Performance effects of digital technology adoption and product & service innovation – A process-industry perspective

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PERFORMANCE EFFECTS OF DIGITAL TECHNOLOGY ADOPTION AND PRODUCT & SERVICE INNOVATION – A PROCESS-INDUSTRY PERSPECTIVE

ABSTRACT

European manufacturing companies face increasing pressure to adopt digitalization technologies discussed in the emerging paradigm of Industry 4.0. On the other hand, innovation capabilities both in terms of introducing new products and new services are of outmost importance to gain competitive advantage. Technology adoption and firm innovativeness are often interrelated, but this relation is not well understood, and in particular, the way in which digital technology adoption, product and service innovation, and competitive advantage are related to process industries has not yet been investigated. This paper develops and operationalizes a conceptual framework for product and service innovation, thereby incorporating digital technology adoption. Through an exploratory study, using quantitative data from the European Manufacturing Survey (EMS)-2015, we analyze data from 747 cases in the process industries from D, NL, A, CH, and DK. Our main findings show that companies with higher levels of digital technology implementation (breadth and depth) can introduce more radical product and service innovations. Companies with both radical innovations and service innovation make significantly greater use of their implemented technologies' potential. Radical product innovation also yields higher returns on sales, but contrary to our assumptions, service innovation in process industries does not. We find that, in the low-tech sectors, digital technologies are used to generate product and services innovations which then translate into higher performance. In contrast, in the high-tech sectors, digital technologies have a direct impact on performance and are thus rather accustomed to realizing the efficiency gains not primarily used for innovation.

Keywords: Product Innovation, Service Innovation, Technology Adoption, Process-Industry

1. INTRODUCTION

Global manufacturing is undergoing major changes, and industries must react to the growing competitive pressure arising from customization and individualization (Tseng, 2003; Brettel, 2016). The flexibility required to endure these changes is achieved through automation and digitalization technologies based on the utilization of intelligent data systems and technology (Spath, 2013). This leads to increased attention to the potential of adopting technology and digitalization across industries (Lasi, 2014) to achieve a competitive advantage. While technology adoption can increase a company's manufacturing and process capabilities (Bergfors & Larsson, 2009; Colotla et al., 2016; Gagliardi, 2013), it might not be enough to achieve a sustainable competitive advantage over competing firms. The ability to introduce new products to the market has been recognized to be of central importance to gaining competitive advantage (Porter, 1998). However, the product innovation rates of European firms are not very promising, as only around 30% of them have introduced a new or significantly improved product or process during a three-year period (Hollanders & Es-Sadki, 2017). A central question therefore is whether technology adoption as a form of process innovation can benefit firms also in their efforts to become more product innovative and to introduce new products *and* services. Especially, this relationship between technology and new products and services has been barely explored with regard to companies in the process industries, where a strong relation exists between production technology and innovation (Lager et al., 2013). These industries focus on the treatment and transformation of raw materials (Lager, 2017; Storm et al., 2013) and might be less inclined to use technologies as a means for product and service innovation. Examples of firms in the process industries include rubber and plastic manufacturers, chemical and pharmaceutical firms, producers of minerals and metals, and food and beverage manufacturers. Research from other industries has shown that digital technology adoption is an essential cornerstone for manufacturing firms to introduce new services (Goduscheit & Faullant, 2018). By offering stand-alone services or services offered to support the installation or use of combined tangible products (Antioco et al., 2008; Ulaga & Reinartz, 2011), manufacturing companies can increase their overall competitiveness, but the extent to which the adoption of digital technologies is related to both new product and new service introduction, and ultimately also to competitiveness, is unclear. Single cases from the process industries show the potential of digital technologies for new product and service development; in the mining industry, sensor and virtual representation technology enable firms to establish a digital twin of the subterranean and geographically often-distant mining systems that facilitate real-time remote monitoring (Prinsloo et al, 2019), and increases safety and efficiency. In the chemical and pharmaceutical industries, digital technologies enable new R&D approaches by making it possible to implement faster simulations when using new chemicals or a more sustainable production of chemicals on the basis of big data or artificial intelligence. Digital technologies also allow firms not only to sell raw materials, but also to perform specialized analysis to test the materials in the application (e.g., friction properties of lubricants in breaks), thereby leading to service innovation.

Although the relationship between product innovation and process innovations in terms of technology adoption has been discussed in the literature in conjunction with the product-life-cycle concept (e.g. Utterback & Abernathy, 1975), it is unclear whether the technology adoption of individual firms enables them to introduce more innovative products and more innovative services. This is an interesting angle for examination, because technology adoption and product innovation require different organizational skills (Damanpour & Golpakrishnan, 2001; Schleimer et al., 2020); technology adoption requires skills in the application of technology to improve efficiency in production and commercialization, whereas product innovation requires a firm to assimilate customer need patterns in order to design new products and services. We are therefore particularly interested in whether digital technology adoption and use in firms is associated with the ability to introduce incrementally and radically new products and services to the markets and whether the introduction of products and services of higher novelty are also related to competitive advantage in terms of higher profitability.

Previous research has explored either the effects of single specific digital technologies on firm performance and innovation (e.g. IoT in the mining industry, Prinsloo et al, 2019; Additive manufacturing in supply chains, Luomaranta & Martinsou, 2020; Sensor technology in the gas industry, Yamazoe, 2005; and IoT technology in the manufacturing industry Kao et al., 2019) or the application of digital technologies on a very coarse overall level (e.g. the presence of digital technologies in the firm examined in Ferreira et al., 2019 or Khin et al. 2019). However, the effect of digital technology adoption on innovation and performance based on a broader set of specific digital technologies (i.e. the digital technology portfolio) has not yet been investigated. Digital technologies, however, are interrelated, and they build on each other, because they are based on the generation of data, and thus the effectiveness of digital technologies should not be assessed in isolation but in their entirety. Moreover, our research is novel in that it considers not only the number of digital technologies adopted but also the depth of their implementation in the firm, thus facilitating a more fine-tuned analysis. Finally, digital technologies can have a generative effect (Nambisan, 2019) on innovation by enabling traditionally goods-producing companies to expand their innovation activities from product to service innovation, thereby amplifying the basis for competitive advantage. This expansion into service innovation has not been investigated within a large-scale sample and not within the process industries. Based on these research gaps, we will investigate the following research questions:

a) Is digital technology adoption (in terms of breadth and depth of adoption) related to the product innovativeness of firms in the process industries?
b) Is digital technology adoption (in terms of breadth and depth of adoption) related to the service innovativeness of firms in the process industries?
c) Can product- and service-innovative firms in the process industries achieve higher competitive advantage than their less-innovative counterparts?

We generate hypotheses and test them in a sample from the European Manufacturing Survey 2015, with 747 cases at the plant level from five European countries (D, A, CH, DK, NL), and from eight different process industries. By assessing the number of adopted technologies out of 10 digital technologies (labelled as digital technology breadth) and by assessing the extent of use of these adopted technologies (labelled as digital technology depth), we analyze the association between digital technology adoption and product- and service-innovation capability and further the association between innovation capability and competitive advantage in terms of profitability (ROS).

