International Journal of Innovation Studies 4 (2020) 76–84

Contents lists available at ScienceDirect

International Journal of Innovation Studies

journal homepage: http://www.keaipublishing.com/en/journals/international-journal-of-innovation-studies

Industry 4.0 technology implementation in SMEs – A survey in the Danish-German border region

Fei Yu*, Tim Schweisfurth

University of Southern Denmark, Alsion 2, 6400, Sønderborg, Denmark

ARTICLE INFO

Article history:
Available online 3 September 2020

Keywords:
Industry 4.0
SMEs
Technology implementation
Survey

ABSTRACT

Industry 4.0, known as the fourth technological transformation towards digital-physical systems in manufacturing, creates a disruptive impact on industries. Manufacturing companies, especially small and medium-sized ones, are facing various challenges and must constantly innovate to remain competitive. One way to innovate is by implementing new technologies into company processes. In this study, we investigate how technology, company and industry related factors are associated with the implementation of Industry 4.0 in SMEs. We collect data via a survey with a focus on Industry 4.0 in SMEs. The results indicate that knowledge and expected benefits of technology are the drivers for the implementation of Industry 4.0 technologies. They also show that companies with high levels of process automation and high product variety are more likely to implement Industry 4.0 technologies. Our study creates a better understanding of the status, challenges and plans within Industry 4.0 implementation in SMEs, which will support the development of SME-friendly manufacturing tools and systems and craft managers' and policymakers' understanding of Industry 4.0 technologies.

1. Introduction

Manufacturing companies are facing a variety of challenges and have to constantly innovate to remain competitive. One way to innovate is to engage in process innovation, i.e, the introduction of new processes or new ways of doing (OECD, 2018). Process innovation is an important source of innovation especially for small and mediums sized companies (SMEs) (Raymond & St-Pierre, 2010). Such companies can benefit more from efficiency gains related to process innovation than from effectiveness gains related to product innovation, as they are often situated in rigid supply chains and produce made to order products.

Recently, SMEs have been confronted with the digitalisation of industrial processes and what has been labelled Industry 4.0, which enables real-time data interchange and boost of flexibility, speed, productivity and quality of production (Li, Hou, & Wu, 2017; Russman et al., 2015; Thoben, Wiesner, & Wuest, 2017). Even if SMEs heavily rely on efficiency in manufacturing for value creation and thus are likely to profit from investments into Industry 4.0 related process innovation, the adoption and implementation of Industry 4.0 technologies (hereafter referred to as I 4.0 technologies) in SMEs is lagging behind, in contrast to large companies (Stentoft, Jensen, Philipsen, & Haug, 2019; Stentoft; Rajkumar, 2019; Stentoft; Rajkumar, & Madsen, 2017).

* Corresponding author.
E-mail addresses: fei@mci.sdu.dk (F. Yu), schweisfurth@mci.sdu.dk (T. Schweisfurth).

https://doi.org/10.1016/j.ijis.2020.05.001

In this paper, we investigate the reason for this lag and which factors drive or hinder the diffusion of I 4.0 technology into SMEs. Specifically, we focus on the implementation of technology as one critical stage of the innovation diffusion process (Rogers, 2003). In this context, technology implementation refers to the practical use of technology to enhance process performance. We investigate how technology-related, company-related and industry-related factors are associated with the implementation of I 4.0 technology, i.e., the stage at which the technology is implemented in product development processes or production.

This investigation is relevant because it fosters our understanding of how companies can become more innovative. It will help managers to craft technology strategies and policymakers to foster the implementation of new technologies. In this paper, we contribute to this understanding, and we expect to create insights about the present situation of industry 4.0 technology implementation in SMEs. The goal is to create a systematic view on the factors that are related to the implementation of industry 4.0 technologies in SMEs from different perspectives at the technology level, the company level and the industry level.

We collected data via a survey with the focus on Industry 4.0 in SMEs in German and Danish companies. We choose the German-Danish border region for two reasons. First, there are many SMEs present in the region which fits the focus of our study. Second, using a cross-border sample allows us to increase the generalisability of our findings across the national context. The survey is designed to create an understanding of the factors that drive SMEs' implementation of I 4.0 technologies. We find that, on the technology level, it is the knowledge and expected benefits of a technology that drive the implementation of I 4.0 technologies. We also find that companies with high levels of process automation and high product variance are more likely to implement such technologies. The results help to create a better understanding of the status, challenges and plans of Industry 4.0 implementation in SMEs, which will support the development of future SME-friendly manufacturing tools and systems and craft managers' and policymakers' understanding of the implementation of I 4.0 technologies.

