation function (e.g., manipulation, disempowerment, surveillance, discrimination, precarity, stress: Kellogg, Valentine, and Christin, 2020). One example of this with regard to search and recombination is using AI to perform search and recombination itself, akin to what some academic researchers call the "automation of science" (King et al., 2009). In this regard, at some point, certain elements of the R&D process might be automated to scan for and propose new solutions. However, how these AI systems are developed could have a profound impact on reinforcing versus overturning existing knowledge structures. Will algorithmic approaches to R&D lead to an accelerated broadening of knowledge search, or will it lead to something like self-reinforcing "opinion bubbles" on social media? Formally and systematically incorporating the nuances of AI into our baseline model would be a highly interesting extension for future research.

Other extensions of our frameworks might include the identification, through theoretical and/or empirical methods, of the optimal balance between digital and legacy skills (it is not obvious that an imbalance toward digital is necessarily a good thing, despite popular press "hype" in that direction) or the identification of the contingencies that lead to reinforcing versus overturning existing knowledge structures.

Finally, this study has been conducted by analyzing several literature streams in an inductive fashion and using logic to link them, occasionally referencing real-world examples as anecdotes of the innovation possibilities enabled and constrained by digitalization and connectivity. Our predictions would thus benefit from future empirical work in measurement, hypothesis development and testing, and understanding of the contingencies and nuances of these new concepts.

Conclusion

Digitalization is having a large influence on many if not most aspects of business life, and product innovation management is no exception. We hope that the frameworks developed above stimulate a conversation about the different paths digital transformation exercises may take, especially with regard to knowledge search and recombination and how that might filter down to innovation outcomes. It is an exciting topic with many opportunities for future research in innovation management, information systems, strategy, and organization theory!

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