We assume (and our empirical analysis confirms) that firms with higher breadth and depth of digital technology adoption and use are associated with higher degrees of product and service innovativeness. We also find that companies that can introduce products of higher novelty have a higher competitive advantage in terms of profitability. However, in contrast to our hypothesis, we do not find a positive association between the ability to introduce new services to the market and competitive advantage. This means that, within our sample of process industry firms, competitive advantage in terms of profitability is driven mainly by the ability to introduce significantly new products to the market, whereas service innovations do not pay off.

2. CONCEPTUAL FRAMEWORK

2.1 CHARACTERISTICS OF THE PROCESS INDUSTRY

The process industries are characterized by long, complex, and rigid supply and value chains and products consisting of materials or ingredients rather than components (Lager et al., 2013). This requires an efficient production of commodity and/or functional products, often based on efficient process technology (Lager & Frishammar, 2012) (Lager, 2016). Technology and process innovation is often developed through collaboration with suppliers of process technology, and companies must develop skills through collaboration to secure efficient development and implementation of technology processes (Lager & Frishammar, 2012). Because of the complexity of the process industry and the pressure to develop mature key enabling technologies, innovation plays a central role in the success of the process industries (Lager et. al, 2013) in combination with the integration of information and smart technology (Qian et al., 2017). The process industries are characterized by the incremental refinement of existing products and processes and rather little radical development (Lager, 2002). Although the process industries are substantially different among themselves and especially from other manufacturing non-process industries, they exhibit similarities and synergies both in relation to innovation and technology management (Lager, 2016). Even though the general structures in the process industries are alike, there are differences in how effectively the process companies are. Most process industries are closely tight to their supplier base and the R&D processes, both within the process and product innovation are therefore dependent on close collaboration along the supply chain. Some process industry sectors have integrated their supplier base (corporate owned), which can potentially have a positive influence on the innovation intensity (Lager, 2016).

2.2 DIGITAL TECHNOLOGIES IN THE CONTEXT OF INDUSTRY 4.0

The fourth industrial revolution, Industry 4.0, is a widely discussed paradigm in both industry and academia (e.g. Albach et al., 2015; Lee & Yang, 2014; Colotla et al., 2016; Machado et al. 2019). Although the literature presents different perspectives, four main concepts are identified as common denominators of the I 4.0 paradigm:

- **Digital Technologies**, both hard technologies as Robotics, 3D printing and soft technologies as forms of artificial intelligence (AI) and machine learning (ML), virtual and augmented reality (VR/AR), and big data analytics and simulation (Colotla et al., 2016);

- **Digitalization and data** are core elements enabling the transition from automation to digitalization, thereby facilitating predictive capacity and adaptability, which are derived effects of the Industry 4.0 (Schuh et al., 2017). Software-driven technologies such as datamining and machine learning play a significant role in the transformation toward digitalization (I 4.0) and are historically widely used in the process industry (Ge et al., 2017);
- **Innovation** is central in terms of technology drivers within product and process innovation-enabling potential innovations within services (Albach et al., 2015);
- **New Business Development** based on opportunities evolved from new combinations of technologies leading to innovating business models (Lee & Yang, 2014).

All four domains are interrelated and can be discussed both individually and as part of the industry 4.0 paradigm. The academic discussion of Industry 4.0 is broad and includes a wide variety of concepts and elements. This paper explores the relations and characteristics between innovation and adoption of digital technologies in the context of the process industry. To ensure clear contribution, this paper will not discuss Industry 4.0 in its entirety but center the discussion on the two cornerstones of digital technologies and innovation outlined above.

2.3 DIGITAL TECHNOLOGY ADOPTION DRIVING INNOVATION

The future dominating paradigm within manufacturing is characterized by the high extent of use of digital technologies. It highly relies on the digitalization of data, processes, and enabling technology (Burmeister et al., 2016), with the potential to build competitive advantage through technology resources, company capabilities, and high-level innovation (Drath & Horch, 2014). The technology drivers are many, but literature is consolidating regarding the main technology concepts of robotics, additive manufacturing, and augmented and virtual reality. Furthermore, control and management through big data/analytics, simulation, and integration (vertical and horizontal) work towards the creation of the digital twin concept that can be established within both products and processes (Liao et al., 2017; Colotla et al., 2016). All of these technologies rely on a certain level of digitalization, and their connection with the Internet-of-Things (both products and processes) and the Cloud are vital elements of this entire paradigm shift. As a form of process innovation, these technologies essentially change the way firms create and deliver products and services (Piening & Salge, 2015: 82). They impact the innovation potential of both product and service innovation through highly differentiated and customized products, synchronized product/service combinations, or value-added services (Burmeister et al., 2016). The level of digital manufacturing technologies is important in relation to digital capabilities, which potentially support service innovation (Lerch & Gotsch, 2015; Parida et al., 2015). Studies show that the level of digital capabilities plays an important role in the value creation toward customers and thereby the building of competitiveness (Lenka et al., 2017). The adoption of new technologies (as a form of process innovation) thus not only makes internal products and delivery processes more efficient, but essentially allows for entirely new product and service innovations or a combination of the two. Consider for example robotic technologies that facilitate precise manufacturing at levels and speeds previously unknown and at the same time enable firms to offer affordable prices attractive to the customers. Recent studies support this view and show that, for manufacturing firms, the shift from being a manufacturer of goods to becoming a performance provider is essentially linked to the adoption of digital technologies (Ardolino et al., 2017). In this sense, digital technologies not only offer alternative ways to produce goods or deliver services, but they also act as generative resources (Nambisan et al., 2019) that provoke unexpected change and introduce new combinations of actors and ingredients that have not been foreseen; this is also true for the process industries. In not only the pharmaceutical and chemical industries, but also in the food industry, digital technologies allow for dramatically shorter experimentation and analysis cycles, with a focus on the most promising combinations. These technologies can boost customized new product development of drugs, special chemicals, and food ingredients at batch sizes that have not been profitable before and can therefore allow firms to serve untouched markets. Through digital technologies relying on data, companies become more agile to approach the market, because they have more data from their clients and the market and can better predict developments, thereby leading to more successful product innovations. For example, large breweries can now produce smaller batches of special beers because they have better knowledge of their systems and can more effectively control them throughout the entire production process, including customized packaging and labelling, which allows for a higher degree of customization and better market response. The adoption of digital technologies is therefore strongly related to the ability of a firm to introduce new products and services

(Kirner et al., 2009), and we expect highly innovative firms to have implemented more of these digital technologies and to use them to a higher extent.

In this context, we distinguish between the breadth of digital technology adoption and the depth of digital technology adoption. The concept of breadth reflects whether a technology has been adopted or not; however, it does not capture the extent of use of a certain technology. Therefore, the concept of depth assesses the extent to which a technology's potential has been used. If a technology has been used to its full extent, it can be assumed that deep knowledge has been built around this technology, which serves as a further resource for innovation avenues (Katila & Ahuja, 2002). This argumentation is in line with several other academic approaches; e.g., in studies on open innovation in which search breadth and depth are explored (Laursen & Salter, 2006) as well as in the context of knowledge use and innovation capabilities (Katila, 2002). For our context, we argue that the more digital technologies a firm uses (breadth), the wider the repertoire of possible combinations will be for product innovation. However, innovation (and creative performance in general [Amabile, 1996]) not only needs a wide array of possible combinatory elements, but also depends on the depth of knowledge available in these areas. The extent of use of a technology's potential reflects how acquainted a firm is with the technology and how much knowledge it managed to build around it. The more a firm can use the full potential of a technology, the more likely it is that this knowledge will translate into new or radically new products. We therefore propose:

H1: Process industry firms with higher product and service innovativeness are characterized by higher digital technology implementation in terms of a) the number of technologies adopted (breadth) and b) the extent of use of these technologies (depth).