2. Brief literature review

2.1. Industry 4.0

Industry 4.0, the fourth technological transformation, is a very broad cross-disciplinary concept. It has been widely used in the engineering field where it was first introduced, but it has also attracted attention in other domains such as economics and management (Piccarozzi, Aquilani, & Gatti, 2018). From a technology perspective, the solid foundation of Industry 4.0 is built by the fast development of the Internet of Things (IoT) (Atzori, Iera, & Morabito, 2010) and cyber-physical systems (Khaitan & McCalley, 2015), which provide modern telecommunication solutions and enables interaction between cyber and physical components, respectively. Sanders, Elangeswaran, and Wulfsberg (2016) define Industry 4.0 as "the fourth industrial revolution applying the principles of cyber-physical systems, internet and future-oriented technologies and smart systems with enhanced human-machine interaction paradigms" (p 816). Similarly, Pan et al. (2015) address that "Industry 4.0 represents the ability of industrial components to communicate with each other" (p 1537). Both interpretations emphasise features of communication and interaction between humans and machines, which requires the use of IoT solutions and yield the creation of large amounts of data. Russman et al. (2015) take both machines and humans in consideration and express Industry 4.0 as "a new digital industrial technology" (p3) that ensures the "connectivity and interaction among parts, machines, and humans" (p2), and it will transform the manufacturing "from single automated cells to fully integrated, automated facilities that communicate with one another" (p2). The authors further elaborate on the nine foundational technology advances that power the transformation of industrial production. These technologies include simulation, autonomous robots, the industrial IoT, horizontal and vertical system integration, additive manufacturing, augmented reality, big data and analytics, cyber security and cloud computing. In this paper, Industry 4.0 represents the digital transformation in industry referring to those nine key technologies (Alcácer & Cruz-Machado, 2019; Russman et al., 2015).

Several review papers have addressed the barriers, challenges and future research focus on Industry 4.0 (Alcácer & Cruz-Machado, 2019; Galati & Bigliardi, 2019; Liao, Deschamps, Loures, & Ramos, 2013; Mohamed, 2018). Liao, Deschamps, Loures, & Ramos (2017) pointed out the research agenda from four different perspectives including a context perspective, a collaboration perspective, a research effort perspective and an implementation perspective. In their view, industry is hesitant in implementing the new technologies due to unclear possible benefits, unclear implementation details and large required investments (Galati & Bigliardi, 2019; Liao et al., 2013; Theorin et al., 2017). Mohamed (2018) conducted a systematic review of the literature and listed the challenges and benefits of Industry 4.0. He concluded that the majority of companies are hesitant to implement Industry 4.0 technologies due to the uncertainty of financial benefits and a lack of knowledge and skills. Especially for SMEs, with increased level of complexity, the real benefits and requirements as well as the impact on the business model are not clear (Alcácer & Cruz-Machado, 2019; Galati & Bigliardi, 2019).

2.2. Industry 4.0 implementation in SMEs

Compared to the broad discussion of Industry 4.0, there is less literature on I 4.0 technology in manufacturing SMEs. Stentoft, Rajkumar, and Madsen (2017) conducted a survey and collected the responses from 33 large, 127 medium-sized and 110 small manufacturing companies covering all regions of Denmark. The survey focuses on Danish companies' strategy process, readiness for Industry 4.0, drivers and barriers for industry 4.0 and operation and development. The survey indicates that robots, digital communication and automatic analysis and visualisation of data are the most relevant technologies to manufacturing companies. Simulation, 3D printing and cloud computing have a moderate degree of relevance to the companies. In contrast, big data, IoT and augmented reality have the smallest degree of perceived relevance. Although SMEs are also aware of the importance and relevance of the technology, they have much lower degrees of implementation concerning these technologies than large companies. The main motivation for the implementation of I 4.0 technology is to reduce costs, to improve time-to-market, legal requirements/changed legislation and lack of qualified workforce; the main barriers are lack of knowledge, more focus on operation at the expense of developing the company, lack of understanding the strategic importance, too few human resources and the need for continued education of employees (Stentoft et al., 2017). The group further identified the potential impact of the drivers and barriers for Industry 4.0 readiness and practice among SMEs (Stentoft et al., 2019). The results show that additional resources are needed for preparing SMEs to be ready for the digital transformation and, interestingly, they also indicate that the barriers, which decrease the readiness, have a low impact on the implementation of I 4.0 technologies (Stentoft et al., 2019).

In another large-scale survey, Thomas and Barton (2012) collected data from 260 manufacturing SMEs in the UK and compared the results to a similar survey conducted in 2003. Instead of targeting the specific I 4.0 technologies in SMEs, the survey was designed to investigate SMEs' migration towards advanced manufacturing technologies, which can be classified as information technology, engineering technology and production technology. The results show that SMEs hesitate to implement advanced manufacturing technologies due to the high risk. Also, the size of the company is an important critical factor in effective implementation (Thomas & Barton, 2012). Smaller SMEs focus more on operational aspects of technology implementation, while larger SMEs develop strategic planning, business formalisation and control systems to support the implementation process. Spena, Holzner, Rauch, Vidoni, and Matt (2016) did a small-scale questionnaire with 27 SMEs in Northern Italy to investigate the status and requirements of flexibility and changeability in manufacturing and assembly systems. The results show a low level of automation within manufacturing and assembly among the interviewed companies. Regarding the business environment, they are facing increasing demands on delivery, increasing quality requirements, increasing variety and price competition on the market. The authors of this study pointed out that the production system should have a certain level of flexibility to fulfil the uncertain future requirements (Spena et al., 2016). Sommer (2015) performed a systematic review of nine studies and concluded that there is a clear relationship between the company size and the readiness of enterprises to make use of Industry 4.0 enabling technologies. In 2016, the Boston Consulting Group and Innovationsfonden (Colotla et al., 2016) created a report based on a patent analysis and a survey with 530 responses from Danish manufacturing companies in which the relevance, barriers and expected impact of Industry 4.0 were assessed. They conclude that there is a connection between the size of the enterprise and the level of implementation of I 4.0 technologies. Large and medium-sized companies outperform smaller companies but at the same time, the large and medium-sized companies are outperformed by the German companies within the same size range. Danish companies expect Industry 4.0 to add speed, flexibility and customisation to the manufacturing systems and thus yielding higher productivity, though not at the expense of jobs (Colotla et al., 2016). Schröder (2016) describes how the implementation rate of I 4.0 technologies is higher in larger companies, but when it comes to enablers such as Big Data and artificial intelligence, the implementation rate is low regardless the size of the company.

