It takes two to Tango: Analyzing the relationship between technological and ad-ministrative process innovations in Industry 4.0

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Abstract

Industry 4.0 brings about fundamental changes in firms' processes. New digital technologies but also organizational and administrative processes need to be addressed. However, existing research mainly emphasizes the technological aspects of Industry 4.0, paying little attention to the organizational perspective. Conducting a qualitative meta-analysis, this study examines the interplay between technological process innovations and administrative process innovations emergent in Industry 4.0. Results show that technological and administrative process innovation occur both sequentially and simultaneously, and complement each other in the context of Industry 4.0. Consequently, the interplay between the two types of innovation is complex in Industry 4.0. Additionally, this study reveals that strategy, work design, and people management are crucial for Industry 4.0 initiatives. The study sheds light on the ways in which firms adopt technological and administrative process innovation in the pursuit of Industry 4.0. In addition, the findings highlight the importance of considering Industry 4.0 not merely from a technological perspective and provide insights on the various factors that should be considered concerning Industry 4.0.

Keywords*: Industry 4.0; smart manufacturing; process innovation; technological innovation; administrative innovation; management innovation*

1. Introduction

Industry 4.0 (I4.0) gains great attention in practice and academia alike and marks a new industrial stage that not only extensively transforms the industrial world but also affects social and economic conditions (Osterrieder et al., 2020). At its core, I4.0 aims to revamp traditional manufacturing into smart manufacturing settings with the exploitation of novel digital technologies and their benefits for business performance (Meindl et al., 2021; Calış Duman and Akdemir, 2021). Accordingly, firms put significant efforts and investments in the implementation of new technologies into their operations and production processes (Fatorachian and Kazemi, 2018). However, technological innovations "hardly ever function in isolation" (Rosenberg, 1979, p. 26), and firms that introduce new technologies solely, without implementing appropriate innovations in the organizational sphere, frequently face difficulties in taking full advantage of their technological advances (e.g., Battisti et al., 2015). The highly automated car manufacturing industry, as it currently shifts towards electric drive, could hereby serve as a prime example to illustrate the difficulties that are observable throughout businesses: While the introduction of novel technologies is challenging but manageable, firms especially struggle with adapting their organizational routines, processes, and procedures (Deloitte, 2019).

To consider both technological and organizational renewals, the concept of technological process innovations (TPI) and administrative process innovations (API) is particularly useful. TPIs are defined as new technology introduced into a firm's production or operations (Damanpour et al., 2009). Conversely, APIs embody novel ways to organize company activities and can be a new organizational method in business practice, administrative procedure, structure, or workplace organization. In terms of the relation between TPI and API, innovation research has discussed synchronous and sequential (see Damanpour, 2020). Aligned with the notion of TPI and API, the dual-core model suggests that companies have a technical core and an administrative core (Daft, 1978). The technical core signifies the production of products and services, whereas the administrative core concerns administrative, organizational, and managerial aspects (Zmud, 1982).

Recently, scholars have begun to recognize the need to address not only the introduction of new technologies but also administrative renewals related to I4.0. In fact, substantial renewals in firms' administrative aspects were stressed to be essential for realizing the benefits of I4.0 technology implementation (Büchi et al., 2020). However, the vast majority of I4.0 research emphasizes technological developments and extensively discusses the technological side of this new industrial paradigm. In such a sense, I4.0 is frequently associated with its key enabling technological innovations and numerous studies examine firms' adoption of TPI (e.g., Frank et al., 2019). Notwithstanding the importance of technology, the emphasis put on I4.0 technological innovations appears to be a shortcoming in the literature because it comes along with a restricted view on I4.0-related innovations. We argue that the largely technology-oriented scholarly discussion of I4.0 is at stake of neglecting *non*-technological innovations as API. I4.0-studies' tendency to examine firms' adoption of new technology under-attending the introduction of administrative changes bears the risk of underestimating – at worst neglecting – the breadth of innovations embracing the new industrial paradigm I4.0 (Culot et al., 2020). Shedding light on API is important because firms have difficulties in understanding the organizational perspective of I4.0 (Wagire et al., 2020) and face problems in identifying the actions needed for transitioning towards I4.0 (Ghobakhloo, 2018).

Another open point is that the debate about synchronous and sequential interactions between TPI and API is still ongoing and inconclusive findings impede the understanding of the relationship between TPI and API in general, and within the context of I4.0 in particular. In fact, the interplay between TPI and API in I4.0 remains an open question, as it has been largely unexplored. Recently, Robert et al. (2020) have called for research on this open question and with this study, we follow the call and attempt to provide answers. Studying TPI and API in I4.0 also answers the calls by Damanpour (2020, 2017) who claimed that further research on the relatedness of innovation types in a variety of contexts is warranted.

In line with the presented research gaps, the primary objective of this study is to explore the interplay between TPI and API in I4.0. In particular, this paper seeks to examine TPIs and APIs that are prevalent in I4.0 and analyze interrelations and patterns that may exist between them. To further extend the knowledge about the organizational side of I4.0, we also focus on the administrative core that is increasingly highlighted to be relevant in the context of I4.0 (Piccarozzi et al., 2018). Therefore, as a secondary objective, we aim to identify administrative core dimensions that are pivotal to I4.0. To address these objectives, we conduct a qualitative meta-analysis which is an exploratory, abductive research method that allows to refine, extend, or generate theory by re-interpreting previous qualitative studies (Hoon, 2013).

Our findings expose the importance of pursuing both technological and administrative renewals when transitioning towards I4.0. This study adds to the literature by examining the relatedness of innovation types in I4.0. Besides, we contribute to research by revealing that TPI and API interplay in sequential, simultaneous, and complementary ways in I4.0. The results indicate specific elements of work design and people management as well as strategy as organizational factors that should be carefully taken into consideration to support firms' I4.0 endeavors.

The remainder of the paper is structured as follows. The next section establishes the conceptual background of our study and presents a review of relevant literature based on which we outline the methodology in section 3. Section 4 describes the research findings and section 5 discusses them, presenting specific propositions. Implications, limitations, and avenues for future research conclude the paper.

2. Conceptual Background and Literature Review

2.1 Technological and Administrative Process Innovation

Innovation theorists have long distinguished between technological and administrative innovation (e.g., Damanpour et al., 1989; Kimberly and Evanisko, 1981). This distinction is well-established in the literature and finds widespread scholarly consensus (e.g., Gunday et al., 2011). Daft (1978) was among the first scholars drawing attention to this distinction and based on his empirical findings, he suggested the dual-core model of innovation according to which firms have a technical core and an administrative core with which innovations are associated. The theoretical assumptions of the dual-core model have received empirical support (e.g., Henriques and Sadorsky, 2007) and the usefulness of distinguishing between technological and administrative innovation is uncontested until today (e.g., Bellamy et al., 2020). Whereas the technical core is mainly concerned with the production of products and services, the administrative core is in charge of administrative and managerial aspects such as planning, controlling, and coordinating the overall functioning of the company (Zmud, 1982). Encompassing organizational structure, human resources, and administrative systems such as rules and procedures, the administrative core represents the organizational side of a company (Jaskyte, 2011). The dual-core

model is further based on the premise that each core has its own characteristics (e.g., goals, activities, problems) and is essential for the entire company's functioning. Aligned with Daft, innovations can relate to the technical or administrative core, leading to TPIs and APIs, respectively (Damanpour et al., 2009).