2.4 PRODUCT INNOVATION AND COMPETITIVE ADVANTAGE IN PROCESS INDUSTRY

Innovation is of a multidimensional nature and the OECD manual identifies four types of innovation: 1) product, 2) process, 3) marketing method, and 4) organizational method (OECD/European Community, 2005). According to the Oslo Manual, the definition of product innovation incorporates both the introduction of "a good or service that is new or significantly improved with respect to its characteristics or intended uses." The product stands out from other types of innovations as the result of a creative process in which new and existing ideas are combined in a novel way to produce an invention or a configuration that was previously unknown (Duncan, 1976) and that includes successful commercialization (Tidd & Bessant, 2013). As such, product innovation is a source of revenue and is often equated with innovativeness. The prominence of product innovation refers to the role of the product as the main contributor to performance, whether related to financial or market performance.

A frequent distinction in the literature on product innovation is made regarding the degree of novelty; i.e. whether an innovation is of incremental or radical nature (Schumpeter, 1939; OECD/European Community, 2005). Incremental innovations typically build on existing knowledge, as they enhance the performance of existing products and are targeted to existing customers (Christensen, Johnson, & Rigby, 2002). In contrast, radical innovations create new knowledge or combine existing knowledge with new knowledge (Hill & Rothaermel, 2003). They give rise to fundamental changes in activities of an organization or industry with respect to current practices. It poses new questions, develops new technical and commercial skills, and presents new ways of resolving problems (Camisón-Zornoza, Lapiedra-Alcamí, Segarra-Ciprés, & Boronat-Navarro, 2004). For process industries, radical innovations often pose challenges but also opportunities to respond to major disruptions in the environment. For example, it is expected that the chemical and the pharmaceutical industry will develop radically new solutions in genome editing, carbon recycling, digital health and agriculture, and the waste-to-chemicals areas (Deloitte & Verband der Chemischen Industrie). In the food and beverage sector, recent radical innovations include lab-grown meat, protein-grown feed for animals, or cottonseed meal (Kuzminov et al., 2018). Within the tire industry, Goodyear introduced the concept of biologically filled capsules that eliminate time-consuming tire changes with the simple insertion of different capsules (TechNews). These examples show that radical innovations are often associated with the development and use of new technology, create entirely new markets, and often replace existing technologies and related products. Radical innovations have been shown to be of long-term importance for companies, as they can create market disequilibria that allow for longer-lasting competitive advantages (Utterback & Abernathy, 1975). Studies show that radical product innovation is positively related to growth and return on sales (Xin, Yeung, & Cheng, 2008) as well as to stock exchange development and other performance related indicators (Slater, Mohr, & Sengupta, 2014). We therefore expect a positive relationship between radical product innovation and competitive advantage, and we propose the following:

H2a: Process industry firms introducing radical product innovations have a higher competitive advantage (as measured by ROS) than firms introducing only incrementally new products or no product innovations.

2.5 SERVICE INNOVATION AND COMPETITIVE ADVANTAGE IN PROCESS INDUSTRIES

As indicated by the Oslo Manual, the definition of product innovation incorporates both the introduction of goods and services that are significantly new with respect to their characteristics or intended uses. Also, early articles analyzing how managerial decisions translate into competitive advantage include products as well as services (Hansen, Perry, & Reese, 2004; Penrose, 1959). Nonetheless, academic research has developed clearly distinct research streams on product and service innovation (Coombs & Miles, 2000), and only more recently has the distinction between products and services begun to vanish (Vargo & Lush, 2004). This marks an era in which manufacturing firms increasingly also introduce service innovations by combining their products with value-added services (Kowalkowski, Windahl, Kindstrom, & Gebauer, 2015). Research has shown that, in their efforts to combine products and services, companies undergo certain stages of maturity (Lutjen, Tietze, & Schultz, 2017; Martinez, Neely, Velu, Leinster-Evans, & Bisessar, 2017) and that, in mature industries, services at the end of the lifecycle can even replace products (Cusumano, Kahl, & Suarez, 2015). For process industries, service innovations at first glance do not seem as plausible as machine manufacturers, for example, because firms in process industries typically do not sell spare parts or expand into maintenance. In contrast, some firms in service industries have started to sell service outcomes instead of products. For example, a Norwegian firm selling coatings for ship hulls started analyzing the impact of the coating on the ship's energy consumption and offers this service to its clients to optimize recommendations for coatings. In the food and beverage industry, service models include offerings of weekly sets of meals instead of single products and renting shelf spaces in supermarkets instead of selling to wholesalers. In pharmaceutical industries, some firms have started to negotiate outcomes-related contracts with hospitals for medicine treatments (Elkins, 2019). Service innovation thus is an additional factor that can contribute to building a competitive advantage, because firms typically offer better value proposition to the customer and can create lock-in effects. The issue of whether the combination of new services and products is also attractive in terms of profitability is strongly debated, and it seems that this relation is contingent on several factors such as servitization intensity (Fang, Palmatier, & Steenkamp, 2008) and experience and ability in product innovativeness (Eggert, Hogreve, Ulaga, & Muenkhoff, 2014). Nonetheless, we expect a positive relationship between service innovation and competitive advantage, because service innovations have been shown to positively affect different parameters of performance, such as customer relationship quality and firm performance (Antioco, Moenaert, Lindgreen, & Wetzels, 2008; Homburg, Fassnacht, & Guenther, 2003). We therefore propose:

H2b: Process industry firms introducing service innovations in addition to product innovations have a higher competitive advantage (as measured by ROS) than firms introducing only product innovations.

Figure 1 illustrates our research framework:

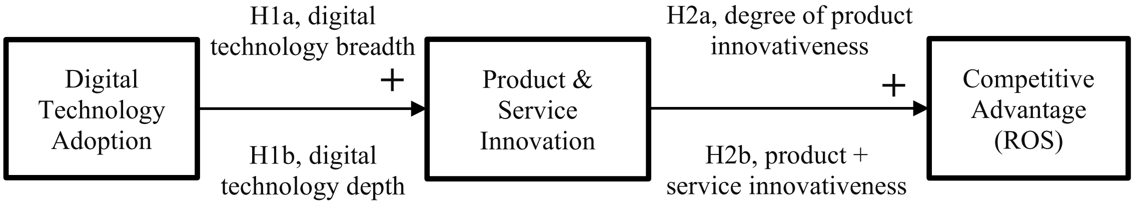

Figure 1: Conceptual framework

3. RESEARCH DESIGN

The paper builds on the survey data from the European Manufacturing Survey (EMS) 2015, including data from Germany, Austria, Denmark, Switzerland, and the Netherlands, with an original dataset consisting of 2.391 cases. The focus is on analyzing the process industries, as the data analysis concentrates on process industry cases (but initially also gives a short overview of the main demographic characteristics of firms from the entire sample, including firms from non-process industries). Selecting the process industry cases for the analysis, we follow the recommendations of Lager (2017) and separate and select process industry cases in our sample based on 2-digit NACE codes (see Table 1). The NACE code system is a European classification system to support the statistical categorization of economic activities and products (NACE, 2006). Based on this selection, we received a total of 747 cases in the process industries to form the basis of our analysis. In the process industries, 81% of all responding plants in the dataset are classified as either low or medium-low technology-level firms. The non-process industry cases have only 62% in the same categories, with an overall higher technology level.