Evidences are showing a relationship between the adoption of I 4.0 technologies and the reshoring of manufacturing activities in European manufacturing companies (Dachs, Kinkel, & Jäger, 2019; Müller, Dotzauer, & Voigt, 2017; Stentoft; Rajkumar, 2019). Dachs et al. (2019) employed a sub-set of the European Manufacturing Survey 2015 that includes 1705 companies that have done captive offshoring or offshore outsourcing and contains 1435 companies from Austria, Germany and Switzerland with less than 250 employees. The results show a positive and significant association between the adoption of I 4.0 technologies and the reshoring activities. The findings are in line with the empirical study done by Stentoft and Rajkumar (2019), who investigated a total number of 270 Danish companies with more than 85% of them being SMEs. The results show that the drivers and barriers for Industry 4.0 have an impact on the perceived relevance of Industry 4.0 among companies, including materials and manufacturing technologies, smart IT connecting technologies and data processing and big data. The perceived relevance has a further impact on the reshoring of manufacturing activities.

2.3. Factors related to implementation of I 4.0 technology

The brief literature review indicates that the implementation of I 4.0 technology is a complex topic that can be affected by many different factors. To come up with a systematic view, we tried to summarise the factors from three perspectives, i.e., factors at the technology level, factors at the company level and factors at the industry level. Table 1 shows the list of factors that affect the implementation of Industry 4.0 technology, which have been investigated in the literature so far. Even if the literature is not fully conclusive on the role that the company size plays for the implementation of I 4.0 technology, SMEs are less likely to implement new technologies, compared to large companies. More importantly, however, there is no literature that investigates the factors affecting the implementation of I 4.0 technologies in SMEs by structuring them into the three levels suggested by us. In this paper, we aim to contribute to this understanding by answering the following research questions:

Table 1
Summary of related empirical studies.

Factors driving the implementation of Industry 4.0 technology		Empirical studies	Sample size and region
Technology-related factors	Degree of relevance Knowledge about technology Effect on flexibility	Stentoft et al. (2017)	33 large, 127 medium and 110 small-sized manufacturing firms in Denmark
		Spena et al. (2016)	27 SMEs in North Italy
Company-related factors	Size of the company	Colotla et al. (2016)	530 Danish manufacturing companies
	Strategy reasoning process and readiness for Industry 4.0	Stentoft et al. (2017)	33 large, 127 medium and 110 small-sized manufacturing firms in Denmark
		Stentoft et al. (2019)	190 SMEs in Denmark
	Characterisation, compatibility and innovative behaviour of SMEs in advanced manufacturing technology implementation	Thomas and Barton (2012)	260 SMEs in the UK
Industry-related factors	Regulatory and industry pressure	Kuan and Chau (2001)	575 small firms in Hong Kong, China
	Globalisation strategies	Stentoft and Rajkumar (2019)	270 manufacturing firms in Denmark
		Dachs et al. (2019)	1700 manufacturing firms from Austria, Germany, and Switzerland
		Müller et al. (2017)	50 German firms with global sourcing and production activities

a) Which technology-related factors are associated with the implementation of the Industry 4.0 technologies in SMEs, and how are they associated?
b) Which company-related factors are associated with the implementation of the Industry 4.0 technologies in SMEs, and how are they associated?
c) Which industry-related factors are associated with the implementation of the Industry 4.0 technologies in SMEs, and how are they associated?

3. Methods

3.1. Samples

We collected data in a sample of small and medium-sized manufacturing companies in the German-Danish border region (the region of Southern Denmark and Northern Germany). We obtained company addresses and contact information from the company databases Bisnode (Bisnode, 2018) and Orbis (Orbis, 2018). After filtering the companies for duplicates, we had a list of 4669 manufacturing companies in the region. We decided to focus on companies with more than 10 and less than 250 employees and production facilities in the region. This yielded an address base of 1573 companies which then all were contacted via phone and asked whether they were willing to participate; 751 agreed to participate. Of these companies, of which 665 could be reached (email bounced from the other ones), we collected 26 partial answers and 59 full answers. Using these 59 observations for our analysis yields a response rate of roughly 8.9% (59/665).

