Open process innovation and digitalization of manufacturing

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Abstract

Manufacturing companies seek to innovate their processes by improving their digital maturity. Many companies develop process innovations within the boundaries of their plants with limited knowledge exchange with outside sources. From the open innovation literature, we know that opening up and sharing knowledge with the environment can induce product innovations. We suggest this also applies to process innovations, such as new digital technologies. We conduct a survey of 184 Swiss manufacturing companies and analyze the effect of openness on digital maturity. We find that openness generally relates to a higher digital maturity, but more so for some technologies than others.

Keywords: process innovation, openness, digitalization

Introduction

The open innovation literature suggests that a firm can innovate its processes faster if it follows an open strategy (Pisano, 1997; Reichstein and Salter, 2006; Robertson, Casali and Jacobson, 2012; Trantopoulos et al., 2017; Vega-Jurado, Gutierrez-Gracia and Fernandez-de-Lucio, 2009). Openness refers to the ability of a firm to let knowledge float in- and outbound from and to sources outside the company (Chesbrough, 2003).

A manufacturing firm that applies "open *process* innovation" (von Krogh et al., 2018) benefits from accessing knowledge outside its boundaries to innovate its processes. External knowledge can for example be accessed from the firm's suppliers, customers, or research partners. Accessing and using external knowledge can be crucial when innovating processes with latest technologies, in which the focal firm often lacks the necessary expertise and experience. The phenomenon of using external knowledge has been well discussed in the product innovation literature (Chesbrough, 2003), but has received much less attention in the process innovation literature (von Krogh et al., 2018). The purpose of this paper is to unveil the relation between openness and digitalization of manufacturing, and provide advice for which technologies open process innovation improves the integration.

We expect that increasing openness in process innovation relates positively with a firm's digital maturity. Since smaller firms could lack the resources to develop new technologies in-house, we assume openness for them to be more important than for larger firms. We therefore control for the firm size. Further, we expect the type of production strategy to be an important factor of the model and therefore control for it. We assume that companies with mainly demand-driven production strategies benefit stronger from openness.

The paper proceeds with the theoretical background, which leads to the development of our hypotheses. Thereafter, the data collection and methodology are presented. The subsequent chapter introduces the findings of the quantitative research, which are discussed in the following section. Lastly, findings and results of this research are summarized and suggestions for further research presented.

Theoretical background and hypotheses development

Digitalization is among the most significant trends in both, society and industry (Hagberg et al., 2016). Although technologies connected with digitalization are not new, various examples have proven that digitalization potentially impacts the success of manufacturing firms (Yoo *et al.*, 2012; Brynjolfsson and Mcafee, 2014; Kang *et al.*, 2016). As competition requires organizations to innovate their processes to improve their market position, the implementation of digital technologies becomes even more challenging (Sinha and Noble, 2008). Sendler (2018, p.44) argues that "digitalization is a very clear example of how technical progress often – if not always – solves humankind's problems while, at the same time, more or less exchanging them for new ones".

The potentials of digitalization include among others increasing revenue, productivity or innovation gains (Matt et al., 2015). From an industry perspective, digitalization addresses both the possibility to improve internal processes, as well as digital innovation that has the potential to reinvent services, products, or business models (Yoo et al., 2012; Berghaus and Back, 2016). In brief, the characteristics of digital technologies are defined as computing, communication, connectivity and information processing capabilities (Bharadwaj et al., 2013). This research focuses on digital technologies and thus the internal perspective of digitalization.

The terms *digitalization* and *digitization* are often used interchangeably but are to be distinguished. According to Legner *et al.* (2017), digitization is the process of making systems digital, while digitalization is the sociotechnical phenomenon of adopting digital technologies in organizational contexts. Thus, by concentrating on digitalization, the current state of the Swiss manufacturing industry will be investigated with the help of a maturity model.

Maturity models are typically used to describe the state of a firm (Becker et al., 2009) or the development process towards a definite target (Pöppelbuß and Röglinger, 2011). Hence, maturity models can have a descriptive dimension to reveal the status quo or a prescriptive functionality that enables firms to follow definite development paths to access capabilities to reach a higher maturity level (Mettler, 2011; Netland and Alfnes, 2011). An overview of existing maturity models in the context of digitalization has been provided by (Schumacher et al., 2016). Next to identifying the status quo, the common goal of the different maturity models is to identify a target maturity level and thereby improve the processes of the firm. The changes of the processes necessary to close this gap are not only incremental but can be bigger and thus be rather defined as an innovation than an improvement.