Industrial sectors by NACE (2 digit)		NACE tech level Low	 Low-med.	 Medium-high	 High	Total cases
10	Manufacture of food products	201				201
11	Manufacture of beverages	20				20
17	Manufacture of paper and paper products	50				50
20	Manufacture of chemicals and chemical products			101		101
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations				39	39
22	Manufacture of rubber and plastic products		151			151
23	Manufacture of other non-metallic mineral products		122			122
24	Manufacture of basic metals		63			63
Total cases in process industries		271 (36%)	336 (45%)	101 (14%)	39 (5%)	747 (100%)
Total cases in non-process industries*[1]		379 (23%)	480 (29%)	596 (36%)	189 (12%)	1644 (100%)

Table 1, EMS-2015 data set organized based on NACE codes.

*[1]: The following non-process industries are represented by NACE code in the dataset: 16-18 (manufacture of wood, pulp, paper, and rel. products; publishing and printing, 24-25 (manufacture of basic metals and fabricated metal products), 26 (manufacture of computer, electronic, and optical products), 27 (manufacture of electrical equipment), 28 (machinery), and 29-30 (manufacture of transport equipment).

The EMS collects data at the factory level across Europe every third year, since 2001 and has served as data basis for several academic publications (Kirner et al., 2009; Jäger et al., 2015; Lay et al., 2010). The survey consists of a questionnaire with core questions for all participating countries. The questionnaire covers multiple fields including innovation (product, process, and service), company performance (ROS) and characteristics (size and industry), and technology concepts. The digital technology concepts have been adapted concerning the use of I4.0-related technologies, such as robotics, additive manufacturing, digital production planning management, automated data management, and system integration. The data collection began in April 2016, and after data cleaning and compilation across the participating countries were completed, data was made available for research during mid 2017. All data are compiled and managed by Frauenhofer ISI, Karlsruhe, and have been tested for representativeness. All data and calculations are handled by IBM SPSS statistics 25.

3.1 DESCRIPTIVE STATISTICS

The 747 process industry cases have been analyzed according to the descriptive statistics of country distribution, company age, and company size. In both the process- and non-process industries (Table 2) the distribution of cases are similar, and approx. 50% of all cases are German.

Country	Process industry cases	%	Non-process industry cases	%
Germany	380	51	802	48,8
Austria	66	9	147	8,9
Switzerland	180	24	445	27,1
Denmark	86	11	145	8,8
The Netherlands	35	5	105	6,4
Missing	0	0	3	0,2
Total	747	100	1644	100
Size	**Process industry cases**	**%**	**Non-process industry cases**	**%**
20-49 employees	267	35,7	699	42,6
50-249 employees	374	50,1	733	44,7
250-499 employees	71	9,5	116	7,1
499-999 employees	23	3,1	58	3,5
1.000+ employees	10	1,3	35	2,1
Missing	2	0,3	3	0,2
Total	747	100	1644	100

Table 2. Case distribution regarding employees, firm size

The distribution in firm size between process- and non-process industries is similar, and in both case groups, approx. 86% of all cases are small- and medium-sized enterprises (20-249 employees). The process industries are often considered to be organized in larger corporations, and the number of SMEs in the dataset can therefore be a bit misleading. However, the EMS data is collected at the site or factory level, which explains the characteristics of the data. In further reference to specific cases, the terminology "plant/plants" will be used. Larger corporations organize their manufacturing capabilities in networks, in which sites or factories have specific strategic and operational objectives, with different technologies and capabilities contributing to the product portfolio (Miltenburg, 2009). Thus, in principle, large organizations can participate in the EMS with multiple sites or factories, but their capabilities and characteristics are diverse. The distribution of cases based on year of establishment is also similar between the process- and non-process industries, with very small variation. Among older companies within the process industry, those established between 1900-1940 account for 13.7%, and companies established between 1940 and 2000 account for 64.3%. Recently established companies from 2001-present account for 12.8%, and 9% of companies date back to before 1900.

3.2 DEVELOPING VARIABLES

Based on Figure 1, three sets of variables are developed to investigate Hypotheses 1 and 2. In Hypothesis 1, the digital technology level (breadth and depth) is the independent variable, and the innovation level is dependent. In Hypothesis 2, the innovation level is the independent variable, and return of sales (ROS) is the dependent. Thus, the following variables are developed:

Digital technology breadth and depth. The EMS survey covers several manufacturing technologies, and for this analysis, 10 different technologies have been identified. The technologies are: 1) Industrial robots for manufacturing processes, 2) Industrial robots for handling process, 3) Technologies for safe human-machine interaction, 4) Additive manufacturing technologies for prototyping, 5) Additive manufacturing technologies for mass production, 6) Software for product planning and scheduling, 7) Near real-time production control system, 8) Supply chain management (system), 9) Systems for automation and management of internal logistics, and 10) Product lifecycle management systems. Each of the 10 technologies is to some degree linked to the concept of Industry 4.0 and digitalization. In the EMS survey, each technology can be answered with no=0, planned=1, or yes. If the respondent indicated "yes," the technology has been adopted, and an additional question elaborates on how much of the potential utilization is realized and takes the values of low=2, medium=3, or high=4. Based on the technology variables, both the *breadth,* i.e. number of technologies implemented (max. 10), and the *depth of technology implementation*, i.e. the degree of used potential of the technology (10 technologies x max. 4 = max. 40), have been calculated for each company. Table 3 shows the % of firms that have adopted each technology.

Technologies	**No use**	**Planned**	**Sum No use**	**Utilization of technology potential**		
				low	**med.**	**high**
Industrial robots for manufacturing processes*	73.1	4.1	77.2	2.4	7.5	8.3
Industrial robots for handling processes**	56.4	6.0	62.4	4.4	10.7	17.3
Technologies for safe human-machine interaction	87.6	4.7	92.3	1.2	2.1	1.2
Additive manufacturing technologies for prototyping	82.6	6.4	89.0	2.7	2.3	1.9
Additive manufacturing technologies for mass production	90.0	2.8	92.8	0.8	1.7	1.2

Software for production and scheduling***	28.1	5.8	33.9	4.8	18.9	34.9
Near real-time production control system**	51.9	9.4	61.3	2.3	11.5	19.1
Digital exchange of product/process data in supply chain*	60.6	6.2	66.8	6.3	11.2	9.1
Systems for automation and management of internal logistic*	56.9	10.3	67.2	3.9	13.3	10.2
Product-Lifecycle-Management system or product/process data management	70.1	5.8	75.9	1.6	4.3	3.5

Table 3: % distribution of degree of usage and utilization of technology potential, process industry cases.
(***; **, *; highly adopted technologies)

The descriptive statistics of the technologies shows that "software for production and scheduling" (ex. ERP systems as SAP and AXAPTA) has been widely implemented, and more than 50% (marked with ***) of the responding cases indicate that they utilize the technology's potential to a medium to high degree. "Industrial robots for handling processes" and "Near real-time production control systems" have also been widely implemented, with approximately 25-30% (marked with **) of the cases answering medium or high utilization of the technology potential. "Industrial robots for manufacturing," "Digital exchange of product/process data in supply chain," and "Systems for automation and management of internal logistic" show some degree of implementation, but less than 25% (marked with *) answer medium to high with regard to the utilization of the technology's potential.