Due to the small response rate we needed to make sure that the sample of the respondents was not systematically different from the population. We used wave analysis to check whether we are dealing with a biased sample (Armstrong & Overton, 1977; Rogelberg & Stanton, 2007), drawing on the logic that respondents who only filled out the first parts of the survey were assumed to be similar to non-respondents; no significant differences between partial and full respondents would thus indicate a non-biased sample. We compared the distribution of core company characteristics of partial ($n = 26$) and full respondents ($n = 59$): using chi-square tests we found a difference concerning the companies' product variance (partial respondents tend to have less product variance, $p = 0.005$), but not for employees, turnover, country, type of production and degree of automation ($p > 0.10$). We thus conclude that sample bias is not a major problem in our study. Nevertheless, we checked the mentioned factors in our analyses.

3.2. Measures

First, we asked respondents of our survey to report some general company characteristics. Then, to measure the dependent variable of our main analyses, we asked companies to provide more specific information about nine selected I 4.0 technologies and the extent to which they have implemented or are planning to implement each of these technologies (1 - No plans to invest/implement, 2 - We plan to invest/implement in the next 4 years, 3 - We plan to invest/implement in the next 2 years, 4 - We have already invested in/implemented this). Since our target group consists of SMEs, we chose a measure that covers a four-year time span, which is a reasonable future within the scope of the SMEs. These technologies were chosen based on an Industry 4.0 report by The Boston Consulting Group (Russman et al., 2015) and include the nine key technologies simulation, autonomous robots, the industrial IoT, horizontal and vertical system integration, additive manufacturing, augmented reality, big data and analytics, cyber security and cloud computing. The questions and measures we used can be found in the appendix. The questions were developed based on prior studies (Kuan & Chau, 2001; Spena et al., 2016; Stentoft et al., 2017). Because the implementation of technology still is a complex process, we needed to investigate the influencing factors from different perspectives. Therefore, we chose status quo of production and degree of automation (Spena et al., 2016) to understand the factors at company level, regulatory and industrial pressure (Kuan & Chau, 2001) to investigate the influence at industry level and readiness and degree of technology implementation (Stentoft et al., 2017) to evaluate technology-related issues. The summary statistics can be found in Table 2.

4. Findings

4.1. Degree of I 4.0 technology implementation

First, we investigated the current degree of I 4.0 technologies' implementation (see Fig. 1). We can see that many companies have not implemented any I 4.0 technologies by now. No company has shown interest in augmented reality, and more than 90% of the companies have no plan to invest in the Internet of Things, even though it is one of the most highlighted technologies for many years. The interests in additive manufacturing, big data and simulation is relatively low. Less than 1 percent of the companies have started to tap into additive manufacturing and only 1.65% are into big data. However, more than 15% of the companies plan to invest or implement these technologies in the next two or four years. 6.78% of the companies use simulation, and more companies plan to use the technology in the future (11.86%). Similarly, almost 12% of the companies have used robots, and 27.11% have plans to upgrade the facility with robotic technology. Those technologies, which have reached a high degree of implementation in our sample, are systems integration and cloud computing which at least 20% of the companies have implemented. Cyber security has the highest degree of implementation which more than 50% of the companies have implemented or plan to implement in the coming years.

Companies have started to tap into I 4.0 technologies in areas that can be easily linked to the existing information system – all the top technologies represent add-ons or extensions to existing information systems. This may be due to the obvious value that the technologies can create for the companies. The same applies to the use of robots, which are used directly in product development and production. Looking at technologies that require the integration of digital and physical technologies, the state of the implementation is very low. However, there seems to be an increasing potential for the implementation of digital technologies, such as simulation and big data. In the next section we investigate the drivers and inhibitors of I 4.0 technologies.

4.2. Drivers of I 4.0 technology implementation

To understand which factors drive the implementation of I 4.0 technologies, we used regression analysis on the technology level. We predicted the effect of our core variables on technology implementation. The unit of analysis, technology implementation in companies, is clustered in the nine technologies and the responding 59 companies. To account for systematic differences between technologies and companies, we clustered the errors in technologies and companies (Wooldridge, 2010). We performed multiple clustering using the Stata clus_nway routine (Kleinbaum, Stuart, & Tushman, 2013) to estimate two-way clustered errors (Cameron et al., 2011). The results keep the same significance and direction if we drop the clustering.

We used two types of regression to analyse our results (see Table 3): linear and ordered logit regression. Our dependent variable can be either interpreted as an interval scale or an ordinal scale. We thus assumed to use a linear specification of our dependent variable for the OLS model and an ordinal specification for the ordered logit model. Using two different estimation methods increases the robustness of our findings and allows for methodological triangulation. The findings are uniform and consistent across models. Both models show good fit ($P = 0.000$ for overall model fit). The results from the linear regression are graphically depicted in Fig. 2. The graph shows the plot of the coefficients for each independent variable including the 95%

Table 2
Summary statistics.

