

Drivers and Barriers for Industry 4.0 Readiness and Practice: A SME Perspective with Empirical Evidence

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Abstract

The technological development is moving rapidly enabling manufacturing companies with new possibilities for digital transformations to offer products and services to current and new markets at competitive costs. Such modern technologies are, among others, discussed under the umbrella term Industry 4.0. This paper reports on the results of a questionnaire-survey of 308 small and medium-sized manufacturers about their readiness for digitalized manufacturing and their actual practice in this area. The paper provides empirical evidence for that perceived drivers for Industry 4.0 lead to increased Industry 4.0 readiness, which, in turn, leads to a higher degree of practicing Industry 4.0. The paper also finds that barriers make companies less Industry 4.0 ready but this apparently does not have any significant impact on Industry 4.0 practice. The results are of importance for companies in planning transformation processes towards digitalized processes.

1. Introduction

Manufacturing companies have with increased intensity over the last two decades experienced a true globalization by moving manufacturing abroad and reshoring to other destinations or bringing it back to home destinations. Drivers for moving manufacturing abroad have been reported to include e.g. cost advantages, proximity to customers and requirements for local content [48]. Primary drivers for reshoring manufacturing are reported as a need to improve quality, lead-time and flexibility [6, 46].

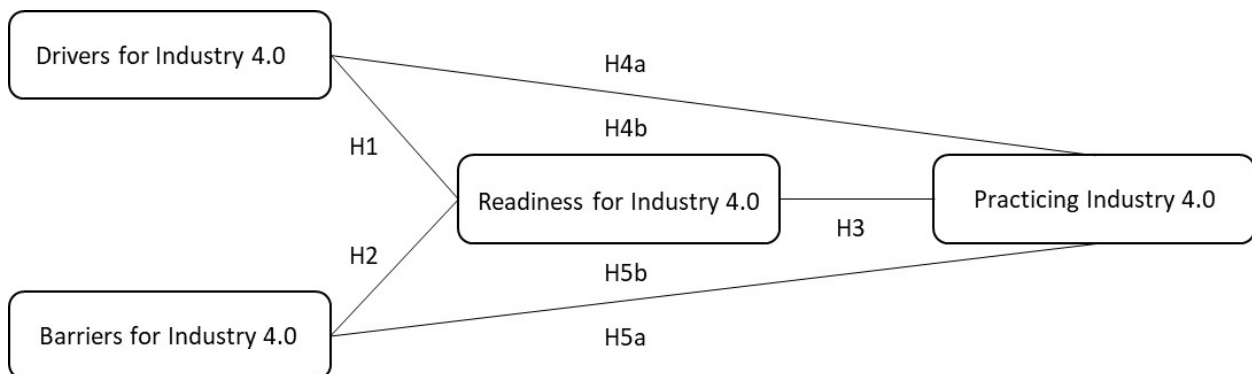
Recently, another driver for reshoring manufacturing or avoiding that manufacturing is moved abroad has been discussed in extant literature which is the use of new technologies such as automation and robotization [3, 12, 46, 47, 49]. Such new drivers, termed the fourth industrial revolution or Industry 4.0, is based on Cyber-Physical Systems; the integration of virtual and physical manufacturing systems [11, 24, 27]. Companies are facing both application pull and technological push regarding

Industry 4.0 [27]. Application pull takes place in terms of a need to shorten new product development times; increased individualization in demands; increased need for flexibility in production; increased decentralization to cope with faster decision-making and increased resource efficiency. Application push takes place in terms of increased mechanization and automation of processes; increased digitalization in manufacturing and the continued miniaturization of electronic devices.

In Europe, a small and medium-sized enterprise (SME) is defined as a firm employing fewer than 250 persons; with a total turnover that does not exceed EUR 50 million and that has an annual balance sheet total not exceeding EUR 43 million [16]. SMEs share some different characteristics compared with larger enterprises that are important to consider when analyzing and evaluating Industry 4.0 relevance and practice for SMEs. SMEs have fewer resources and experience in managing new technologies [8, 10, 53]; CEO involvement in daily operations and having a dominating operation focus at the expense of strategic and development oriented activities [9, 15, 22]. In the context of digital manufacturing, SME's are interesting to study for at least three reasons. First, SMEs counts the highest number of enterprises compared with larger enterprises and do thus represent a considerable target group for digitalization. Second, SMEs do, compared with large companies, operate with fewer resources [33]. Third, SMEs are usually less bureaucratic and generally have greater incentives to be successful than large firms [35].

A recent literature review of Industry 4.0 with a special emphasis on SMEs found that there is a lack of empirical founded research on the application of Industry 4.0 technologies [32]. Furthermore, a study has shown that larger companies seem to be more Industry 4.0 ready than SMEs [45]. Especially SMEs seems to struggle with adapting and implementing these technologies [24]. Thus, it must be assumed that barriers for Industry 4.0 are more evident in such companies. However, little is currently known about implementations of Industry 4.0 in SMEs. This paper seeks to fill part of this gap by analyzing data from 308 SMEs within various manufacturing sectors,

Figure 1. Theoretical framework



examining how SME managers’ perceptions of drivers and barriers for Industry 4.0 technologies affect their readiness for engaging with such technologies; how increased readiness affects the extent to which Industry 4.0 technologies are adopted; and how readiness mediates the effects of drivers and barriers on practicing Industry 4.0 technologies (see Figure 1). With practicing Industry 4.0 means an actual use of one or more of such technologies.