TPI refers to the use of new technology or the introduction of such into a firm's operating processes and systems (Meeus and Edquist, 2006). Hence, TPIs imply renewal in the production process and thus directly relate to a company's primary work activities (Crossan and Apaydin, 2010). In contrast, APIs are defined as new ways to organize company activities and coordinate human resources and "have no technological elements as such" (Edquist et al., 2001, p. 15). APIs relate to a firm's administrative and organizational aspects and represent more productive ways to organize work. Accordingly, APIs are indirectly related to the company's primary work activity but directly related to its organization and affect its management aspects (Jaskyte, 2011). In this way, APIs imply changes in the way a firm is managed and organized and lead to modifications in organizational structure, management processes, administrative systems, and managerial approaches (Damanpour and Aravind, 2012). Thus, TPI is a means to change the operating system, and API a means to change the management system (Damanpour, 2020). Within I4.0, an example of TPI is cloud manufacturing whereas the establishment of a dedicated analytics unit to interpret IoT-generated data represents an API.

The conception of TPI and API is still in currency and applied across disciplines with numerous studies relying on Daft's dual-core theorizing (e.g., Aboelmaged, 2014; De Vries et al., 2016). The notion of TPI and API is further supported by the socio-technical systems theory which embraces the idea that changes in a company's technical or social system necessitate changes in the other system to maintain the company in balance (Trist et al., 2013). TPIs and APIs are, respectively, affecting the technical and social system (Damanpour and Evan, 1984). As an emphasis, the social system consists of the organizational members and the relationship among them and includes rules, roles, procedures, and structures relating to the interactions among organization members (Damanpour et al., 1989). Drawing on the concepts of TPI and API serves well the purpose of this study as it reflects a more general distinction between technology and organization/social structure (Crossan and Apaydin, 2010).

2.2 Interplay between TPI and API

Research has pointed to the relatedness of TPI and API (e.g., Hervas-Oliver and Sempere-Ripoll, 2015; 2018) and the literature offers partially competing argumentations concerning the interplay among them. Whereas some scholars have claimed that API is a prerequisite for TPI (Damanpour, 2014), others have asserted that TPI precedes API (e.g., Evan, 1966). Still others have proclaimed a simultaneous occurrence of TPI and API (e.g., Georgantzas and Shapiro, 1993). To date, nevertheless, the debate about the sequence of TPI and API or their simultaneity is ongoing in the literature (Anzola-Román et al., 2018;

Arranz et al., 2019). Likewise, empirical evidence has produced contradictory and inconsistent results. Drawing on data of manufacturing firms, Gunday et al. (2011) for instance concluded that APIs pave the way and prepare an environment for the adoption of TPI. Similarly, Damanpour et al. (1989) found that API leads to TPI in public libraries. Conversely, Ettlie (1988) showed that successful manufacturing firms adopt TPI and API simultaneously and claimed that the congruence between the two innovation types is especially important in competitive conditions. In contrast to those earlier findings, recently Arranz et al. (2019), who focused on a sample of 3.795 manufacturing firms, did not find support for the argument that API is a pre-requisite for TPI. Even so, their results suggested a complementary relationship between TPI and API, and the complementary effect on firm performance occurred when TPI preceded API. Camisón and Villar-López (2014), on the contrary, identified that a sequential adoption of API preceding TPI had beneficial performance consequences in manufacturing firms. Altogether, research confirmed associations between innovation types, however, findings on the interactions between TPI and API are inconclusive. One reason thereof may be that interaction patterns of innovation types were reported to be contingent on the industry in which a firm operates (Damanpour et al., 2009), firm characteristics, and characteristics of the environment (Damanpour, 2020). Further, national context was stressed to matter for explaining firms' introduction of TPI and API (Ballot et al., 2015). Numerous studies underlined the need to better understand and shed further light on the interactions between TPI and API (e.g., Arranz et al., 2019; Hullova et al., 2019). With this study, we answer the calls of several researchers to conduct further research on the interplay between innovation types (e.g., Alexiev et al., 2018).

2.3 TPI and API in Industry 4.0

The term "I4.0" appeared in 2011 (Kagermann et al., 2013) and represents a new industrial paradigm that currently attracts considerable attention in practice and academia alike (Osterrieder et al., 2020). The central element of I4.0 is smart manufacturing (Lu and Weng, 2018) which has been described as an integrated, flexible manufacturing system able to adapt in real-time to changing conditions (Kusiak, 2018). Consequently, I4.0 comprises a shift to an intelligent manufacturing concept (Thoben et al., 2017). Despite the growing interest in I4.0, until now a widely accepted and unifying definition of I4.0 does not exist and there is no agreement on its characteristics (Lee and Lim, 2021).

We advocate that the perspective of TPI preceding API applies to the context of I4.0 and we base our reasoning on extant research. Essentially, studies unanimously stress that I4.0 primarily follows a technological trajectory with the various emerging digital technologies giving rise to I4.0 in the first place (e.g., Dalenogare et al., 2018; Frank et al., 2019). Hence, I4.0 is largely driven by a technological imperative indicating that in this new industrial paradigm TPIs may likely precede APIs because firms have a dominant focus on the introduction of new technology. This corresponds to what Hullova et al. (2019)

label “process sequential complementarity” differing in that we assume that a new manufacturing process technology stimulates and ultimately results in the introduction of a new administrative approach, not a new product. To substantiate this view, we draw on the theorizing originally established by Evan (1966) that has recently been substantiated by Arranz et al. (2019). In his seminal work, Evan introduced the model of organizational lag which postulates “a discrepancy in the rate at which new technical and administrative ideas are implemented in an organization” (p. 52). The main hypothesis is that APIs typically tend to lag behind TPIs within firms. Given the higher tangibility, visibility, closer link to profitability, and shorter duration to show effects of TPIs in contrast to APIs, firms pursue TPIs more intensively. Based on this, we posit that TPIs are firms’ primary strategic thrust in the pursuit of I4.0, implying that APIs may likely lag behind TPIs in the context of I4.0.

First and foremost, I4.0 is inherently associated with innovations (Koh et al., 2019). Specifically, I4.0 has been a buzzword related to breakthrough technologies and the resulting technological innovations within industrial firms (Robert et al., 2020). In such a sense, I4.0 is frequently associated with key technological innovations that enable I4.0 (Olsen and Tomlin, 2020). Aligned with this, it has been studied how manufacturing firms implement I4.0 technologies, thereby shedding light on adoption patterns (Frank et al., 2019). Hence, technologies have been a major subject of discussion in the literature. Essentially, I4.0 is a multi-technology field as it covers a great multitude of technologies. Emerging digital technologies such as cyber-physical-systems, internet of things, industrial internet, cloud computing, and big data and analytics were highlighted as the main pillars of I4.0 (Fatorachian and Kazemi, 2018; Frank et al., 2019). Also, studies have discussed advanced robotics, artificial intelligence, blockchain, or 3D printing as enablers of I4.0 (Xu et al., 2018). Following this, I4.0 relies upon advanced technologies which are reshaping manufacturing industries (Büchi et al., 2020). Moreover, I4.0 has been considered as the implementation of digital technologies into operations and production processes (e.g., Reischauer, 2018). Extant literature has suggested that such implementation offers several benefits to firms (e.g., Kamble and Gunasekaran, 2021). Likewise, the impact of technologies on industrial performance has been analyzed (Dalenogare et al., 2018). In general, I4.0 is expected to bring several benefits such as cost savings, quality improvements, resource efficiency, increased flexibility, as well as extensive integration and interoperability (e.g., Wagire et al., 2020). Implementing digital technologies into operational processes allows firms to gain vast efficiency benefits (Yu et al., 2015). Consequently, I4.0 supports the long-term competitiveness of firms (Kagermann et al., 2013).