The variable **degree of product innovation** was computed on two CIS-type questions. The first asked the respondent whether the firm has introduced a product that was new to the firm during the period 2012-2015. The second question asked the respondents whether the firm had introduced products that were not only new to the firm, but also new to the market, during the same period. If both questions were answered with "yes," the firm was categorized as a radical product innovator. If only the first question was affirmative, it was classified as an incremental innovator. This type of measurement has also been practiced in several rounds of the community innovation survey (CIS) by EUROSTAT (CIRCABC) and served as the basis for academic publications (e.g. Hashi & Stojčić, 2013; Fagerberg et al., 2012).

For **service innovation,** respondents were asked whether the firm had introduced any new services to the market during the period 2012–2015. Based on these questions, a two-by-three Product-Service-Innovation (PSI) matrix is established as the analytical framework. The case distribution in each of the six categories, for both process- and non-process industries, is displayed in Table 4. The distribution is similar between the process- and the non-process industry firms, with a slightly higher innovation rate in the non-process industry firms.

		Product Innovation		
		None	**Incremental**	**Radical**
Service Innovation	**No**	44,7% (36,7%)	23,8% (23,1%)	19,8% (22,7%)
	Yes	3,1% (4,3%)	2,3% (4,9%)	6,3% (8,3%)

Table 4. Case distribution in PSI index in % for process and non-process industries in ( ), based on 747 cases from process industries and 1,644 cases from non-process industries.

For each of the 6 fields in the PSI matrix, three indicators were calculated: Return of Sale (ROS) as a proxy for competitive advantage, and digital technology breadth and digital technology depth as indicators of digital technology adoption.

Return of Sale (ROS) serves as a proxy for competitive advantage (Laureti & Viviani, 2011; Guzmán et al., 2012) and shows the *return of sales* before tax in 2014 (ROS). This is measured by a five-step scale indicating the development of ROS over the last year; 1 = negative; 2 = 0-2%; 3 = 2-5%; 4 = 5-10%; 5 =above 10%. When ROS is combined with the PSI matrix, the average of all responding plants is calculated for each group.

It is now possible to calculate the variables *technology breadth*, *technology depth,* and ROS for each of the six categories in the PSI matrix. The main dataset consists of 747 valid cases, but due to missing items (error data or questions respondents do not want to answer), the number of cases varies, depending on which combination of variables that are analyzed. Table 5 provides a detailed descriptive picture along the single industrial sectors within the process industries, including all relevant variables of our study. There is no unequivocal relation across variables. The industrial sectors with the highest rates of radical innovation are NACE sector 17 (manufacture of paper and paper products), 22 (manufacture of rubber and plastic products), and 23 (manufacture of other non-metallic mineral products), whereas the highest scores within service innovation are observed in NACE sector 21 (manufacture of basic pharmaceutical products and pharmaceutical preparations) and 24 (manufacture of basic metals). The three highest scores of ROS mean are NACE sector 17 (manufacture of paper and paper products), 20 (manufacture of chemicals and chemical products), and 21 (manufacture of basic pharmaceutical products and pharmaceutical preparations). In the following section, further analysis has been conducted based on the interrelations among the variables. The technology variables (breadth and depth) serve as independent variables, product and service innovation are both dependent variables (in relation to technology breadth and depth), and the independent variables include return on investment (ROS), which serves as the dependent variable only.

	Industrial sectors by NACE (2 digit)	**Product Innovation**			**Service innovation**	**Tech breadth**	**Tech depth**	**1 (neg)**
		Non	**Incremental**	**Radical**				
10	Manufacture of food products (201)	50,7	26,9	22,4	5,7	1,89	6,17	8
11	Manufacture of beverages (20)	65,0	20,0	15,0	10,5	2,15	7,50	0
17	Manufacture of paper and paper products (50)	42,0	26,0	**32,0**	4,7	3,08	7,84	7,3
20	Manufacture of chemicals and chemical products (101)	37,6	37,6	24,8	15,4	2,23	7,37	6,0
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations (39)	46,2	28,2	25,6	**21,6**	2,51	8,69	3,1
22	Manufacture of rubber and plastic products (151)	47,7	22,5	**29,8**	16,4	3,21	**10,19**	14,3
23	Manufacture of other non-metallic mineral products (122)	46,7	22,9	**30,4**	13,6	2,28	8,03	8,2
24	Manufacture of basic metals (63)	57,1	20,6	22,3	**22,4**	3,16	**10,25**	12,9
Total process industry		357 (48%)	195 (26%)	195 (26%)	87 (12,9%)	2,49	8,07	53 (9,0%
Total non-process industry		674 (41%)	460 (28%)	510 (31%)	288 (19,3%)	2,53	8,18	157 (12,2

Table 5: % distribution of variables based on industrial sector.
Due to missing dataset variables are based on different cases within the process industry, product innovation = 747 cases, service innovation = 673 cases, tech breadth/tech depth = 742 cases, and return on sales, ROS = 587 cases
Calculation of the ROS mean is based on the categorization (1-5).

4. FINDINGS

For digital technology breadth, the mean-values of digital technology depth and ROS are calculated for every field in the PSI matrix, and corresponding changes between the fields are tested for significance.

4.1 DIGITAL TECHNOLOGY BREADTH AND INNOVATION

Upon investigating Hypothesis 1a, we look into the relationship between digital technology breath and product and service innovativeness. Based on the calculated mean-value of the digital technology breadth variable for the 6 fields in the PSI matrix (Table 6), it becomes clear that the average number of adopted digital technologies is significantly increasing as the degree of product innovation moves from non-innovation to incremental and further to radical innovation. Though the average number of adopted digital technologies increases when service innovation is added, there is no significant difference, unless the product innovation has reached the radical level.

	Product innovation				
	No	Δ→	Incremental	Δ→	Radical

Service innovation	No	2,051	**0,401 (0,025*)**	2,452	**0,596 (0,009*)**	3,048
	Δ↓	0,540 (0,271)		0,136 (0,811)		**0,931 (0,022*)**
	Yes	2,591	-0,003 (0,997)	2,588	**1,391 (0,041*)**	3,979

Table 6: Product and Service Innovation matrix: digital technology breadth

Note: Δ = difference between two PSI categories, score in each category is between 0-10, significance level is displayed in ( ) and the mean difference is significant at p>0,05 (*)

It becomes obvious that companies with no product or service innovation (digital technology breadth = 2,051) have a significantly lower adopted technology mean than companies with both radical innovation and service innovation (digital technology breadth = 3,979). This means that the higher the level of both product and service innovation a company has, the higher the average number of digital technologies is adopted. Hypothesis 1a states that firms with higher product and service innovativeness have a higher digital technology adoption is therefore confirmed.