2. Hypothesis development

This section examines the concept of Industry 4.0, readiness as well as drivers and barriers reported in extant literature, which in turn, leads to the development of hypothesis for empirical tests.

2.1 Industry 4.0

The term Industry 4.0 originates from the German “Industrie 4.0” invented in 2011 in Germany as an German Federal Government initiative to strengthen the competitiveness of the German manufacturing industry [20, 24]. Many definitions of Industry 4.0 are proposed [34, 37]. In this paper, we rely on the following understanding of Industry 4.0: “... it involves the technical integration of Cyber-Physical Systems into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes. This will have implications for value creation, business models, downstream services and work organization.” [25]. Furthermore, Industry 4.0 technologies are under rapid development and consequently the theoretical and conceptual understanding [30, 34]. Nine technologies have been proposed to unfold the Industry 4.0 umbrella [40]: 1) big data and analytics, 2) autonomous robots, 3) simulation, 4) horizontal and vertical system

integration, 5) internet of things (IoT) (including sensors), 6) cyber-security, 7) the cloud, 8) additive manufacturing and 9) augmented reality. To this list can be added: 1) artificial intelligence, 2) mobile technologies and 3) RFID and RTLS technologies [41, 42]; thus, the total number of technologies to be studied counts 12.

2.2 Industry 4.0 readiness

The term “IT readiness” is used to describe the degree to which companies are able to exploit and derive benefits from IT technologies [1, 14, 18, 26]. An adjacent concept to readiness is maturity. Readiness can be distinguished from maturity in the sense that readiness is assessed before engaging in maturing processes whereas maturity is assessed from the actual implementation and forward [43]. Thus, the focus in this paper is on the early stage of this technology adoption and not on maturity levels in transformation processes.

Since empirical data on implementing Industry 4.0 still is sparse, we rely on literature concerned with IT in general. However, as Industry 4.0 concerns the application of technology, it seems reasonable to assume that the IT readiness dimensions also are applicable in a digital technology context. The Industry 4.0 readiness dimensions would then include: pressures to change existing processes; willing to take risks with the technologies; having sufficient knowledge about the technologies, having employees with the right competencies and the right motivation to work with the technologies and having the right amount of top management support in terms of financial support and attitudes) [18]. Lack of readiness is identified as one of the major reasons of failures of ERP implementations [2]. Thus, the more readiness in a company the more utilization of the technology when judged being relevant for their business.

Table 1: Drivers and barriers for Industry 4.0

Drivers	Category	Source(s)
Legislation/standards	Legal requirements/changed legislation (e.g. CE labeling)	Irisgroup (2013)
Strategy	Conscious strategy on Industry 4.0	Kane et al. (2015); Pagani (2013)
	Customer requirements	Geissbauer et al. (2016); Probst et al. (2017)
	In order to reduce costs	Colotta et al. (2016); Dujin et al. (2014); Geissbauer et al., (2016); McKinsey Digital (2015); Moeuf et al. (2018)
	In order to improve time-to-market	Lasi et al. (2014); McKinsey Digital (2015); Moeuf et al. (2018)
	Competitors practice Industry 4.0	Geissbauer et al. (2016)
Workforce	Lack of qualified work force	Probst et al. (2017)
Public adviser system	Work initiated with input from the public advisor system	Irisgroup (2013)
Barriers	Category	Source(s)
Legislation/standards	Lack of standards	Geissbauer et al. (2016); Huang et al. (2013); Kagermann et al. (2013); Trappey et al. (2017)
Management	Lack of understanding of the strategic importance of Industry 4.0	Geissbauer et al., (2016); Schönreiter (2017); Stentoft et al. (2017)
	Too few financial resources	Walendowski et al. (2016);
	Too few human resources (man power)	Arlbjørn et al. (2009)
	More focus on operation at the expense of developing the company (ambidexterity)	Arlbjørn and Mikkelsen (2014); Arlbjørn et al. (2009)
	Lack of data protection (cyber security)	Lee et al. (2016); Walendowski et al (2016), Yu et al. (2015)
Workforce	Lack of qualified work force	Geissbauer et al., (2016); Kagermann et al. (2013); Walendowski et al (2016)
	Lack of knowledge about Industry 4.0	McKinsey Digital (2015); Prinz et al. (2016); Ren et al. (2015); Schönreiter (2017);
	Requires continued education of employees	Kagermann et al. (2013)
	Lack of employee readiness	Haug et al. (2011); Kwahk and Lee (2008); Lee et al. (2007); Walendowski et al (2016)
	Lack of understanding the interplay between technology and human	Autor (2015); Walendowski et al. (2016)

2.3 Drivers and barriers for Industry 4.0

In practice, there are several drivers as well as barriers for focusing on industry 4.0 and, in turn, move to actual implementation and operation of such technologies. The concept of Industry 4.0 is relatively new with promises of leapfrogging performance in the digital enterprise. Current research is still dominated by grey literature but academic contributions are now beginning to appear in academic journals [30, 32]. However, studies focusing on specific drivers as well as barriers for Industry 4.0 and its actual application seem to be sparse in extant academic literature. Table 1 contains a list of drivers and barriers for adopting IT systems. The table has been compiled by various sources ranging academic papers to grey literature that contains viewpoints and discussion on these issues. As mentioned previously, Industry 4.0 is a nascent

research area where extant academic literature lacks adequate drivers as well as barriers for Industry 4.0. Based on adjacent literature to Industry 4.0 such as ERP and grey literature, it has been possible to compose potential drivers and barriers for Industry 4.0 as shown in Table 1 and attempts to investigate their impact on Industry 4.0 readiness and accordingly to the actual practice of Industry 4.0. Accordingly, we hypothesize that:

H1: Perceptions of higher drivers for Industry 4.0 promote higher Industry 4.0 readiness.