In sum, studies tend to explicate overwhelmingly on the technological perspective of I4.0 and lengthily discuss I4.0 technologies. Scholars increasingly acknowledge that technology is only one part of “the complex puzzle that must be solved for organizations to remain competitive in a digital world” (Vial, 2019, p. 118). Generally, technology cannot be implemented independently and aspects at the organizational and managerial level should be taken into consideration (Cagliano et al., 2019). Indeed, I4.0 is much more

multifaceted and poses not only technological but also organizational and managerial challenges (Shet and Pereira, 2021). For example, the higher human-machine interactions pose challenges in terms of management and require novel ways of work management, administration, and planning (Robert et al., 2020). As put forward by Nosalska et al. (2019), I4.0 is a concept of both technological and administrative renewal. Culot et al. (2020) disentangle the constituting elements of I4.0 and what they find is, on the one hand, technological innovations and, on the other hand, novel organizational aspects and business models which are "required to unfold the potential of technology" (p. 4). However, organizational aspects of I4.0 are reported in the academic literature mostly implicit and little detailed. Also, it has been stressed that realizing the benefits of I4.0 technological innovations requires new organizational structures and processes, necessitating firms to undergo fundamental changes (Fatorachian and Kazemi, 2018). Furthermore, work organization and design have been identified as a priority of action, and academic scholars have put attention on studying these factors (Liao et al., 2017). Several studies underline the importance of innovating both technological and administrative processes in the context of I4.0 (e.g., de Sousa Jabbour et al., 2018; Horváth and Szabó, 2019). Administrative aspects of I4.0 are particularly relevant because they were found to be a barrier to the adoption of advanced technologies (Wagire et al., 2020). Xu et al. (2018) proclaimed that the alteration of administrative processes is vitally important in I4.0 given the digitization of manufacturing and production processes. Unanimously, introducing innovation in the administrative core is an important component of I4.0 according to de Sousa Jabbour et al. (2018). However particularly in this area remain significant research gaps. Unsurprisingly, we are witnessing calls to further study the organizational and management aspects of I4.0 (e.g., Büchi et al., 2020). Additionally, we still lack investigations of the interrelatedness of technological and administrative issues of I4.0 as called out for by Robert et al. (2020). Accordingly, administrative aspects of I4.0 need to be studied more in-depth and one of the open key questions is how technological and administrative renewals interplay within I4.0. Thus, we ask the following research questions:
(RQ1): How do TPI and API interplay in I4.0?
(RQ2): Which dimensions of the administrative core are relevant for I4.0?

3. Research Method

To answer the research questions, we conduct a qualitative meta-analysis. A qualitative meta-analysis is an exploratory, abductive research method (Mantere and Ketokivi, 2013) that draws on evidence of qualitative studies and pursues "the purpose of making contributions beyond those achieved in the original studies" (Hoon, 2013, p. 523). By re-interpreting previous qualitative studies, recurring patterns across the re-examined cases can be identified and, thereby, a qualitative meta-analysis allows to refine, extend, or generate theory. To do so, the qualitative data are accumulated, organized, and interpreted aiming to achieve "a level of understanding that transcends the results of the individual studies" (Rauch et al., 2014, p. 334). Thus, we follow an interpretive method rather than an aggregative one. As such, qualitative meta-analyses do not aim at integrating studies' findings

(Berente et al., 2019). Instead, in conducting a qualitative meta-analysis, qualitative studies' information is used as "`first hand´data" which are to be analyzed and, subsequently, result in meta-interpretations (p. 880). In other words, we engage in re-interpreting primary studies' interpretations (Hoon, 2013).

Qualitative meta-analyses are not to be confused with "aggregative" syntheses like literature reviews or quantitative meta-analyses (Berente et al., 2019). Notably, qualitative meta-analyses allow one to explore relationships around the same phenomenon (Combs et al., 2019) and can reveal new relationships between concepts that existing theory has not taken into account (Maxwell, 2012). Scholars increasingly stress the potential of and need for qualitative meta-analyses in organization and management research (e.g., Habersang et al., 2019). Although importance is increasingly attributed to this method, Combs et al. (2019) lament that it is still under-represented in organization and management research. In our study, a qualitative meta-analysis is appropriate because it allows us to understand interactions between TPI and API by interpreting studies' evidence of I4.0-related innovations.

3.1 Data Sources

Aligned with the I4.0 focus of our research, qualitative studies dealing with I4.0 should be found. Because I4.0 is mainly associated with manufacturing (Sung, 2018), we deemed journals in the production and operations management area as the appropriate outlet. To ensure validity, we consider only peer-reviewed journal articles. To identify relevant journals, we used the Academic Journal Guide (AJG) 2018 developed by the Association of Business Schools that rates business journals based on citation analysis and a peer review and consultation process. Given our interest in I4.0, we determined the AJG fields "Operations and Technology Management" and "Operations Research and Management Science" as the relevant areas. From these two fields, we selected all journals ranging from the highest rankings 4* (journals of distinction) to and including 2 (well-regarded journals). This resulted in a base of 67 journals. Utilizing the database Scopus, we searched the 67 journals deploying the search string "Industry 4.0" OR "smart manufacturing" to identify relevant studies. The term I4.0 is the main keyword used in research, practice, and policy for describing the shift in worldwide industrial systems (Chiarello et al., 2018). Some countries (e.g., the United States, Japan, Korea, among others) use the label "smart manufacturing" to describe the same phenomenon (Ibarra et al., 2018). Accordingly, I4.0 is also known as smart manufacturing (Osterrieder et al., 2020) and studies frequently use the two terms interchangeably (Nosalska et al., 2019). Our choice of key terms is furthermore justified by the fact that I4.0 has received the most definitional efforts and became "*de facto* the label for the phenomenon" (Culot et al., 2020, p. 4). Considering the ongoing confusion between I4.0 and related concepts (e.g., industrial internet), which is claimed to compromise research progress (Culot et al., 2020), we decided to focus on those terms that are more widespread. It is important to note that we opted for this rather broad search string and deliberately omitted innovation-related search terms to not miss studies that

just implicitly address innovation. Nevertheless, we acknowledge a potential limitation caused by the search terms used. In sum, the search resulted in an initial sample of 283 studies.

Initially, we screened the 283 identified studies by reading their titles and abstracts. Conducting a qualitative meta-analysis, studies based on qualitative data were the only research design allowable. Thus, we checked the research design of the studies to eliminate studies that are not eligible. In this step, we also removed duplicates. Articles not relying on qualitative methods, such as conceptual or review papers without data, empirical papers using quantitative methods, or model and simulation articles should be excluded. We categorized the 283 studies and found 31 qualitative studies. For 80 studies, the research methodology was not clear from their titles and abstracts. These articles could not unequivocally be categorized which required the full paper to be read. Hence, we accessed the full texts of these 80 papers to read, manually screen, and categorize them. This step revealed 4 qualitative studies. We excluded one article centered on frugal innovation which is out of our study's scope. Altogether, out of the initial sample of 283 papers, a total of 35 qualitative studies referring to I4.0 or smart manufacturing were identified for the meta-analysis. This is a reasonable amount of studies as the objective is to conduct an in-depth analysis and interpretation. A workable amount of studies for qualitative meta-analyses is corroborated when looking at the final sample sizes of three qualitative meta-analyses recently published in highly respected, international peer-reviewed journals. Berente et al. (2019), published in a world elite journal (i.e., *MIS Quarterly*); Habersang et al. (2019), published in a top journal (i.e., *Journal of Management Studies*); and Küberling-Jost (2019), published in a highly regarded journal (i.e., *Journal of Business Ethics*) included 35, 43, and 20 studies, respectively. Our sampling procedure is depicted in Figure 1.