4.2 Digital Technology Depth and Innovation

Investigating Hypothesis 1b, we look into the relationship between digital technology depth and product and service innovativeness (Table 7). The average digital technology depth (extent of use) is increasing, as both the product innovation moves from non-innovation to incremental and further to radical innovation. Plants in addition being service innovative also score highest according to digital technology depth. However, only in the transition from incremental to radical product innovation and introducing service innovation for radical product innovators does our analysis reveal a significant difference in the use of digital technology depth. Though the average number of utilizations of technologies increases when service innovation is added, there is no significant difference, unless the product innovation has reached a radical level.

		Product innovation				
		No	Δ→	Incremental	Δ→	Radical
Service innovation	No	6,699	1,171 (0,068)	7,870	**2,014 (0,012*)**	9,884
	Δ↓	0,619 (0,683)		0,6299 (0,734)		**3,223 (0,028*)**
	Yes	7,318	1,182 (0,607)	8,500	**4,606 (0,042*)**	13,106

Table 7: Product and Service Innovation matrix: Technology depth

Note: Δ; the difference between two PSI categories is the score in each category, which is between 0-40. The mean difference is significant at p>0,05 (*)

This means that plants with higher levels of product innovation demonstrate on average higher utilization of the technologies they have adopted. Furthermore, companies with radical product innovation have a significantly higher digital technology utilization when adopting service innovation. Hypothesis 1b states that plants with higher product and service innovativeness have a higher digital technology adoption, which is therefore partially confirmed in terms of technology depth.

4.3 Innovation and Return of Sales (ROS)

Investigating Hypothesis 2, we analyze the relation between product and service innovation and competitive advantage as measured by ROS (Table 8). Analyzing the mean of return on sales in the six different fields, an interesting picture appears. As expected, there is an increase in the variable mean, when companies move from no product innovation to incremental and radical innovation. When plants also have service innovation, we see a negative development in the mean of ROS. The only transition that is significant is from incremental innovators to radical innovators.

		Product innovation				
		No	Δ→	Incremental	Δ→	Radical
Service innovation	No	3,143	0,175 (0,163)	3,318	**0,379 (0,014*)**	3,697
	Δ↓	-0,143 (0,630)		-0,185 (0,576)		0,09 (0,971)
	Yes	3,000	0,133 (0,754)	3,133	0,573 (0,129)	3,706

Table 8: Product and Service Innovation matrix: return of sales (ROS)

Note: Δ; the difference between two PSI categories lies in the score in each category between 1-5. The mean difference is significant at p>0,05 (*)

This leads to the conclusion that, to increase financial performance, the degree of product innovation is more significant than the introduction of service innovations. In other words, service innovation in our sample does not pay off. Instead, only those plants that can introduce radically new products to the market also have a higher return on sales. Possible explanations for the non-significance of service innovations could be that services are not billed separately but are offered in close connection with tangible products or rather seen as a way to increase customer retention. Another alternative explanation could be that firms only recently started to introduce services, and therefore the payoff in terms of profitability is not yet visible.

We have controlled for correlation with a set of control variables, firm size, and age as well as industry affiliation (see appendix Table 1). There is an expected correlation between company size and innovation but no correlation between our main variables and firm age. Certain industries are inclined to have higher innovation rates, as already indicated in our descriptive Table 5. In summary, Hypothesis 1a is confirmed and Hypothesis 1b is partially confirmed. Hypothesis 2a is confirmed, but Hypothesis 2b is not confirmed.

5. FURTHER EXPLORATORY ANALYSIS

5.1 TECHNOLOGY PROFILE ANALYSIS

The findings clearly point to a relation between the level of product innovation and service innovation and both digital technology adoption and utilization. There is also a clear connection between the increasing level of product innovativeness and return on sales, though it is only partly significant.

Based on the most significant findings, further exploratory technology analysis is focused on the transition from no innovation (or product and service) to radical product innovation and service. The aim is to identify differences in the technology configurations, i.e. whether the more innovative firms not only apply more technologies and to a deeper extent, but also whether they use a different set of technologies. Table 9 provides an overview of the following three dataplots of technology configurations in Figures 2, 3, and 4.

The dataplot in Figure 2 compares non-innovators and companies with only service innovation. It shows that service innovators in contrast to non-innovators have especially higher scores in the utilization of industrial robots (both manufactruing and handling), AM for prototyping, and systems for automation of internal logistic. The other six technologies are at the same level, and there is no significant difference.

Analysing the technology configurations between non-innovators and companies with radical product innovation, Figure 3 shows that radical innovators have a higher average technology utilization of industrial robots and a range of data-driven/digital technologies, as systems for automation of internal logistics, data exchange in the vertical supply chain, near real-time control systems, and software for production planning. Thus, compared to non-innovators, the radical product innovators use the same digital technologies but to a significantly higher extent, and in addition, they exhibit a significantly higher level especially in the use of industrial robots.

Figure 4 compares the technology utilization between non-product innovators with radical product innovators also having introduced service innovations. Radical product-service innovators are distinguished by significantly higher levels in their use of near-real-time technologies, software usage, and vertical data exchange technologies.

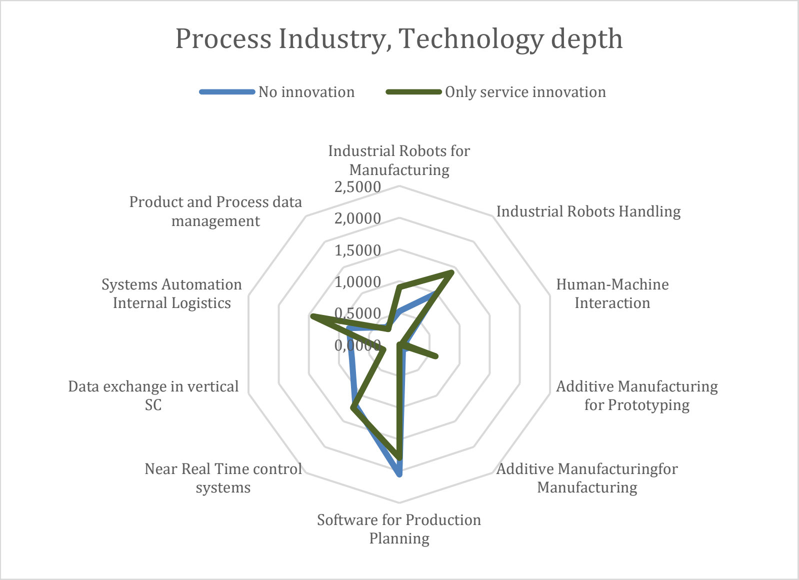

Figure 2, Technology depth, no innovation versus service innovation

		Product Innovation		
		No	Incremental	Radical
Service innovation	No	●	● —— Figure 3 ——→	
		Figure 2 ↓		
	Yes	●	● —— Figure 4 ——→	