H2: Perceptions of higher barriers for Industry 4.0 decrease lower Industry 4.0 readiness.

H3: Industry 4.0 readiness promotes adaptation of Industry 4.0 technologies. H4: Perceptions of higher drivers for Industry 4.0 promote the adaptation of Industry 4.0 technologies (a) directly, and (b) indirectly by increasing industry 4.0 readiness.

Table 2. Means, standard deviations and correlations

	Mean	Std. Dev.	1	2	3	4	5	6	7
1. Data Comp Power & Conn	1.83	.75							
2. Analytics and Intel.	1.54	.74	.585**						
3. Human Machine Int.	1.14	.56	.476**	.500**					
4. Digital Physical Conv.	1.59	.85	.603**	.578**	.469**				
5. Cyber Security	2.65	1.31	.437**	.290**	.105	.245**			
6. Readiness	2.95	.73	.487**	.334**	.266**	.386**	.315**		
7. Drivers	2.54	.71	.491**	.291**	.199**	.370**	.313**	.574**	
8. Barriers	2.56	.72	.041	.016	-.001	.023	.056	-.055	.394**
9. Firm Age	11.55	5.21	-.055	-.046	-.077	-.047	.07	.027	-.054
10. Firm Size	21.73	3.94	.124*	.011	-.034	.029	.149**	.065	.037
11. Low Cost Strat.	2.97	1.14	.07	.024	.002	-.001	.115*	.09	.150*
12. Differentiation Strat.	4.22	.89	.220**	.165**	-.019	.184**	.119*	.194**	.119
13. Proactive Strat.	3.67	1.03	.417**	.294**	.173**	.355**	.143*	.381**	.261**
14. White collar inn res	23.20	25.09	.380**	.369**	.302**	.298**	.002	.244**	.092
15. Blue Collar inn res	44.14	55.71	-.06	-.097	-.049	-.082	.004	-.056	-.058
16. Export	29.44	34.33	.144*	.217**	.111	.178**	.019	.139*	.063
	8	9	10	11	12	13	14	15	
9. Firm Age	-.059								
10. Firm Size	.014	.174**							
11. Low Cost Strat.	.022	.013	.084						
12. Differentiation Strat.	.059	-.087	.012	-.138*					
13. Proactive Strat.	-.057	-.089	.099	-.066	.446**				
14. White collar inn res	-.039	-.144**	-.082	0	.159**	.390**			
15. Blue Collar inn res	-.147*	.044	-.019	.089	-.078	-.067	-.190**		
16. Export	-.026	.121*	.151**	-.021	.159**	.252**	.082	.014	

*) significance $p < .05$; **) significance $p < .01$ (2-tailed test).

H5: Perceptions of higher barriers for Industry 4.0 decrease the adaptation of Industry 4.0 technologies (a) directly, and (b) indirectly by decreasing Industry 4.0 readiness.

3. Method

3.1. Data collection

Data in this paper is developed through a questionnaire-survey about the use of information technology and digital technologies to business development for SMEs. The questionnaire was focused on manufacturing enterprises from 10 to 250 employees and was distributed in April and May 2018. To identify the relevant population, the Danish

company data base “Bisnode”. The database allowed us to search for manufacturing companies within the size scope in a structured manner. The process resulted in a cross list 3,400 companies. After a cleansing process of the company list (companies that by error appear on the list and companies for which contact information not was available), the net list of companies amounted to 2,632.

All companies were approached through phone by hired students from the University of Southern Denmark. The students asked the person that took the call to be directed to person being responsible for business development. If they agreed to attend the survey, a link to the questionnaire-survey was sent by e-mail to the respondent. Reminder e-

Table 3. Regression results

	Unstandardized regression coefficients										
	Model										
	1	2	3	4	5	6	7	8	9	10	11
Constant	.705	.703	-.067	-.100	-	2.078	1.914	-.382	-.548	.492	.034
Readiness			.192**		.129		.187*		.196#		.541**
Drivers	.590***	.427***	.314***	.241***	.167	.174*	.066	.456***	.341***	.543***	.225
Barriers	-	-.096	-.044	.017	.052	-.116	-.066	-.125	-.072	-.041	.105
Firm age	.276***	-.015*	-.003	-.005	-.006	-	-.009	-.011	-.001	-.004	.021
Firm size	.002	.005***	.005***	.003	.003	-.001	-.001	.002	.001	.007*	.006
Low cost strat.	.006	.034	.034	.010	.010	.023	.023	-.006	-.006	-.016	-.016
Diff. strat.	.105	.059	.039	.061	.048	-.114	-.133	.065	.045	.083	.028
Proact. strat.	.119	.145***	.122	.107	.091	.072	.049	.154*	.130	.073	.006
White col inn	.001	.002	.001	.000	.000	.002	.002	.002	.002	-.009*	-.010*
Blue col inn	-.001	.002	.002	.005	.005	-.004	-.004	.001	.001	.004	.005
Export	.001	-.001	-.001	.002	.002	.001	.001	.000	.000	.000	.000
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-.230	Yes	Yes	Yes
N	190	190	190	190	190	190	190	190	190	190	190
Adj R-sqr	.440	.339	.355	.192	.195	.040	.062	.203	.211	.112	.158