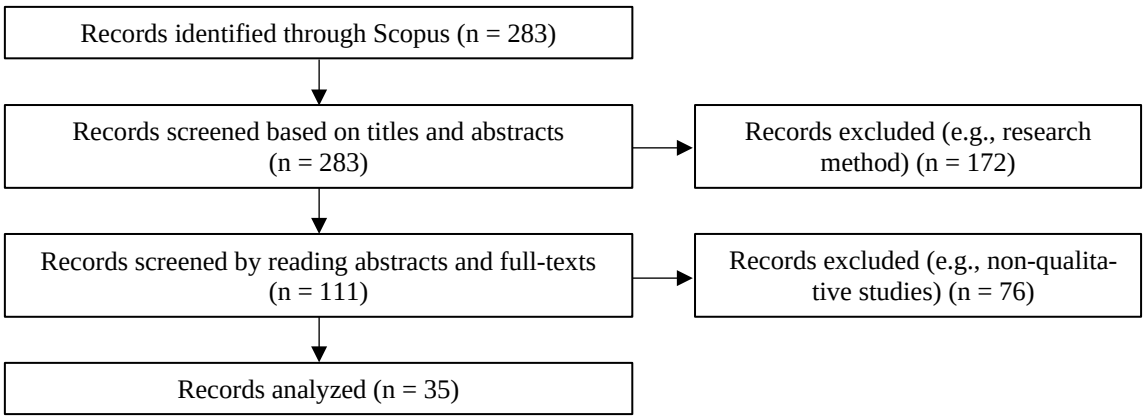

Figure 1. Sampling Procedure

We analyzed the 35 articles by reading their titles, abstracts, and full texts. In doing so, we used a data extraction form for each article to summarize the author(s), title, publication year, journal, journal quality according to the AJG 2018, research design, method(s)

used, among other themes. A detailed description of the data analysis procedure follows in the next section.

3.2 Data Analysis

Aligned with recent qualitative meta-analysis studies (e.g., Habersang et al., 2019; Küberling-Jost, 2019), our data analysis followed abductive reasoning and comprised deductive and inductive elements (Mantere and Ketokivi, 2013). The data analysis proceeded following Habersang et al. (2019) and consisted of three major steps.

First, we developed a deductive coding scheme based on the literature (Table 1). The dual-core model of innovation (Daft, 1978) and the organizational lag model (Evan, 1966) served as the interpretative background and guiding framework to analyze the data and answer the research questions. To develop the deductive coding scheme, we reviewed relevant literature related to the two conceptual models and theoretically derived concepts. This theoretically informed deductive coding scheme should give us a "glimpse of the possible" (Fleming and Sorenson, 2004, p. 912) for the ensuing analysis (Habersang et al., 2019). In this way, data and existing theory are considered jointly (Gioia et al., 2013).

Second, a within-case analysis was performed by coding each study. Within our coding procedure, we used the generated deductive coding scheme, and supplementary we conducted open coding (Gioia et al., 2013). For the within-case analysis, we adhered to Hoon (2013) and specifically paid attention to the findings, discussion, and conclusion sections of the studies under investigation. Thereby, we analyzed each study regarding the variables that affect others, variables that tend to belong together or not, and variables that must eventuate for others to occur subsequently. Altogether, we generated 335 first-order concepts: 26 deductive codes and 309 inductive codes. Our data analysis proceeded in an iterative manner involving several cycles of coding and analysis.

Third, we performed a cross-case analysis to identify dominant patterns across the studies. Seeking for similarities and differences, the first-order concepts were grouped and linked into abstracted second-order themes. That is to say, we conducted pattern matching. Finally, we constructed a data structure (Figures 2 and 3, section 4) displaying our results. It is important to note that Figures 2 and 3 (section 4) show 2 exemplary first-order concepts only for each second-order theme.

The coding has been conducted independently by one of the three researchers. Ambiguous aspects and difficult interpretations were discussed in the research team. External validity has been safeguarded by using several case studies and a rationale for the selected cases. Additionally, to enhance external validity, we used theory and literature alongside emerging data in the development of propositions.

Theoretical background	Central themes	1st order concepts (deductive codes)	Exemplary sources
Dual-core model of innovation	Technical core and administrative core of an organization; innovation proposal and decision to adopt	Organizations have a technical and administrative core with which innovations can be associated; technical innovations originate from an organization's technical core, administrative innovations originate from an organization's administrative core; technological innovation emerges bottom-up by lower employees who are experts in technical core activities; administrative innovation follows a top-down process initiated by upper-level managers; administrative innovation can precede technical innovation; administrative innovations can facilitate technical innovation over time	Daft, 1978; Kimberly and Evanisko, 1981; Damanpour et al., 1989
Organizational lag model	Rate of innovation adoption (technical innovation vs. administrative innovation) in organizations	Discrepancy in the rate at which technical and administrative innovations are implemented in an organization; administrative innovations tend to lag behind technical innovations; technical innovations could also lag behind administrative innovations but they do so infrequently; the slower-moving innovation type retards the faster-moving innovation type; technical innovations are more tangible and directly related to outcomes in contrast to administrative innovations; administrative innovations require more time to show effects; administrative innovation is developed near the top of hierarchy and trickle down; technical innovation is developed near the bottom of the hierarchy and trickle up; greater organizational lag is associated with lower organizational growth rate; balanced adoption rate boosts performance; focusing on a specific type of innovation over time negatively impacts organizational performance	Evan, 1966; Damanpour and Evan, 1984; Damanpour et al., 2009

Table 1. Deductive Coding Scheme

4. Findings

In the following, we present the findings associated with *RQ1* (section 4.1) and *RQ2* (section 4.2), respectively.

4.1 Interplay between TPI and API in I4.0

Four ways of interaction between TPI and API emerged from our analysis, as displayed in Figure 2.