	Variable	Mean	SD	Min	Max	1	2	3	4	5	6	7	8	9	10	11
1	Degree of implementation	1.569	1.046	1.000	4.000	1.000										
2	Knowledge about technology	2.224	1.534	1.000	7.000	0.441	1.000									
3	Benefit of technology implementation	2.198	1.737	1.000	7.000	0.468	0.527	1.000								
4	Cost of technology implementation	2.677	1.938	1.000	7.000	0.152	0.150	0.439	1.000							
5	Degree of automation	1.130	0.443	1.000	4.000	0.209	0.186	0.125	0.058	1.000						
6	Method of production	1.184	0.624	1.000	4.000	0.064	0.078	0.096	−0.027	0.215	1.000					
7	Variety of products	4.756	0.645	1.000	5.000	0.057	0.064	−0.022	0.079	−0.092	−0.195	1.000				
8	Number of employees	0.580	0.184	0.250	1.000	0.142	0.187	0.154	0.112	0.099	0.153	−0.192	1.000			
9	Turnover	3.110	1.578	0.000	8.000	0.053	−0.028	−0.010	−0.048	0.323	0.251	−0.227	0.465	1.000		
10	Regulatory pressure	0.365	0.178	0.143	0.857	0.134	0.320	0.348	0.074	0.221	0.084	−0.004	0.172	0.282	1.000	
11	Industrial pressure	0.447	0.252	0.143	1.000	0.167	0.283	0.419	0.274	0.154	0.096	0.046	0.202	0.151	0.651	1.000

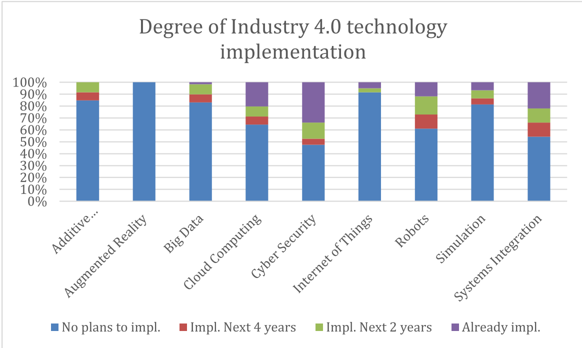

Fig. 1. Degree of Industry 4.0 technology implementation.

Table 3
Results for linear and ordered logit regression (dependent variable – degree of technology implementation).

	Linear regression					η^2	Ordered logit regression				
	Coeff.	SE	t	*P*	sig		Coeff.	SE	t	*P*	sig
Technology variables											
Knowledge about technology	0.174	0.071	2.450	0.040	*	0.056	0.409	0.151	2.710	0.007	**
Benefit of technology implementation	0.233	0.047	4.940	0.001	**	0.104	0.545	0.109	4.990	0.000	***
Cost of technology implementation	−0.033	0.031	−1.070	0.314		0.004	−0.099	0.104	−0.960	0.340	
Firm variables											
Degree of automation	0.213	0.083	2.580	0.033	*	0.021	0.543	0.153	3.560	0.000	***
Method of production	−0.022	0.051	−0.440	0.672		0.001	−0.049	0.134	−0.370	0.715	
Variety of products	0.199	0.059	3.390	0.010	*	0.009	0.594	0.256	2.320	0.020	**
Number of employees	0.244	0.228	1.070	0.316		0.002	0.573	0.629	0.910	0.362	
Turnover	0.046	0.041	1.130	0.292		0.003	0.194	0.121	1.600	0.110	
Industry variables											
Regulatory pressure	−0.716	0.220	−3.250	0.012	*	0.011	−1.911	0.879	−2.170	0.030	**
Industrial pressure	−0.028	0.168	−0.160	0.874		0.000	0.385	0.447	0.860	0.390	
Country	0.061	0.091	0.670	0.522		0.000	0.208	0.389	0.540	0.592	
Constant	−0.708	0.540	−1.310	0.226							
Log-likelihood							−359.496				
F-Test	20.940										
Significance Overall model	0.000						0.000				
N	531.000						531.000				
(Pseudo) R^2	0.293						0.020				

Errors clustered in firms and technologies are shown; ***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.

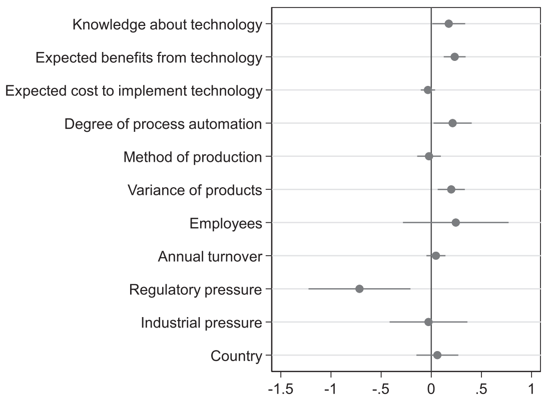

Fig. 2. Coefficient plot from linear regression (dependent variable – degree of technology implementation).

confidence intervals. The points represent estimates for the coefficients' effect sizes. The coefficients can only be interpreted as being significantly related to the degree of technology implementation, if the intervals and the 0 line are not overlapping. We find a significant effect of the following variables:

Regarding research question a) concerning technology-related factors, we find that knowledge about technology and the expected benefit is significantly associated with the implementation of I 4.0 technologies. The cost of the technology does not play a significant role.

Regarding research question b) concerning company-related factors, we find that the degree of automation and the variety of products offered by a company are significantly associated with the implementation of I 4.0 technologies: companies with higher variety and a high degree of automation are more likely to implement these new technologies. Company size, neither employees nor turnover, is not significantly related to the implementation of I 4.0 technologies.