***) p < .001; ** p < .01; *) p < .05; #) p < .10

Table 4. Tests for mediation using bootstrapping (unstandardized values)

Dependent variable	Total direct effect (SE)	Direct effect (SE)	Indirect effect (Boot SE)	Boot LLCI	Boot ULCI
Data Comp Power & Conn	.3796*** (.0779)	.2647* (.0911)	.1148 (.0530)	.0170	.2258
Analytics and Intel.	.2527* (.0869)	.1767# (.1027)	.0761 (.0602)	-.0352	.2021
Human Machine Int.	.1803* (.0739)	.0849 (.0868)	.0954 (.0699)	-.0200	.2474
Digital Physical Conv.	.4853*** (.1034)	.3463** (.1222)	.1390 (.0599)	.0320	.2664
Cyber Security	.5474*** (.1519)	.2674 (.1775)	.2800 (.0990)	.0859	.4753

***) p < .001; ** p < .01; *) p < .05; #) p < .10

mails were sent several times during April and May 2018. This process resulted in agreements to attend the questionnaire-survey by 736 companies. Out of these, 190 have provided full and useable answers leading to a response rate at 25.8 percent.

3.2. Measures

3.2.1. Dependent variables. “Readiness for Industry 4.0” was measured using a scale adapted from Haug et al. (2011) [18] including seven 5-point Likert scale questionnaire items. We modified the questions to embrace Industry 4.0 technologies (see appendix 1). Factor analysis confirms a one-factor solution

explaining 53.9 percent variance and Cronbach’s alpha is .852. To construct the index, we used the average score of the seven items. To measure firms’ “practicing Industry 4.0” we compiled a list of 12 digital technologies inspired by [31, 40, 41, 42], asking respondent of the extent to which they use each technology (see appendix 1). Based on [31, 41, 42], the 12 technologies are grouped into five sub-categories: 1. Data, computational power, and connectivity (big data and analytics, IoT, cloud computing, horizontal and vertical system integration, mobile technologies and RFID and RTLS systems); 2. Analytics and intelligence (artificial intelligence and simulation); 3. Human-machine interaction (augmented reality); 4. Digital-to-physical conversion (autonomous

robots and additive manufacturing), and 5. Cyber security (cyber security). The first four categories are borrowed from [31] while the fifth category is added from [41, 42].

3.2.2. Independent variables. “Drivers for Industry 4.0” was measured using an index constructed from eight 5-point Likert scale questionnaire items (see appendix 1). Factor analysis confirms a one-factor solution explaining 45.6 percent of variance, and Cronbach’s alpha is .826. The index is constructed using the average score of the eight items. “Barriers for using Industry 4.0” was measured using an index based on 11 5-point Likert scale questionnaire items (see appendix 1). Factor analyses supports a one-factor solution explaining 48.9 percent of variance, and Cronbach’s alpha is .890. The index is calculated as the average score of the 12 items.

3.2.3. Control variables. We control for firm size measured by number of employees, and we control for firm age measured in years since founding. We also included controls for firm strategy based on measures on the extent to which the firm pursue a low cost, differentiation, and a proactive strategy, and we include control for the percentages of white and blue-collar workers’ time spent on innovation activities. Furthermore, the effect of firms’ level of exporting, and for the extent to which the firm rely on internal as opposed to external resources in their appliance of digital technologies has been controlled. Finally, we control for the effect of industry applying 2-digit NACE codes.

4. Results

Table 2 presents the means, standard deviations, and the correlations of the variables. We first notice that firms in the sample with an average score of 2.9 for the readiness construct perceive to be neither well nor poorly prepared to take on the challenge of new digital technology. When it comes to firms’ use of new digital technologies, the scores are relatively low. Cyber security has the highest average score (2.65), indicating low – to moderate use of cyber security solutions. Especially human machine interaction technologies seem to be absent in the SME sample, scoring only 1.14, with a score of 1 indicating no use. These numbers spark the interest in examining the role of drivers and barriers for the use of (or lack of) digital technologies.

Results from the regression analyses are shown in Table 3. Model 1 analyses the effects of barriers and drivers for digital technologies on the readiness of SMEs. The positive significant coefficient for “drivers”

confirms our hypothesis 1, that drivers for digital technologies promote firms’ readiness. In a similar way, the negative significant coefficient for “barriers”, supports hypothesis 2 that barriers for Industry 4.0 decrease firms’ readiness. Models 2 to 11 analyses the impact of barriers, drivers, and readiness on firms’ use of digital technologies in the five specified categories. Models 2, 4, 6, 8, and 10, which do not include readiness, all confirm a positive impact from drivers on firms’ extent of use of the respective digital technologies. In four of the five models introducing readiness (models 3, 7, 9, and 11), the coefficient is positive and significant, thus supporting hypothesis 3. None of the models find any significant effect of barriers to Industry 4.0 on firms’ use of digital technologies. Hence, no support was found for hypothesis 3. In all models (3, 5, 7, 9, 11), the introduction of the readiness variable was associated with a decrease in the effect from drivers on digital technology use. In models 5, 7, and 11, the driver coefficient turned insignificant, while the Industry 4.0 driver coefficient remained significant for models 3 and 9. Following the joint significance test [7], these results suggest that the effect of Industry 4.0 drivers on SMEs’ extent of using digital technologies is partly mediated by an increase readiness.