Table 9, PSI matrix - figure overview for analysis of technology configurations

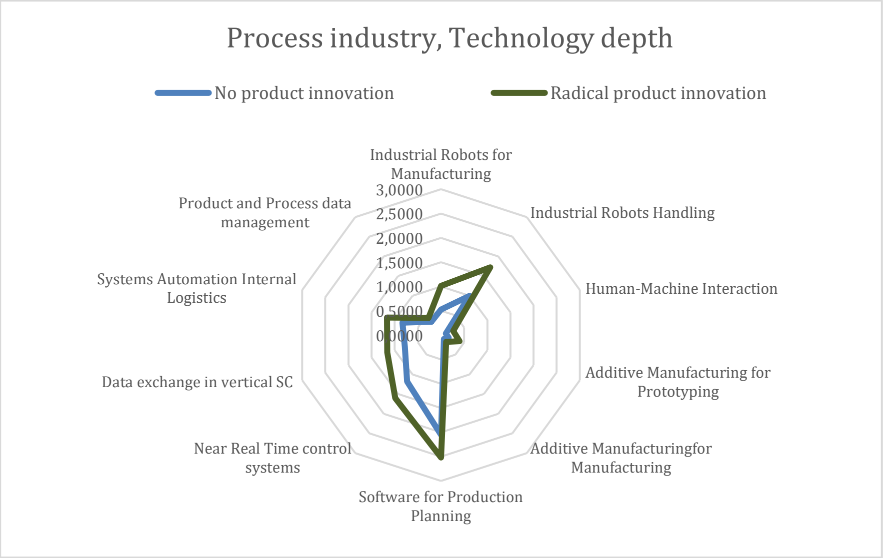

Figure 3, Technology depth, no innovation versus radical product innovation

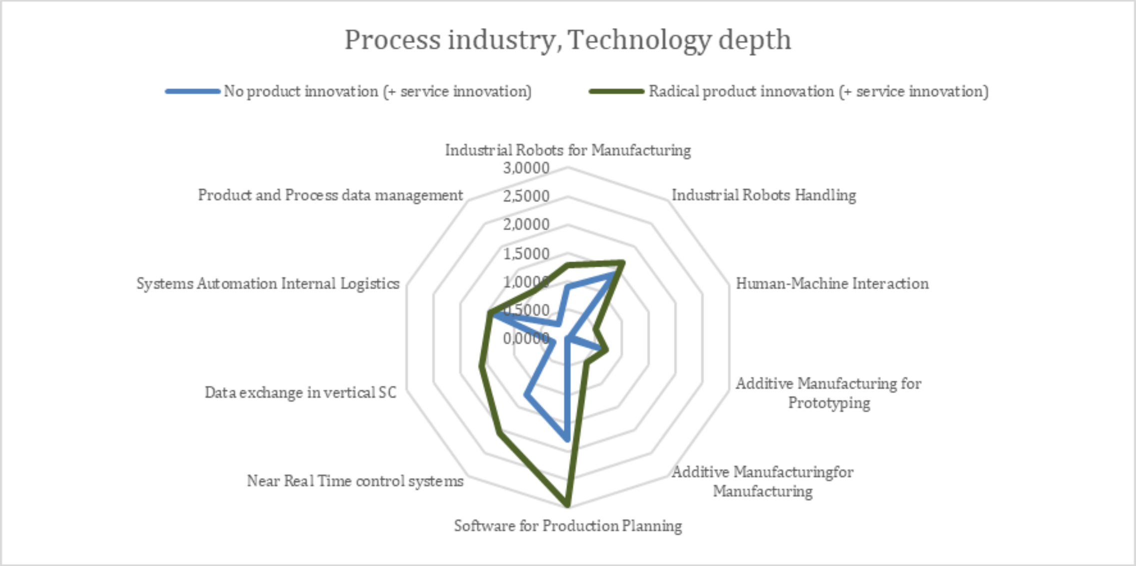

Figure 4, Technology depth, no innovation versus radical product innovation, both including service innovation

5.2 *INDUSTRY-SPECIFIC ANALYSIS ON THE TECHNOLOGY-INNOVATION-COMPETITIVE ADVANTAGE RELATIONSHIP*

The focus of the main analysis was to test the associations between digital technology adoption and product and service innovation and between innovation and ROS. A naturally arising question is whether technology itself can have an effect on competitive advantage (ROS) and whether there are differences between the industries. We therefore split our sample into firms belonging to high-tech vs. low-tech industries according to the NACE classification; low-tech are manufacturers of foods, beverages, paper and paper products, rubber and plastic products, non-metallic mineral products, and basic metals (n=607); high-tech are manufacturers of chemicals and chemical products, pharmaceutical products, and preparations (n=140). With this data split, we conducted a mediation analysis in SPSS using the process macro v3.5 by Andrew F. Hayes (Hayes, 2018). We specified Model 4 with ROS as the dependent variable Y, technology breadth and depth as the independent variables (X), and new product and service development (PSI) as the mediator (M). With this model, it is possible to reveal whether technology adoption in itself can have a direct effect on ROS or whether it is fully mediated through product and service innovation. The results reveal interesting differences between the two technology level groups.

For the low-tech industries, our original model holds true; i.e. we see a direct effect of technology adoption on innovation (p=.0000) and of innovation on ROS (p=.0244), but no direct effect from technology adoption to ROS (p=.4790). There is a significant indirect effect of technology adoption on ROS, as the lower and upper confidence interval do not include 0 (BootLLCI .0008 - BootULCI .0088). This indicates that plants in the low-tech industries achieve higher competitive advantage through product and service innovations and that digital technology adoption facilitates new product and service development.

For the other group of high-tech industry firms, we see a different pattern; i.e. we see no direct effect of technology adoption on innovation (p=.0700) or from innovation on ROS (p=.8190), but a direct effect from technology adoption to ROS (p=.0012). Thus, there is no significant indirect effect of technology adoption on ROS (BootLLCI -.0042 - BootULCI .0073) but instead a direct significant effect. This indicates that, in high-tech plants, digital technology adoption drives ROS but not the innovation activities of these firms. It is important to note that these findings are based on the comparison between firms of the same tech-level group (and not across the two different groups); i.e. chemical and pharmaceutical firms apparently do not rely on digital technology adoption for their new product and service development. Instead, it seems that digital technologies are mainly used to realize efficiency gains which have a direct effect on ROS. This finding is also supported by the relative low innovation rate in these NACE groups (20/21).

6. DISCUSSION AND ACADEMIC CONTRIBUTION

In this study, we aimed to investigate whether digital technology implementation renders companies as more innovative in terms of incremental and radical product innovation and service innovation. Our results clearly show that process-industry companies with higher levels of product and service innovation have implemented more digital technologies (breadth), and they make use of the technologies' potential to a higher extent (depth). The potential of digital technologies lies both in making internal processes more efficient but also in enabling them to create entirely new products and services. In our sample of 747 plants from the process industries, we see that the degree of technology implementation increases both with the degree of product innovation (from no product innovation to incremental and to radical) as well as with the introduction of service innovation. The group of firms having introduced both radical product innovations and service innovations has the highest values in digital technology adoption.

We also found differences among firms according to their tech level. In high-tech-level industry firms (pharma and chemical industries), we found a direct association between digital technology adoption and ROS, whereas in low-tech firms, this relationship is fully mediated by product and service innovativeness; i.e. the low-tech firms in the process industries can especially leverage digital technology adoption for introducing product and service innovations, thereby increasing ROS, while in high-tech industry firms, digital technologies are used to realize efficiency gains and therefore translate directly into higher ROS.