Regarding research question c) concerning industry-related factors, we find that perceived regulatory pressure is negatively related to the implementation of I 4.0 technologies, as opposed to industry pressure which does not seem to play a role. Also, Danish and German companies were equally likely to implement I 4.0 technologies.

We also added the partial eta squared for our OLS regression (see Table 3), which is a measure for the magnitude of the effect of each variable. Inspecting the effect of size, it becomes clear that technology characteristics have a much stronger impact on the adoption of a specific technology than company or industry variables.

5. Discussion

5.1. Scholarly implications

In this paper, we investigate the state of implementation of nine I 4.0 technologies nested in 59 companies from the German-Danish border region. We find that the implementation of I 4.0 technologies is remarkably low, especially for I 4.0 technologies related to new production and product development technologies. This is in line with the findings from the study by Stentoft et al. (2017). The SMEs have very little interest in augmented reality, IoT and big data. The share of implemented technologies is higher (if only moderate) for I 4.0 technologies related to information systems and communication technology. We can only speculate why this is the case. One reason could be that many companies use information and communication systems that are easily digitalised. In such cases, the implementation of new technologies will not be driven by the company, but the locus of innovation resides outside the organisation with big IT companies. Another reason for the finding that SMEs are especially likely to refrain from implementing I 4.0 technologies related to new production and product development technologies resides in a competence-based explanation. Companies are especially resistant to change in areas in which they have their core competencies, as they assume that their existing technologies are superior to external ones since they have been developed inhouse (Antons & Piller, 2014; Katz & Allen, 1982).

We also conduct regression analyses to understand which technology-related and company-related factors drive the implementation of I 4.0 technologies. We find that on the technology level, companies are significantly more likely to implement a technology when they recognize the benefits of the technology and have high knowledge in a specific technology. While the former finding seems intuitive, the latter findings speaks strongly to the literature of absorptive capacity. Absorptive capacity (Cohen & Levinthal, 1989, 1990, 1994) is the ability of the company "to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (1990, p. 128) - it is the mechanism that makes external technological knowledge available to and useable within the organisation. Theoretically, this means that to implement external knowledge, companies already have to have some knowledge in the relevant domain to understand and interpret new external technologies. This is exactly what we find in our data. If companies lack the knowledge and thus the absorptive capacity for specific I 4.0 technology, they are much less likely to invest and implement a specific I 4.0 technology. Also, as shown by Stentoft et al. (2017), the lack of knowledge is one of the main barriers to the implementation of new technologies. Therefore, we recommend that technology providers could focus on the development of those technologies that are suitable for SMEs to implement. For instance (Zheng et al., 2019), proposes an SME-oriented design approach for the implementation of robotic flexible manufacturing systems. In addition, technology providers should also pay more attention to knowledge transfer and value and thus address the needs of SMEs more specifically.

Interestingly, we also find that companies with higher automation within production and higher variety of products are more likely to implement new I 4.0 technologies. This is in line with the findings from Thomas and Barton (2012), who stated that companies that are new to advanced manufacturing technology found the implementation process including "selecting, purchasing, and implementing the correct type and combination of advance manufacturing technologies to be a daunting prospect and too risky." (p. 753) In contrast, the results from Spena et al.'s (2016) survey show that companies are facing an increasing variety in the business environment, but the needs for automation within production and assembly are still relatively low. An explanation could be that traditional automation solutions are designed to increase productivity with the cost of decreasing flexibility (Wiktorsson, Granlund, Lundin, & Södergren, 2016). However, following the LEAN automation concept (Jackson, Hedelind; Hellström; Granlund, & Friedler, 2011), the new automation production solutions are designed to be flexible and reconfigurable.

Another interesting finding is the negative effect of regulatory pressure on the implementation: The higher regulatory pressure on the company, i.e., the more regulations exist that force companies to implement a technology, the lower is the likelihood that a company implements new technologies: companies in highly regulated industries find it harder to implement new technologies because existing rules make it hard to introduce novelty to their ecosystem. They find themselves in an iron cage of regulations and control which makes it more likely for them to keep their status quo. We believe that more qualitative studies should be carried out to investigate the in-depth knowledge of why and how the SMEs make decisions on technology implementation.

5.2. Practice implications

Our study has implications for SMEs that feel threatened by the emergence of Industry 4.0 and related technologies. Our study shows that intra-company knowledge about these technologies is crucial to respond to external changes and to understand the benefits of such technologies. This means that managers in SMEs have to train their production staff and product engineers in these methods to enable employees to assess such technologies and evaluate which ones are promising and which ones are not. Without such knowledge, companies are likely to reject new technologies since they cannot understand their potential and benefits. This has also implications for policymakers aiming at speeding up the diffusion of I 4.0 technologies, who should try to facilitate knowledge transfer between those entities that know I 4.0 technologies (technology producers or universities) and SMEs. Furthermore, implementing a new technology is not only about the technology itself. Bundled regulations create barriers for SMEs to implement the technology. A clear framework that could guide the company through the journey of implementation would be very helpful for SMEs.