Performing bootstrapping tests [19] (see Table 4) confirms that readiness partly mediates the effects from Industry 4.0 drivers on SMEs’ use of (1) data, computational power, and connectivity technologies, (2) digital-to-physical conversion technologies, and fully mediates the effects on (3) cyber security technology. Overall, the results – although with minor differences among the five categories of Industry 4.0 technologies – thus support hypothesis 4a and 4b, that SME managers’ perceptions of drivers affect adaptation of Industry 4.0 technologies both directly and indirectly by affecting readiness. The results, however, leaves no support to hypothesis 5a and 5b, suggesting that SME managers’ perceptions of barriers do not affect the adaptation of Industry 4.0 technologies, neither directly, nor by affecting readiness.

5. Discussion

The first overall interesting result is an apparently low degree of Industry 4.0 readiness and concrete use among the sample of Danish SMEs. Compared with another empirical analysis of Danish manufactures [45], large companies were found to have a significant higher Industry 4.0 readiness than SMEs, which can be explained by larger companies relatively higher availability of resources to exploit the technologies. The relatively low scores on all the variables indicate

either a low degree of push to apply the technologies and thus lack of awareness of the technologies or conscious choices due to a lack of experienced technological pull within their business areas. The current stage of Industry 4.0 application among SMEs might mature in the coming years as more practical applications developed by larger companies or innovative SMEs allows such innovations to diffuse to SMEs for further application. According to OECD [36], manufacturing jobs in Denmark are among the most ICT intensive in the OECD countries and Denmark also have a robot intensity above the average for OECD countries. If we use these findings as an approximation of Denmark being in the forefront in applying Industry 4.0 technologies, despite the relatively low level of readiness, then the results indicate that most of OECD countries do have an even lower level of readiness. This result indicates a need for resources for preparing SMEs to the digital adaptation and transformation.

Another interesting result is that the analysis suggests that Industry 4.0 barriers decrease SMEs readiness to Industry 4.0, but this does not have any significant relationship with practicing Industry 4.0. Thus, the barriers make the SMEs less Industry 4.0 ready, but despite this it seems not to influence their practical utilization of the technologies. Opposite, Industry 4.0 drivers promote SMEs use of digital technologies, partly by increasing their readiness in terms of motivation, competence, and organizational support. It is surprising that the barriers are not decreasing the practical utilization of Industry 4.0 technologies. Barriers such as lack of knowledge, lack of standards and lack of employee readiness neither affect the Industry 4.0 readiness significantly, nor do they affect the adaptation of Industry 4.0 technologies. Seemingly, SMEs are quite robust in taking up the challenges imposed by these barriers. The results indicate that companies and policy makers should focus on the drivers instead of the barriers to improve Industry 4.0 readiness and true implementations. It seems like looking at the opportunities outweigh a focus on the constraints or that the barriers will be become more neutralized by working and responding to the drivers.

The analysis also shows that there is a significant relationship between Industry 4.0 readiness and the actual practice of Industry 4.0. This result indicates, that if a company from e.g. strategic reasons wants to digitalize their manufacturing toward a smart factory they can benefit from first working on increasing the readiness in terms of the variables shown in appendix 1. This result is also important for policy makers who develop initiatives to support SMEs increased readiness.

A final point for discussion is the mediating effect of readiness on practicing Industry 4.0. With this, the study analyze how much of the practical use of Industry 4.0 can be explained by first being ready before using it. All drivers are found to have direct impact on practicing Industry 4.0. When this practice is studied using readiness as a mediator, four of the drivers have a significant relationship with practicing. The category “analytics and intelligence” (including the variable of artificial intelligence and simulation, see appendix 1) has a positive relationship but is not significant. The use of artificial intelligence and simulation seems not first to require a readiness for it. The mean value for this category of Industry 4.0 technologies is quite low (1.54 cf. Table 2) indicating a relatively low use of it. An explanation could be that the few SMEs reporting to use artificial intelligence and/or simulation may have such technologies as part of their business model where a readiness is not required because it exist per se.

6. Conclusion

This paper has set out to analyze and discuss the relationship of drivers as wells as barriers for Industry 4.0 technologies on Industry 4.0 readiness and actual practice. The paper presents novel data to a research area that to date lacks empirical data on the readiness and actual application of Industry 4.0 among SMEs. Data from the presented survey reveals in general low averages for drivers and barriers, readiness and practice. The analysis finds support for drivers that possess a positive impact on Industry 4.0 readiness and the use of industry 4.0 technologies. However, the analysis does not find support for barriers that impact companies reported readiness and practice. Thus, overall the analysis finds support for hypotheses 1, 2, 3, 4a, and 4b but no support for hypotheses 5a and 5b. These results are important for companies to consider if, and when, they are planning transformation processes towards more digitalized processes.