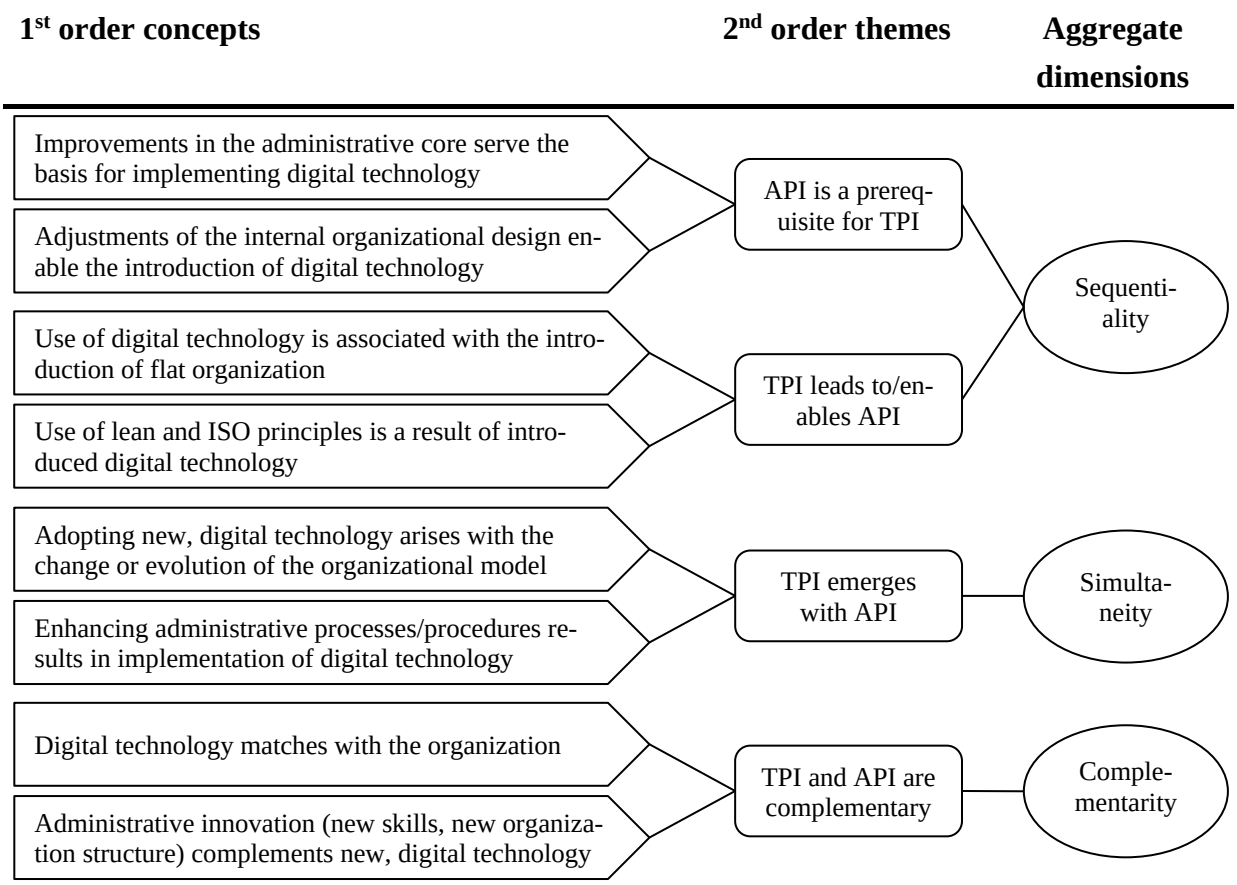

Figure 2. Data Structure – Interplay between TPI and API in I4.0

4.1.1 Sequentality of TPI and API

On the one hand, we found that API represents an important basis for TPI. Particularly, the results show that API is a prerequisite for TPI. That is to say, modifications in a company's organizational structure and administrative procedures are required to prepare for the introduction of new technologies. APIs represent the first step as they help create a corporate environment that is ready and prepared for technological advancements. APIs establish a fertile ground on which I4.0 technologies can be implemented and leveraged. In this sense, changes in the organization such as structural improvements or new ways to organize work are preparatory and they are required to create the basis for successfully implementing new technologies. For instance, Zangiacomi et al. (2020) report that the adoption of lean management approaches is "an important prerequisite and enabler for the implementation of new [technological] solutions" and that "changes [are] needed to adapt an organization to I4.0 technologies" (p. 150). Firms frequently implement a flat organization structure when aiming to ramp up their technological landscape, so that the flat, decentralized design becomes a key necessity. Bertoncel et al. (2018) for instance report that the creation of a "leaner organizational structure" was established to be able to set up a fully automated and digitalized factory. Another example in that respect is innovating the organizational structure by creating localized IT units to be able to leverage the potential of technology (e.g., Agarwal and Brem, 2015). The improvement of the

internal organizational design is the starting point for the digitalization path (Martinez, 2019). API being a prerequisite for TPI thus signifies that administrative renewals are realized as a preparatory work to make the internal administrative context ready for the introduction of technological innovation into the production and operations. Hence, APIs are needed to create the basis for the introduction of TPI.

On the other hand, we found that TPI can lead to API, indicating that the use of new technologies can trigger a company to further implement innovations in the administrative and managerial sphere of a firm. The examined studies pointed out that technological changes in the manufacturing system or operational processes like digitalization and automation induce subsequent innovation of administrative processes such as work allocation and organization and content of tasks. In particular, new technology causes the need to set up new tasks and roles, new job profiles, new competencies, or introduce new collaboration modes like remote working. That being said, TPIs can drive the emergence of APIs. In the case of the automotive industry, the transition to new technologies (automation, smart technologies, and intelligent machines) ultimately led to changes in the work and organization of human resources, such as the creation of new recruitment practices, job profiles, staff selection criteria, and competencies (Jerman et al., 2020). New technologies typically put new requirements on the workforce (Bokrantz et al., 2020a) and, thus, newly introduced technologies frequently call for making changes in the processes of work organization and administrative systems. As a consequence of using new technology, firms can create new job profiles. Undoubtedly, technological and IT skills have to be developed in response to newly implemented machines (e.g., Zolotová et al., 2020). The use of higher automation and robotics opens up new possibilities and can trigger a company to adopt remote working practices which require further changes in planning, coordination, objectives, among others. Also, bottom-up information processes occur subsequent to using digital technology. Furthermore, the use of smart manufacturing technologies promotes the introduction of team working (Cagliano et al., 2019). Other than that, machines replace manual and monotonous tasks, providing the possibility to introduce novelty in the allocation of tasks and work tasks and activities. Following this, TPI can trigger API meaning that realized technological advancements within a firm give rise to innovating non-technological aspects.

4.1.2 Simultaneity of TPI and API

The analysis revealed that TPI can also emerge with API. In the attempt to innovate administrative processes, improvement can be obtained by combining the administrative process with new technology. Novel decision-making practices can be for instance linked to the use of a robot that provides data to further support and speed up the decision-making. Furthermore, administering and storing data – which is a rather administrative activity – can be innovated using cognitive computing. As such, a TPI arises out of the aim to innovate an administrative process. In this interaction mode, existing technology can be considered to become obsolete to some extent due to alterations within the administrative core, such as a change in the organizational model. One case shows that improvements in

the administrative purchasing processes elicited the introduction of a new technological solution and the integration of systems (Martinez, 2019). Firms' introduction of I4.0 technology, in this case, arises out and follows from new innovative changes in firms' procedures and processes.

4.1.3 Complementarity between TPI and API

Finally, we discerned a complementary relation between TPI and API. The complementarity signifies that both TPI and API are required and form a part of I4.0 because they complement each other. The three afore outlined interaction patterns are in line with the complementary role between TPI and API as they imply that both TPI and API are required. In this sense, firms implement both technological and administrative changes to ensure alignment. Rather than informing about their sequence, complementarity between TPI and API highlights that the two types are interdependent and have a synergetic interaction, necessitating that firms introduce both in the context of I4.0. Following this, irrespective of their sequence, firms couple TPIs and APIs so that technological renewals come along with administrative renewals and vice versa, in order to obtain a match. From our analysis, it became evident that a new digital technology (e.g., automation) should be accompanied by adaptations in the organization itself like its design, structure, management, workforce, or even business model. Specifically, organizational structure appears to be of the highest priority and has to complement and be compatible with a newly introduced technology. This underscores that technological issues should be integrated with organizational and operational ones (Zangiacomi et al., 2020).

4.2 Dimensions of the Administrative Core

The qualitative meta-analysis further captured administrative core dimensions that appear to be relevant for I4.0, thereby answering *RQ2*.