5.3. Limitations

There are some limitations to our research that are rooted in the data collection. First, we cannot make causal claims for our findings, as the data was collected in a cross-sectional manner. It could be that our dependent variable, implementation of I 4.0 technologies, also affects the independent variables on technology and company level. Also, we cannot fully rule out that our sample is biased, due to a rather small response rate. We have taken statistical measures and checked whether we find biases, without finding any, but we cannot fully rule out this concern. Furthermore, our findings might be specific to the context of SMEs in the border region which experience specific challenges. Thus, future research could investigate whether our findings hold in other contexts as well. Another limitation is that we take a narrow view on Industry 4.0, as we focus on a selection of technologies (Alcácer & Cruz-Machado, 2019; Russman et al., 2015). I 4.0 technology implementation is a much more complex phenomenon and we only zoom in from a technological perspective in our paper.

Declaration of competing interest

The authors declare no conflicts of interest.

Acknowledgement

This work is supported by the InProReg project (project no. DD01-004). InProReg is financed by Interreg Deutschland-Denmark with means from the European Regional Development Fund. Besides, InProReg is financed by Syddansk Vækstforum, which recommended the project to be funded by means from regional industrial development. The authors thank Mr Sönke Wolter and Mr David Grube Hansen for their valuable input to the study and the student assistants for data collection. The authors also thank Mrs Zora Rubahn for editing the paper. And great thanks to the companies for their time and efforts to provide feedback.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijis.2020.05.001.

References

Alcácer, V., & Cruz-Machado, V. (2019). Scanning the industry 4.0: A literature review on technologies for manufacturing systems. *Engineering Science and Technology, an International Journal, 22*(3), 899–919. https://doi.org/10.1016/j.jestch.2019.01.006

Antons, D., & Piller, F. T. (2014). Opening the black box of "not invented here": Attitudes, decision biases, and behavioral consequences. *Academy of Management Perspectives, 29*(2), 193–217. https://doi.org/10.5465/amp.2013.0091

Armstrong, J. S., & Overton, T. S. (1977). Estimating nonresponse bias in mail surveys. *Journal of Marketing Research, 14*(3), 396. https://doi.org/10.2307/3150783

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of Things: A survey. *Computer Networks, 54*(15), 2787–2805. https://doi.org/10.1016/j.comnet.2010.05.010

Bisnode. (2018). *Bisnode company database*.

Cohen, W. M., & Levinthal, D. A. (1989). Innovation and Learning : The two faces of R & D. *The Economic Journal, 99*(397), 569–596.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive Capacity : A new perspective on learning and innovation. *Administrative Science Quarterly, 35*(1), 128–152.

Cohen, W. M., & Levinthal, D. A. (1994). Fortune favors the prepared firm. *Management Science, 40*(2), 227–251. https://doi.org/10.1287/mnsc.40.2.227

Colin Cameron, A., Gelbach, Jonah B., & Miller, Douglas L. (2011). Robust Inference With Multiway Clustering. *J. Bus. Econ. Stat., 29:2*, 238–249. https://doi.org/10.1198/jbes.2010.07136