Based on this study, future research need to analyze variance of readiness and practice across industries and nations. Data is collected among Danish manufacturers which according to OECD are among the forefront countries concerning digital adoption among OECD countries. With this in mind, we still see a low level of readiness among Danish manufacturers; and thus, we could expect an even lower level of readiness among other OECD countries. Future research is needed that could compare Industry 4.0 readiness across nations. Furthermore, future research may also provide more detailed studies on whether some Industry 4.0 technologies are more useable in some industries than in others. Future research can also address different

matureness stages for adopting these technologies from a dynamic perspective and continues to focus on drivers and barriers and how they might change over time to supplement extant maturity models [43]. Finally, the data in this paper is based on answers to a questionnaire-survey based on a single respondent. Building an analysis on one person's view can be viewed as a limitation since one cannot assure that this person has the complete overview of the themes under investigation. Therefore, future research can explore this phenomenon by applying multiple respondents from each company in order to strength the answers.

The practical policy implication of this study might be needs to focus on the drivers as a mean to cultivate Industry 4.0 readiness and implementation the technologies. Governmental support can help with increasing the knowledge level to increase consciousness of an application pull and the opportunities with technology pushes. The relatively low degree of readiness and application among SMEs may indicate an untapped potential for innovating business models using Industry 4.0 technologies. SMEs have in general a more operational focus at the expense of business development activities [53], which, in turn, can lead to investment backlogs in new technologies. Thus, some SMEs might oversee some potential benefits from Industry 4.0 technologies due to a main focus on daily operations while others are reluctant for using the technologies because they, in fact, still could not bring more advantages compared with the costs to clarify and implement the technologies.

7. References

- [1] Abdinnour-Helm, S., Lengnick-Hall, M.L. and Lengnick-Hall, C.A. Pre-implementation attitudes and organizational readiness for implementing an enterprise resource planning system. *European Journal of Operational Research* 146(2), 2003, pp. 258-273.
- [2] Ali, M. and Miller, L. ERP system implementation in large enterprises – a systematic literature review. *Journal of Enterprise Information Management* 30(4), 2017, pp. 666-692.
- [3] Arlbjørn, J.S. and Mikkelsen, O.S. Backshoring manufacturing: notes on an important but under-researched theme. *Journal of Purchasing & Supply Management* 20(1), 2014, pp. 60-62.
- [4] Arlbjørn, J.S., Damgaard, T. and Haug, A. Key success factors for ICT-system implementation in SME's, in: Vervest, P.H.M., van Liere, D.W. and Zheng, L. (eds.), *The Network Experience: New Value from Smart Business Networks*, Springer-Verlag, Heidelberg, 2009, pp. 249-266.
- [5] Autor, D.H. Why are there still so many jobs? The history and future of workplace automation. *Journal of Economic Perspectives* 29(3), 2015, pp. 3-30.
- [6] Barbieri, P., Ciabuschi, F., Fratocchi, L. and Vignoli, M. What do we know about manufacturing reshoring? *Journal of Global Operations and Strategic Sourcing* 11(1), 2018, pp. 79-122.
- [7] Baron, R.M. and Kenny, D.A. The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology* 51(6), 1986, pp. 1173-1182.
- [8] Bili, S. and Raymond, L. Information technology: Threats and opportunities for small and medium-sized enterprises. *International Journal of Information Management* 13(6), 1993, pp. 439–448.
- [9] Buonanno, G., Faverio, P., Pigni, F., Ravarini, A., Sciuto, D. and Tagliavini, M. Factors affecting ERP system adoption: A comparative analysis between SMEs and large companies. *Journal of Enterprise Information Management* 18(4), 2005, pp. 384-426.
- [10] Chang, S.-I. and Hung, S.-Y. Critical factors of ERP adoption for small- and medium-sized enterprises: An empirical study. *Journal of Global Information Management* 18(3), 2010, pp. 82-106.
- [11] Colotla, I., Fæste, A., Heidemann, A., Winther, A., Andersen, P.H., Duvold, T. and Hansen, M. *Winning the Industry 4.0 Race: How Ready are Danish Manufacturers?*, Boston Consulting Group, Boston, USA, 2016.
- [12] Di Mauro, C., Fratocchi, L., Orzesc, G. and Sartor, M. Offshoring and backshoring: A multiple case study analysis. *Journal of Purchasing & Supply Management* 24(2), 2018, pp. 108-134.
- [13] Dujin, A., Geissler, C. and Horstkötter, D. *Think Act: Industry 4.0*, Ronald Berger Strategy Consultants, Munich, Germany, 2014.
- [14] Dyerson, R., Spinelli, R. and Harindranath, G. Revisiting IT readiness: An approach for small firms. *Industrial Management & Data Systems* 116(3), 2016, pp. 546-563.
- [15] Forsman, H. Business development success in SMEs: A case study approach. *Journal of Small Business and Enterprise Development* 15(3), 2008, pp. 606-622.
- [16] EU Commission. *User Guide to the SME Definition*, European Union, Publication Office, Luxembourg, 2015.
- [17] Geissbauer, R., Vedso, J. and Schrauf, S. *Global Industry 4.0 Survey: Building the digital enterprise*, <https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf> (down loaded June 9, 2018), 2016.
- [18] Haug, A., Pedersen, S.G. and Arlbjørn, J.S. IT readiness in small and medium-sized enterprises. *Industrial Management & Data Systems* 111 (4), 2011, pp. 490-508.
- [19] Hayes, A.F. *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression Based Approach*, Guilford Publications, New York, 2018.
- [20] Hermann, M., Pentek, T. and Otto, B. Design principles for Industrie 4.0 scenarios: A literature review. *Working paper No. 1*, Technical University Dortmund, 2015.
- [21] Huang, B., Li, C., Yin, C. and Zhao, X. Cloud manufacturing service platform for small- and medium-