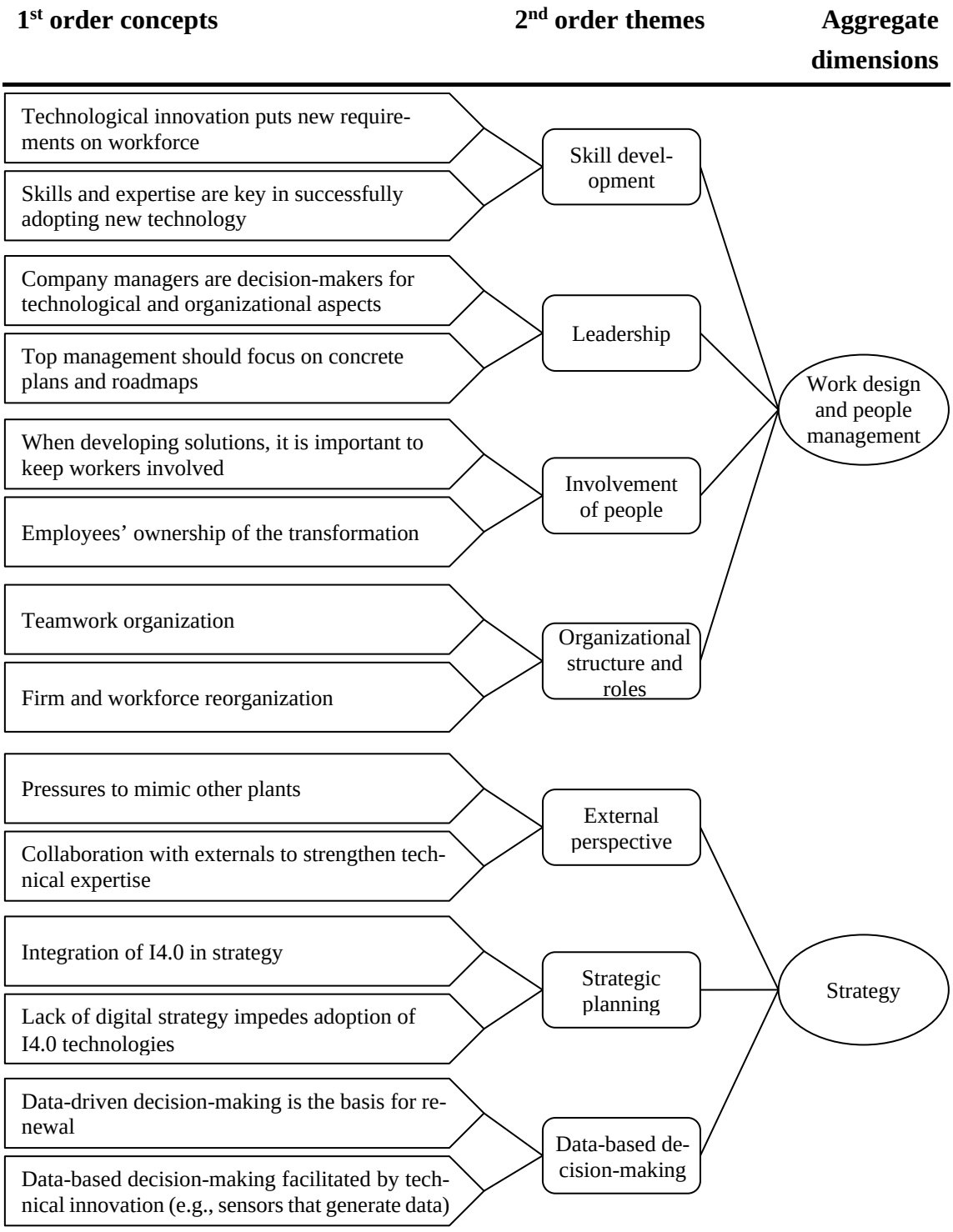

Figure 3. Data Structure – Administrative Core Dimensions Relevant for I4.0

Throughout the studies we analyzed, we found that skills and competencies are fundamental and the results illustrate that skill development is a major factor in the context of I4.0. Particularly, skill development exemplifies that higher and/or different skills are required which is primarily associated with TPI in the way that new, digital technologies put new requirements on the workforce. The need for higher competencies applies to both

the operational level (i.e., employees, operators, and workers) as well as the managerial sphere. Training and education are, therefore, vital activities as part of an organization's I4.0 efforts in order to converge workers' skills with technology. The introduction of automated and digital machines requires new worker skills. Moeuf et al. (2020) observed that "SMEs are missing internal competency enabling the exploitation of Industry 4.0 technologies". Mittal et al. (2020) provided an interview response: "CNC machines were an option, but we did not have the skills required" (p. 1395). The new skills mainly relate to technological/digital competencies and IT capabilities. On these grounds, the relevance of skill development and the attraction of digital talents is increasing (Zangiacomi et al., 2020) and managers are cognizant of the growing need for higher levels of education and training (e.g., Bertoncel et al., 2018). Hence, training is required to develop an appropriate skill base and overcome shortages in competencies. Further, we found that leadership is pivotal for both TPI and API. Precisely, managers and leaders are decision-makers, and their leadership style, mindset, and awareness about technological, managerial as well as operational aspects are highly influential concerning the transformation to I4.0. Involvement of people is a third facet that is highly significant within I4.0. It is of utmost importance to involve the organization members when innovating processes. As an example, in the case of a toy factory, "process improvement is possible just if the people are involved" (Martinez, 2019, p. 1723). Employees' ownership of the transformation, their commitment, and empowerment can be enhanced by involving them. Additionally, organizational structure and job roles are crucial concerning I4.0. Flat organizational structures and lower managerial hierarchy appear to be particularly suitable for I4.0 (e.g., Bokrantz et al., 2020; Cagliano et al., 2019) and cross-functional teamwork is paramount. Consequently, also roles and job profiles play a major role (e.g., Jerman et al., 2020). Skill development, leadership, involvement of people, and organizational structure and roles are subsumed under the dimension "work design and people management".

The second dimension we identified is "strategy" which encompasses three factors as elaborated subsequently. Firstly, we found that organizations engaging in I4.0 adopt what we label an external perspective. On the one hand, this perspective includes collaboration with parties outside of the organization (e.g., other firms) (Zangiacomi et al., 2020). Notably, this sort of collaboration concerns technological aspects as the development of new technologies and an increase in technological expertise (e.g., Agarwal and Brem, 2015). As an example, UPS collaborated with another firm to develop a blockchain-based platform (Kouhizadeh et al., 2020). On the other hand, it comprises an external perspective representing firms' attention to and comparison with the outside of the organization. Firms compare themselves with other similar firms, and SMEs for instance engage in mimicking other firms' developments (Mittal et al., 2019). This aspect can be grasped as benchmarking with externals. Secondly, the meta-analysis pointed out that strategic planning is an essential activity regarding I4.0. To support I4.0 engagements, organizations rely on strategic roadmaps, vision, and digital strategies that help to strategically plan and guide company action. We further observed that firms integrate I4.0 within the strategy or strategic vision (e.g., Moeuf et al., 2020). Importantly, considering I4.0 technology

implementation as tactical and not strategic is an error. Thirdly, the analysis showed that data-based decision-making is an integral part of I4.0 and data replaces experience and intuition in decision-making. Substantially, data-based decision-making is facilitated by TPI which allows for obtaining relevant data. Those new technologies are capable of speeding up decision-making. Blockchain technology generates real-time data that allows to organize logistics activities, improve sustainability aspects, or contribute to collaboration decisions (Kouhizadeh et al., 2020). Human-machine interaction delivers data to the operator and allows faster decision-making by displaying only relevant information (Zolotová et al., 2020). Data-based decision-making can be considered a strategic asset as it serves as the basis for renewal (Mittal et al., 2020).