Colotla, I., Fæste, A., Heidemann, A., Winther, A., Andersen, P. H., Duvold, T., et al. (2016). *Winning the industry 4.0 race, how ready are Danish manufacturers?*.
Dachs, B., Kinkel, S., & Jäger, A. (2019). Bringing it all back home? Backshoring of manufacturing activities and the adoption of industry 4.0 technologies. *Journal of World Business, 54*(6), 101017. https://doi.org/10.1016/j.jwb.2019.101017
Galati, F., & Bigliardi, B. (2019). Industry 4.0: Emerging themes and future research avenues using a text mining approach. *Computers in Industry, 109*, 100–113. https://doi.org/10.1016/j.compind.2019.04.018
Jackson, M., Hedelind, M., Hellström, E., Granlund, A., & Friedler, N. (2011). Lean automation: Requirements and solutions for efficient use of robot automation in the Swedish manufacturing industry. *International Journal of Engineering Research & Innovation, 3*(2), 36–43.
Katz, B. R., & Allen, T. J. (1982). Investigating the not invented here (NIH) syndrome: A look at the performance, tenure, and communication patterns of 50 R & D project groups. *R & D Management, 12*(1), 7–20.
Khaitan, S. K., & McCalley, J. D. (2015). Design techniques and applications of cyberphysical systems: A survey. *IEEE Systems Journal, 9*(2), 350–365. https://doi.org/10.1109/JSYST.2014.2322503
Kleinbaum, A. M., Stuart, T., & Tushman, M. (2013). Discretion within constraint: Homophily and structure in a formal organization. *Organization Science, 24*(5), 1316–1336. https://doi.org/10.2139/ssrn.1749512
Kuan, K. K. Y., & Chau, P. Y. K. (2001). A perception-based model for EDI adoption in small businesses using a technology-organization-environment framework. *Information & Management, 38*(8), 507–521. https://doi.org/10.1016/S0378-7206(01)00073-8
Liao, Y., Deschamps, F., Loures, E. de F. R., & Ramos, L. F. P. (2013). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research, 55*(12), 3609–3629. https://doi.org/10.1080/00207543.2017.1308576
Li, G., Hou, Y., & Wu, A. (2017). Fourth industrial revolution: Technological drivers, impacts and coping methods. *Chinese Geographical Science, 27*(4), 626–637. https://doi.org/10.1007/s11769-017-0890-x
Mohamed, M. (2018). Challenges and benefits of industry 4.0: An overview. *International Journal of Supply and Operations Management, 5*(3), 256–265.
Müller, J., Dotzauer, V., & Voigt, K. (2017). Industry 4.0 and its impact on reshoring decisions of German manufacturing enterprises. In C. Bode, R. Bogaschewsky, M. Eßig, R. Lasch, & W. Stölzle (Eds.), *Supply management research: Aktuelle Forschungsergebnisse 2017* (pp. 165–179). Wiesbaden: Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-18632-6_8.
OECD. (2018). *Oslo manual 2018 - guidelines for collecting, reporting and using data on innovation*. OECD.
Orbis. (2018). Orbis Company Database.
Pan, M., Sikorski, J., Kastner, C. A., Akroyd, J., Mosbach, S., Lau, R., et al. (2015). Applying industry 4.0 to the Jurong Island eco-industrial park. *Energy Procedia, 75*, 1536–1541. https://doi.org/10.1016/j.egypro.2015.07.313
Piccarozzi, M., Aquilani, B., & Gatti, C. (2018). Industry 4.0 in management studies: A systematic literature review. *Sustainability, 10*(10), 1–24. https://doi.org/10.3390/su10103821
Raymond, L., & St-Pierre, J. (2010). R&D as a determinant of innovation in manufacturing SMEs: An attempt at empirical clarification. *Technovation, 30*(1), 48–56. https://doi.org/10.1016/j.technovation.2009.05.005
Rogelberg, S. G., & Stanton, J. M. (2007). Understanding and dealing with organizational survey nonresponse. *Organizational Research Methods, 10*(2), 195–209.
Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press. Retrieved from https://books.google.dk/books?id=9U1K5LjUOwEC.
Russman, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., et al. (2015). *Industry 4.0 the future of productivity and growth in Manufacturing Industries*. https://doi.org/10.1007/s12599-014-0334-4
Sanders, A., Elangeswaran, C., & Wulfsberg, J. (2016). Finally signs of life for healthcare data bank. *Industry 4.0 inplies lean manufacturing: Research Activities in industry 4.0. Function as Enablers for Lean Manufacturing, 70*(2), 19. https://doi.org/10.3926/jiem.1940
Schröder, C. (2016). *The challenges of industry 4.0 for small and medium-sized enterprises*. Bonn: Friedrich-Ebert-Stiftung (August).
Sommer, L. (2015). Industrial revolution-industry 4.0: Are German manufacturing SMEs the first victims of this revolution? *Journal of Industrial Engineering and Management, 8*(5), 1512–1532. https://doi.org/10.3926/jiem.1470
Spena, P. R., Holzner, P., Rauch, E., Vidoni, R., & Matt, D. T. (2016). Requirements for the design of flexible and changeable manufacturing and assembly systems: A SME-survey. In *48th CIRP conference on manufacturing systems* (Vol. 41, pp. 207–212). https://doi.org/10.1016/j.procir.2016.01.018
Stentoft, J., Jensen, K. W., Philipsen, K., & Haug, A. (2019). Drivers and barriers for industry 4.0 readiness and practice: A SME perspective with empirical evidence. *Proceedings of the 52nd Hawaii International Conference on System Sciences, 6*, 5155–5164. https://doi.org/10.24251/hicss.2019.619
Stentoft, J., & Rajkumar, C. (2019). The relevance of Industry 4.0 and its relationship with moving manufacturing out, back and staying at home. *International Journal of Production Research*, 1–21. https://doi.org/10.1080/00207543.2019.1660823, 0(0).
Stentoft, J., Rajkumar, C., & Madsen, E. S. (2017). *Industry 4.0 in Danish Industry - an empirical investigation of the degree of knowledge, perceived relevance and current practice*.
Theorin, A., Bengtsson, K., Provost, J., Lieder, M., Johnsson, C., Lundholm, T., et al. (2017). An event-driven manufacturing information system architecture for Industry 4.0. *International Journal of Production Research, 55*(5), 1297–1311. https://doi.org/10.1080/00207543.2016.1201604
Thoben, K. D., Wiesner, S. A., & Wuest, T. (2017). "Industrie 4.0" and smart manufacturing-a review of research issues and application examples. *International Journal of Automation Technology, 11*(1), 4–16. https://doi.org/10.20965/ijat.2017.p0004
Thomas, A. J., & Barton, R. A. (2012). Characterizing SME migration towards advanced manufacturing technologies. *Proceedings of the Institution of Mechanical Engineers - Part B: Journal of Engineering Manufacture, 226*, 745–756. https://doi.org/10.1177/0954405411424977
Wiktorsson, M., Granlund, A., Lundin, M., & Södergren, B. (2016). Automation and flexibility: Exploring contradictions in manufacturing operations. In *23rd EurOMA conference. Trondheim*.
Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. Cambridge, Massachusetts: The MIT Press. https://doi.org/10.1515/humr.2003.021
Zheng, C., Qin, X., Eynard, B., Bai, J., Li, J., & Zhang, Y. (2019). SME-oriented flexible design approach for robotic manufacturing systems. *Journal of Manufacturing Systems, 53*(September), 62–74. https://doi.org/10.1016/j.jmsy.2019.09.010