- sized enterprises. *International Journal of Advanced Manufacturing Technology* 65(9-12), 2013, pp. 1261–1272.
- [22] Huin, S.F. Managing deployment of ERP systems in SMEs using multi-agents. *International Journal of Project Management* 22(6), 2004, pp. 511-517.
- [23] Irisgroup, *Digitalisering af dansk erhvervsliv [Digitalizing Danish Business Community]*, <http://reglab.dk/wordpress/wp-content/uploads/2016/05/digitalisering-af-dansk-erhvervsliv.pdf> (down loaded June 8, 2018), 2013.
- [24] Issa, A., Hatiboglu, B., Bildstein, A. and Bauernhansl, T. Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment. *Procedia CIRP* 72, 2018, pp. 973-978.
- [25] Kagermann, H., Wahlster, W. and Helbig, J. *Recommendations for Implementing the Strategic Initiative Industrie 4.0*, Linda Treugut, M.A. and acatech – National Academy of Science and Engineering, 2013.
- [26] Kwahk, K. and Lee, J. The role of readiness for change in ERP implementation: Theoretical bases and empirical validation. *Information & Management* 45(7), 2008, pp. 474-481.
- [27] Lasi, H., Fettke, P., Feld, T. and Hoffmann, M. Industry 4.0. *Business & Information Systems Engineering* 6(4), 2014, pp. 239-242.
- [28] Lee, C., Lee, G. and Lin, H. The role of organizational capabilities in successful e-business implementation. *Business Process Management Journal* 13(5), 2007, pp. 677-693.
- [29] Lee, J. Bagheri, B. and Jin, C. Introduction to cyber manufacturing. *Manufacturing Letters* 8, 2016, pp. 11-15.
- [30] Liao, Y., Deschamps, F., Loures, E.d.R. and Ramos, L.F.P. Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research* 55(12), 2017, pp. 3609-3629.
- [31] McKinsey Digital. *Industry 4.0 How to Navigate Digitization of the Manufacturing Sector*, <https://www.mckinsey.com/business-functions/operations/our-insights/industry-four-point-how-to-navigae-the-digitization-of-the-manufacturing-sector> (down loaded June 8, 2018), 2015.
- [32] Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S. and Barbaray, R. The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research* 56(3), 2018, pp. 1118-1136.
- [33] Müller, E. and Hopf, H. Competence center for the digital transformation in small and medium-sized enterprises. *Procedia Manufacturing* 11, 2017, pp. 1496-1500.
- [34] Müller, J., Dotzau, V. and Voigt, K.-I. Industry 4.0 and its impact on reshoring decisions of German manufacturing enterprises, In: Bode, C., Bogaschewsky, R., Eßig, M., Lasch, R. and Stölzle, W. *Supply Management Research*, Advanced Studies in Supply Management, Springer, 2017.
- [35] Nooteboom, B. Innovation and diffusion in small firms: Theory and evidence. *Small Business Economics* 6(5), 1994, pp. 327–347.
- [36] OECD. *OECD Science, Technology and Industry Scoreboard: The Digital Transformation*, OECD Publishing, Paris, 2017
- [37] Pagani, M. Digital business strategy and value creation: framing the dynamic cycle of control point. *MIS Quarterly* 37(2), 2013, pp. 617–632.
- [38] Probst, L., Pedersen, B., Lonkeu, O.-K., Martinez-Diaz, C., Araujo, L.N., Klitou, D., Conrads, J. and Rasmussen, M. *Digital Transformation Scoreboard 2017: Evidence of Positive Outcomes and Current Opportunities for EU Businesses*, EU Commission, Brussel, 2017.
- [39] Ren, L., Zhang, L., Tao, F., Zhao, C., Chai, X. and Zhao, X. Cloud Manufacturing: From Concept to Practice. *Enterprise Information Systems* 9(2), 2015, pp. 186–209.
- [40] Ruessmann, M., M. Lorenz, P. Gerbert, M. Waldner, J. Justus, P. Engel and M. Harnisch. *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*, Boston Consulting Group, 2015.
- [41] Salkin, C., Oner, M., Ustundag, A. and Cevikcan, E. A conceptual framework for Industry 4.0, In: Ustundag, A. and Cevikcan, E. *Industry 4.0: Managing The Digital Transformation*, Springer Series in Advanced Manufacturing, Springer, 2018.
- [42] Saucedo-Martínez, J.A., Pérez-Lara, M., Marmolejo-Saucedo, J.A., Salais-Fierro, T.E. and Vasant, P. Industry 4.0 framework for management and operations: A review, *Journal of Ambient Intelligence and Humanized Computing* 9(3), 2018, pp. 789-801.
- [43] Schumacher, A., Erol, S. and Sihni, W. A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. *Procedia CIRP* 52, 2016, pp. 161-166.
- [44] Schönreiter, I. Significance of quality 4.0 in post merger process harmonization, In: Piazzolo, F., Geist, V., Brehm, L. and Schmidt, R. (Eds.) *ERP Future 2016, LNBIIP 285*, Springer International Publishing, 2017, pp. 123–134.
- [45] Stentoft, J., Rajkumar, C. and Madsen, E.S. *Industry 4.0 in Danish Industry*, Department of Entrepreneurship and Relationship Management, University of Southern Denmark, 2017.
- [46] Stentoft, J., Olhager, J., Heikkilä, J. and Thoms, L. Manufacturing backshoring: A systematic literature review. *Operation Management Research* 9(3-4), 2016a, pp. 53-61.
- [47] Stentoft, J. Mikkelsen, O.S. and Jensen, J.K. Offshoring and backshoring manufacturing from a supply chain innovation perspective. *Supply Chain Forum: An International Journal* 17(4), 2016b, pp. 190-204.
- [48] Stentoft, J., Mikkelsen, O.S. and Johnsen, T. Going local: A trend towards insourcing of production?, *Supply Chain Forum: An International Journal* 16(1), 2015, pp. 2-13.
- [49] Tate, W.L. Offshoring and reshoring: US insights and research challenges. *Journal of Purchasing & Supply Management* 20(1), 2014, pp. 66-68.
- [50] Trappey, A.J.C., Trappey, C.V., Govindarajan, U.H., Chuang, A.C. and Sun, J.J. A review of essential