Key Findings		**Illustrative Sources**
API-TPI/TPI-API-Sequentiality	API is a prerequisite for TPI	Zangiacomi et al. (2020); Agarwal and Brem (2015); Martinez (2019); Calabrese et al. (2020); Mittal et al. (2020); Bertoncel et al. (2018)
	TPI leads to/enables API	Jerman et al. (2020); (Zolotová et al. (2020); Cagliano et al. (2019); Mittal et al. (2020); Bokrantz et al. (2020a)
TPI-API-Simultaneity	TPI emerges with API	Koenig et al. (2019); Martinez (2019); Zangiacomi et al. (2020)
API-TPI-Complementarity	TPI and API are complementary	Agarwal and Brem (2015); Zangiacomi et al. (2020); Bokrantz et al. (2020a); Bokrantz et al. (2020b); Jerman et al. (2020)
Work design and people management	Skill development	Kaasinen et al. (2020); Zolotová et al. (2020); Raj et al. (2020); Jerman et al. (2020); Moeuf et al. (2020); Mittal et al. (2020); Bordeleau et al. (2020)
	Leadership	Raj et al. (2020); Agarwal and Brem (2015); Moeuf et al. (2020); Koenig et al. (2019); Bordeleau et al. (2020); Bokrantz et al. (2020b)
	Organizational structure and roles	Cagliano et al. (2019); Jerman et al. (2020); Agarwal and Brem (2015); Bokrantz et al. (2020b)
	Involvement of people	Mittal et al. (2020); Martinez (2019); Moeuf et al. (2020)
Strategy	External perspective	Kouhizadeh et al. (2020); Bertoncel et al. (2018); Mittal et al. (2020); Agarwal and Brem (2015); Bokrantz et al. (2020b)
	Strategic planning	Raj et al. (2020); Moeuf et al. (2020)
	Data-based decision-making	Bordeleau et al. (2020); Mittal et al. (2020); Martinez (2019)

Table 2. Overview of Findings and Illustrative Sources

5. Discussion

5.1 Overall Implications for I4.0

The findings unveil that both TPI and API are important cornerstones of I4.0. The duality of technology and organization inherent to I4.0 resonates with the sociotechnical systems theory (Trist, 1981). As shown in our study, changes in the technical system require changes in the social system. Based on this, we argue for a systemic view on I4.0 and, in line with Neumann et al. (2021), we put forward that I4.0 is a sociotechnical system that necessitates a balance between the systems to be effective. Besides, the observed importance of social aspects calls for a human-oriented approach to this new industrial paradigm. Several I4.0-studies underline such a perspective, yet operators frequently remain at the core of examination (e.g., Longo et al., 2017). Our study, instead, suggests that organization members from different hierarchical levels (i.e., operative staff up to managerial personnel) should be considered.

In pursuing I4.0, firms couple the introduction of digital technologies into their operations with the implementation of changes in the administrative sphere. Hence, firms engaging in I4.0 combine TPIs and APIs so as to integrate technology and organization, as propounded by Hervas-Oliver et al. (2017; 2020). Whereas the academic debate on I4.0 largely revolves around digital technologies associated with this new industrial paradigm (e.g., Bai et al., 2020; Frank et al., 2019), our findings suggest that I4.0 goes beyond the mere adoption of digital technologies. In line with Olsen and Tomlin (2020), we put forward that I4.0 not only has to do with new technologies but also with administrative renewals. Thus, we suggest that I4.0 is a comprehensive phenomenon that covers both TPI and API such that firms introduce both innovation types as part of I4.0 initiatives.

This gives rise to our first proposition:

Proposition 1: Firms' pursuit of I4.0 requires the introduction of innovation in both technology (TPI) and organization (API) within firms.

5.2 The Interplay between TPI and API in I4.0

Considering TPI and API in I4.0 and answering *RQ1*, our study shows how diversely TPI and API interplay. Results illustrate four ways in which TPI and API can relate to each other.

First, we highlight that in the pursuit of I4.0 TPI can precede API and vice versa. Studies still frequently ignore the adoption sequence (Battisti et al., 2015), such that this present study goes one step further for the TPI and API debate in general, and their relevance in I4.0 in particular. Our finding that API can be a prerequisite for TPI implies a sequential order of innovation in the sense that firms first introduce API, and then they introduce

TPI. This evidence confirms several scholars who have argued that organizational alterations obtained by implementing APIs are a precondition for the successful introduction of new technology (i.e., TPI). In this regard, for instance, Edquist et al.(2001) stated that APIs are "vital for the development and use" of TPI (p. 12). In a similar vein, Hollen et al. (2013) claimed that API precedes the internal deployment of novel technology in the production system. The foundational role of API signifies that API creates a company's readiness to implement and use new technology in the production and operations system. Therefore, APIs represent a means to make a company ready for introducing I4.0 technology (Sony and Naik, 2019).we observed that TPI leads to/enables API, which implies that in some cases, TPI can precede API. This sequential occurrence corroborates the main hypothesis of the organizational lag model: as posited by Evan (1966), APIs can lag behind TPIs. Arguably, the adoption of TPI creates the need for innovation in the organizational factors (i.e., API). Accordingly, TPIs can trigger the introduction of APIs and, in turn, APIs can lag behind TPIs in I4.0. Based on this, we maintain that TPI can have a leading role in I4.0.

Second, in addition to the sequential pattern between the innovation types, we identified their co-emergence (i.e., TPI emerges with API), pointing to the simultaneous occurrence of TPI and API. In other words, firms simultaneously engage in TPI and API in the pursuit of I4.0. This result is in line with synchronous innovation literature whose proponents discuss a simultaneous adoption of TPI and API in organizations (Georgantzas and Shapiro, 1993). Alexiev et al.(2018) substantiated a synchronous innovation pattern in the servitization context; we do so for the process-oriented I4.0 context. Further, we confirm studies that found simultaneous patterns between TPI and API (e.g., Hervas-Oliver et al., 2018). Whereas Hervas-Oliver et al. (2014) conclude that the simultaneous co-adoption of TPI and API is favorable in manufacturing SMEs, our results do not allow us to make interferences concerning the simultaneous pattern within firms of different sizes, when dealing with I4.0 efforts.

Third, TPI and API appear to complement (rather than substitute) each other. The complementarity between TPI and API is consistent with theoretical arguments and previous empirical findings offered by complementarity research (Whittington et al., 1999). Specifically, the result is in line with studies on complementarities-in-use that "have sought to identify relatedness in the use of different practices and to show that certain practices tend often to be linked" (Ballot et al., 2015, p. 218). Drawing on Hullova et al. (2019), who discussed different complementarities between product and process innovation and developed a conceptual framework, we posit that different types of complementarities may exist between TPI and API. Hence, relating the complementarity between TPI and API to their identified sequential and simultaneous interaction, we assume that APIs and TPIs may complement each other both sequentially and simultaneously in the context of I4.0. In making this assertion, we contradict Battisti et al. (2015) who, based on their empirical findings, rule out the existence of simultaneous complementarity and only proclaim a sequential complementarity between TPI and API. Yet, the presumption that both

forms of complementarities exist in I4.0 must be considered with caution, and additional research is required, as our study lacks robust empirical evidence on this matter.

Taken together, the complex interplay between TPI and API underlines that innovation types are interdependent also for I4.0 efforts, as stated by Damanpour about other contexts (2017). The diverse ways in which TPIs and APIs interact suggest that there is no one-size-fits-all approach or a single best strategy in terms of how firms should combine TPI and API in the pursuit of I4.0. Considering the different patterns of interaction that characterize the relationship between TPI and API in I4.0 (i.e., sequential, simultaneous, complementary), it is noteworthy that, whereas most studies support one of these patterns, we provide evidence for each of them, allowing us to argue that each holds true. We thus reconcile that either perspective is valid in its own right and we propose a raison d'être for every pattern. To summarize, aligned with Ballot et al. (2015, p. 229), our study demonstrates that although firms combine TPI and API, "there remains considerable variety in the way firms introduce different forms of innovation".
Hence, we propose:

Proposition 2: In I4.0, TPI and API interplay in sequential and simultaneous way, and complement each other, requiring firms to follow an individual, context-dependent approach to I4.0.