Our results therefore corroborate the thesis that digital technologies serve as a catalyst for product innovation and become generative resources that expand the space of product and service offerings in which a firm operates (Nambisan et al., 2019). It also supports previous findings from qualitative studies that show that digital technologies are a keystone for manufacturing firms to introduce new services (Chester Goduscheit & Faullant, 2018). With the comparison of technology profiles, we demonstrated that especially the most product and service innovative firms implement data- and software-centred technologies to a high degree and can thereby expand into new product and service avenues.

Looking at the adoption of digital technologies from the perspective of process innovations, our study contributes to the knowledge of how process and product innovations are interrelated. Previous research has revealed a statistical relationship between firms as process and product innovators at the same time (e.g. Camisón & Villar-López, 2014; Gunday et al., 2011). In our study, digital technology adoption can also be viewed as process innovation, and the findings highlight that process, product, and service innovation should not be discussed in isolation from each other, because process innovations in their effects are by no means restricted to efficiency gains. Our article therefore responds to the recent call for research on firms' combined innovation strategies (e.g., Tavassoli & Karlsson, 2015) and the effect of such strategies. In contrast to other studies that examined the effect of single technologies on performance and innovation, our study adds knowledge in that we considered the entire digital technology portfolio of a company and how it leads to product and service innovation. This is especially important for digital technologies, because they are based on data and therefore are interrelated and build on each other.

The investigation of whether the innovation efforts also pay off provides a more nuanced picture: the indicator for performance (ROS) used herein is driven only by product innovation, whereas service innovation, despite requiring higher levels of technology implementation, does not seem to pay off. This finding complements studies that have reached a service paradox (Gebauer, Fleisch, & Friedli, 2005) in which companies invest significantly in the creation of new services but fail to exploit them financially. The reasons for this paradox can be manifold, and some studies suggest that the financial performance of new services in manufacturing firms is contingent on their previous experience and success in introducing new products (Fang et al., 2008). Our study does not support this view, because those firms that introduced service innovations in addition to radically new products did not increase their ROS compared to those introducing only radical product innovations. Competitive advantage in our sample is thus driven by the ability to introduce radically new products. This does not rule out the possibility that service innovations still play a significant role in maintaining the competitive position of a firm. It seems plausible that many firms consider service innovations as a means of retaining customers and strengthening the customer relationship rather than defining it as a separate revenue stream. Services might therefore not be billed and thus do not contribute to increasing the ROS. If this is the case, most firms in our sample that offer complementary services might not have reached a high level of service maturity (Nambisam et al., 2019; Sjödin et al., 2018). Many scholars highlight the challenges firms face when adopting digital technologies and shift from offering products to becoming service providers or performance enablers (Ardolino et al., 2017). At the end of this servitization journey, services entirely replace goods, and the business model is completely transformed. For firms in the process industries, this shift might be especially difficult because they cannot shift gradually towards servitization by introducing maintenance or spare parts service. Instead, they will have to make a radical shift right away by offering outcome-based services, as described in Section 2.5 on service innovation and competitive advantage in the process industry (Elkins, 2019). The findings by Cenamor et al. (2017) also suggest that the adoption of digital technologies for service providers does not automatically translate into service success, but product and service modules need to be complemented by information modules that synthesize the data and information and make it understandable and operable by the service front-end and the manufacturing back-end.

In general, our study shows that the level of service innovations is rather low, with only 11.7% of all process industry firms having introduced service innovations in the previous period. However, this share is substantially higher in the process industries of pharmaceutical (21.6%) and basic metal manufacturing firms (22.4%), but whereas more than half of the pharmaceutical firms are in the highest profitability category, for the metal manufacturing firms, it seems much more difficult to establish the relation between service innovations and return of sales. For most other firms in the process industries in our sample, the more secure way to achieve a competitive advantage seems to lead them via introducing radical product innovations to the market: paper manufacturing firms, manufacturers of rubber and plastic products, and of non-metallic mineral products have substantial shares of radical product innovators, and at the same time, they also enjoy high return on sales rates.

Our study therefore contributes to a deeper knowledge of how firms in process industries can achieve competitive advantage via product and service innovation and the role of digital technology adoption in this relationship.

7. MANAGERIAL IMPLICATIONS

Our study underlines the importance of several important findings from which managers in the process industry could benefit. There is a need for continuous development and the adoption of digital technologies, as they support the overall product and service innovation capability of the company and its competitiveness. This is particularly important for the development of radical product and service innovation in the process industries. In particular, technologies related to data and software can support process industry firms to expand their businesses into service-based business models. For many of the companies in the process industry, this will represent a large leap, as they traditionally are not able to make an incremental shift towards service offerings through spare parts and maintenance services. Instead, they will be required to develop entire new business models, as the examples from the pharmaceutical and metal industries show. This implies that they must make a cultural shift from a product-centred to a service-centred company strategy. Firms in the process industry should therefore be aware that merely offering services will not automatically lead to higher revenue or profitability. Our results suggest that managers should first look at how they can leverage digital technologies to create radical product innovations that in time will lead to potential service offering. Specifically, for the process industry, this study can push on the development of a broader acceptance of services as a potential revenue stream, as the process industries are considered immature regarding service and service innovation.

8. LIMITATIONS AND FUTURE RESEARCH

We are aware that our research is not without limitations. First, we used data from the European Manufacturing Survey (EMS) with established measures of technology adoption and innovation. For the innovation measure, although based on the CIS-type measurement for product and service innovation, the measure only captures whether or not firms introduced new products to the market, and not how many. Moreover, the measurement for radical innovation (i.e., if any of these new products were new to the market) tries to reflect the degree of innovativeness. Whether a product that is new to the market is truly radically innovative certainly depends on the characteristics of that market and therefore leaves some room for interpretation. Future studies could therefore try to assess a more fine-grained picture of radical innovations concerning their newness regarding several dimensions (e.g., market, technology, business model, etc.; Schultz et al., 2013).

We measure competiviness by the variable *return of sales* (ROS) before tax in 2014, which is a measure for profitability and company financial margin. This is an expression of a firm's ability to withstand competition and especially its sensitivity toward variations in cost, market prices, and sales (Laureti & Viviani, 2011; Guzmán et al., 2012). We only use one variable to measure competitiveness, and inclusion of return on asset (ROA) and return on equity (ROE) would strengthen the assessment of the competitive advantage. These variables are, however, not available in the EMS survey data. A further limitation is the fact that ROS is measured in the end of 2014, and the innovation variable is expressed in the period of 2012-2015. We argue that the expressed ROS can be perceived as a result of the innovation or technology adoption during the period before. It has not been possible to adjust or alter the dataset to correct for this limitation.

This study analyzed 747 cases from the process industry. Within the current dataset (but outside the scope of this paper), a deeper analysis of characteristics of technologies at the industry level would provide insights on both best cases and trends. A further elaborated analysis could show how the different clustering of technologies relate to both innovation and competitiveness. It would bring relevant knowledge to both academia and industry in terms of technology adoption and innovation potential.

Finally, we see an important avenue for research in studying how process industry firms pursue different pathways towards servitization and how successful firms manage to make the large leap from processing raw materials to offering service outcomes. This might shed greater light on the service paradox and help advance the existing knowledge on service innovations in process industries.

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