standards and patent landscapes for the Internet of Things: A key enabler for Industry 4.0, *Advanced Engineering Informatics* 33, 2017, pp. 208-229.

- [51] Walendowski, J., Kröll, H. and Schnabl, E. *Regional Innovation Monitor Plus 2016: Thematic Paper 3 - Industry 4.0, Advanced Materials (Nanotechnology)*, European Communities, 2016.
- [52] Yu, C., Xu, X. and Lu, Y. Computer-integrated manufacturing, cyber-physical systems and cloud manufacturing – concepts and relationships. *Manufacturing Letters* 6, 2015, pp. 5-9.
- [53] Zach, O., Munkvold, B.E. and Olsen, D.H. ERP system implementation in SMEs: Exploring the influences of the SME context. *Enterprise Information Systems* 8(2), 2014, pp. 309-335.

8. Appendix 1 - Questionnaire-survey

Industry 4.0 readiness (Scale adapted from Haug et al., 2011) [18].

To which degree do you agree to the following statements? (on a five-point Likert-Scale: 1 = to a very low degree and 5 = to a very high degree)

1. We experience a pressure to work with Industry 4.0 (e.g. from customers, suppliers, authorities etc.)
2. We have the willingness to take risks to experiment with Industry 4.0
3. We have the necessary knowledge about Industry 4.0 to judge its importance for our company
4. We have necessary support from top management to judge and work with Industry 4.0
5. Our employees have the right competencies to work with Industry 4.0
6. Our employees have the right motivation to judge and work with Industry 4.0
7. We have economic freedom to work with Industry 4.0

Industry 4.0 (Inspired by Ruessmann et al., 2015 [40]; Salkin, 2018 [41]; Saucedo-Martínez et al., 2017) [42]

To which degree do you apply the following technologies in your company? (on a five-point Likert-scale: 1 = do not use, and 5 = use to a very high degree)

1. Big Data & Analytics (categorized to model 1)
2. Autonomous Robots (categorized to model 4)
3. Simulation (categorized to model 2)
4. Horizontal & Vertical System Integration (categorized to model 1)
5. Internet of Things (IoT) (including sensors) (categorized to model 1)
6. Cyber-Security (categorized to model 5)

7. Additive Manufacturing (e.g. 3D print) (categorized to model 4)
8. Augmented Reality (categorized to model 3)
9. Cloud Computing (categorized to model 1)
10. Mobile Technologies (categorized to model 1)
11. Artificial Intelligence (categorized to model 2)
12. Radio-Frequency Identification (RFID) & Real-time locating system (RTLS) technologies (categorized to model 1)

Drivers for using Industry 4.0 technologies (Scales developed from sources in Table 1)

Please evaluate the following drivers for your company to use Industry 4.0 technologies? (on a five-point Likert-scale: 1 = to a very low degree and 5 = to a very high degree)

1. Customer requirements
2. Competitors practice Industry 4.0
3. To reduce costs
4. To improve time-to-market
5. Due to legal requirements/changed legislation
6. Lack of qualified workforce
7. Have seen/read about what and how others have done
8. Work initiated with input from the public advisor system (incubators, local business support)
9. Work initiated based on requests from consultants
10. Conscious strategy on Industry 4.0

Barriers for using Industry 4.0 technologies (Scales developed from sources in Table 1)

Please evaluate the following barriers for your company to use Industry 4.0 technologies? (on a five-point Likert-scale: 1 = to a very low degree and 5 = to a very high degree)

1. Lack of knowledge about Industry 4.0
2. Lack of standards
3. More focus on operation at the expense of developing the company
4. Lack of data protection (cyber security)
5. Lack of employee readiness
6. Requires continued education of employees
7. Lack of understanding of the strategic importance of Industry 4.0
8. Lack of understanding the interplay between technology and human
9. Too few financial resources
10. Too few human resources (man power)
11. Uncertainty about data security