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5.3 The Dimensions of the Administrative Core particularly relevant for I4.0 Efforts

Regarding our study's second aim of capturing administrative core dimensions relevant in I4.0 (*RQ2*), the findings illustrate that work design and people management, as well as a strategy, are key factors. These dimensions reflect Daft's (1978) technical vs. administrative core distinction and underline the relevance of the latter for I4.0. Although research increasingly pays attention to the organizational perspective of I4.0, studies pursue different foci and, therefore, tend to highlight individual aspects of the administrative core. The present study has consolidated a set of aspects, allowing us to present the organizational implications at a higher level of abstraction.

The dimension of work design and people management consists of skill development, leadership, involvement of people, organizational structure, and roles. In essence, these elements concern the workforce across hierarchical levels, thus reiterating the previously mentioned significance of social aspects in I4.0 (see section 5.1). Leaders' centrality in I4.0 concurs with upper echelons research that attributes a significant role to managers and leaders. Our finding further corroborates studies that have stressed leaders' role in

the context of I4.0. For instance, Srivastava et al. (2022) recently found that top management support positively contributes to I4.0 acceptance. Related, De Sousa Jabbour et al. (2018) presented propositions about the critical role of leadership and top management commitment within the scope of I4.0. This study is consistent with these findings. Yet, whereas existing studies tend to stress the importance of workers' skills due to the demand for higher technical expertise, we put forward that the development of leadership skills is just as crucial as the development of technical competencies. In doing so, we underpin Shet and Pereira (2021), who portrayed 14 managerial competencies for I4.0. It follows that without skilling up, training, and involving the workforce, the benefits of I4.0 might not manifest (Piccarozzi et al., 2018). Considering the identified essential role of participation and work design elements, human resource and change management tools may be particularly useful for I4.0.

The second dimension, namely strategy, indicates that strategic planning, an external perspective, and data-based decision-making are vitally important for any I4.0 initiative. In making the need for a strategic approach to I4.0 salient, our study reinvigorates the seminal I4.0-report by Kagermann et al. (2013) which presented I4.0 as a strategic initiative. The strategic importance we assign to I4.0, furthermore, echoes the strategic management literature and coincides with the studies of Stentoft et al. (2020) and Horváth and Szabó (2019). These researchers, among others, argue that the lack of a strategic approach represents a significant barrier to I4.0 which underlines the need for strategic action in I4.0. Strategic roadmaps provide insights on the steps to be taken in the I4.0 transition (Ghobakhloo, 2018). In this sense, according to Toanca (2016), both large and small firms should engage in the creation of a digital strategy. Lastly, the result of the external perspective in the pursuit of I4.0 is well in line with the open innovation paradigm according to which firms' should open their firm boundaries to acquire external knowledge. The notion of external knowledge search in I4.0 resonates with the study of Hervas-Oliver et al. (2020) that emphasizes open innovation in process-oriented domains. In fact, our result corroborates a small body of I4.0 research that confirms the linkage between I4.0 and open innovation (e.g., Shet and Pereira, 2021).

Based on the above-discussed findings, we derive the following propositions:

Proposition 3: Work design, people management, and strategy are relevant elements for the successful implementation of I4.0 initiatives.

Proposition 3.1: Workers' and leaders' skills as well as involvement are relevant for the successful implementation of I4.0 initiatives.

Proposition 3.2: I4.0 necessitates a strategic approach that includes strategic planning, an open approach, and data-based decision-making.

6. Conclusion

6.1 Scholarly Contributions

The contribution of this study to the scientific debate is two-fold.

First, we contribute to I4.0 research by examining innovations related to this new industrial paradigm. In doing so, we address the limited appreciation of API vis-à-vis TPI in the study of I4.0. Going beyond the otherwise common technological trajectory of I4.0 research, our study sheds light on firms' innovation adoption patterns in the pursuit of I4.0 and demonstrates the importance of both TPI and API. Our findings support researchers who argue that changes in technology and business processes or practices should be addressed and implemented in conjunction to yield I4.0 success (e.g., Culot et al., 2020; Mahmood and Mubarik, 2020). Hence, we further enrich current research on the organizational implications of technological change by emphasizing that the implementation of new technologies is associated with adaptations in the work organization in terms of work design and organizational structure (Cagliano et al., 2019). Moreover, we answer Robert et al.'s (2020) recent call for research on the interplay between TPI and API in I4.0. By illustrating that both the sequential and simultaneous adoption of TPI and API are relevant in I4.0, we provide answers to the questions they urged future studies to clarify.

Second, our study contributes to the stream of literature dealing with management innovation types and their relatedness. This stream has indeed largely overlooked the interplay between TPI and API in the I4.0 context. With our study, we respond to the repeated requests by Damanpour (2020; 2017) for further research on the interplay of innovation types in a variety of contexts. In particular, we take research on the interdependencies between innovation types one step further by showing both sequential and simultaneous interactions alongside a complementary nature between TPI and API in I4.0.

6.2 Practical Implications

First and foremost, practitioners need to be aware of the importance to approach I4.0 not merely from a technological standpoint and understand that I4.0 is far more than technological innovations. Our study highlights that firms are required to address both TPI and API in I4.0. Therefore, companies and managers engaging in I4.0 should not exclusively focus on implementing TPI but equally consider the implementation of innovation in the organizational and administrative aspects, enforcing the adoption of compositions of different innovation types. As such, I4.0 requires coordinated innovation efforts within firms. Also, taking heed of the diverse ways of interactions between TPI and API, managers are required to purposefully design innovation strategies to ensure a fitting composition of TPI and API. In that respect, managers should be cognizant of the potential need to nurture appropriate firm capabilities required for innovation activities on both technology and organization (Hervas-Oliver et al., 2020). Especially firms in which innovations typically follow a technological trajectory (e.g., manufacturing firms) should strengthen their

awareness of and orientation towards non-technological innovations with the aim to promote an organizational context in which diverse innovation types can flourish. Lastly, in order to adopt I4.0, companies should pay attention that leadership supports I4.0 and should fulfill the needs for training and upskilling of their workforce. Based on the importance of the administrative sphere concerning I4.0, we recommend managers to set up I4.0 projects cross-functionally, involving organizational functions such as human resources to ensure to meet interdisciplinary requirements of I4.0 and the breadth of innovations related to I4.0.

6.3 Limitations and Future Research

Our study has several limitations that offer avenues for future research. The main limitations arise from the method chosen for this study. First, our examination is restricted to previous studies on I4.0 and on their context. To support generalizability, we reinforce the call of Damanpour (2020) and encourage further empirical studies to examine the relation among TPI and API across different industries, countries, and firm sizes. A second limitation is the interpretive nature of our study. We, therefore, put forward the need for accumulating further empirical evidence to substantiate our insights on the relationship between TPI and API in I4.0. Particularly, we encourage future research to probe our propositions.

In addition, other interesting avenues for future research lie in examining the contingencies of the different forms of interplay between TPI and API and the factors that affect the favorability of one form over another, also considering performance consequences. Future empirical research could examine when and under which conditions firms should attempt in a sequential adoption of TPI and API and when in a simultaneous, taking into account synergistic effects. Longitudinal studies may be particularly suitable for addressing these points. Also, future studies may take into consideration other innovation types such as product innovation or hybrid innovations that combine API and TPI types to refine the understanding of their relation to TPI and API. Finally, considering the technological trajectory of most I4.0 research, we push ahead with the call by Neumann et al. (2021) and promote research to open up new vistas and explore I4.0 from different perspectives.

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