Scholars distinguish such innovations in different categories (Pavitt, 1984). The OECD Oslo Manual clusters innovation s in three distinct types: *product*, *process*, and *organizational* innovations. Process innovations are therein defined as a 'significantly improved or changed process' (OECD, 2005). The focus of process innovations is to improve the productivity of a firm (Strebel, 2007).

Open process innovation

An organization wants to increase its innovation outcome. Chesbrough (2003) argues that opening up the boundaries of the organization and allowing knowledge to flow in- and outbound is a fruitful way to improve this outcome. He coined the term *open innovation* and many scholars followed up on his work (Bogers *et al.*, 2017). In their extensive study, Laursen and Salter (2006) find a positive inverted U-shape effect of openness on the firms' innovation performance. This work has mainly focused on product innovation (Trantopoulos *et al.*, 2017). However, there is also evidence that those companies that are, on average, more open (at least to a certain point), tend to be more innovative regarding the processes than those that are closed (Reichstein and Salter, 2006). In the operations management literature, for instance, Wagner and Bode (2014) find that a more open relationship between a supplier and a buyer can have positive effects on process innovation.

Measuring process innovations is yet quite difficult. As the digital maturity can be seen as innovating a firm's processes, we will use the maturity as a way to measure the process innovation. This leads to our first hypothesis:

H1: A firm's openness in developing process innovations with outside sources has a positive relation with its overall digital maturity.

The digital maturity can be different depending on the type of technology used. There are different classifications for digital technologies such as the World Economic Forum (2017) one which clusters digital technologies into (1) connectivity and computing, (2) physical transformation, (3) human-machine interfaces, and (4) analytics and intelligence. With the different type of technology we also expect a different effect on openness.

H2: Different technology clusters vary in the effect of openness on their maturity.

We expect that the size of the company can affect the importance of openness. As bigger companies own the budget to build up larger R&D resources in-house, smaller companies might be more dependent on outside knowledge. Therefore, we expect the size of the company to be a control variable.

A factor, which could influence the relation of openness on the digital maturity of firms, is the production policy or order decoupling (penetration) point. Olhager and Selldin (2004, p. 355) explain the order penetration point as that point that determines the point after which a product is produced to a specific customer order. In fact, firms in this context typically apply make-to-stock (MTS), make-to-order (MTO), assemble-to-order (ATO), and engineer-to-order (ETO) policies. Accordingly, the MTS policy means satisfying customer demands with products from stock, while ATO firms assemble pre-manufactured parts upon customer requests (Bertrand and Muntslag, 1993). In contrast, MTO firms only procure and manufacture products upon incoming orders. This policy leads to low inventory cost, high flexibility, but also longer delivery times (Kalantari, Rabbani and Ebadian, 2011). Finally, ETO firms produce products individually for customers, from the design to the shipment. ETO and ATO can been seen as subcategories of MTO (Olhager and Selldin, 2004). The idea of digitalization in manufacturing corresponds with the MTO or ETO policies as it is proposed to economically produce large numbers of product variants up to a minimum batch size in the future (Brettel *et al.*, 2014). We therefore also control for the production strategy in the model. Figure 1 illustrates the resulting research model.

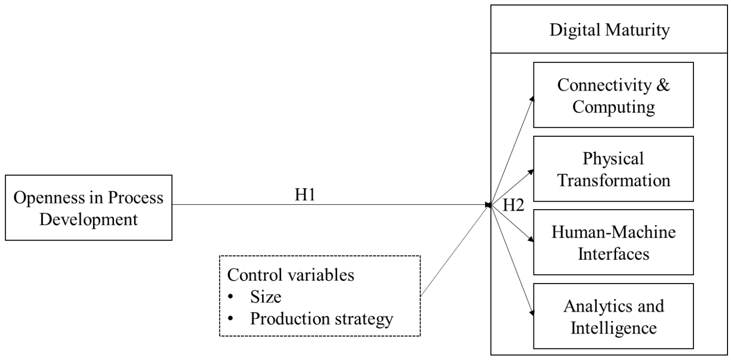

Figure 1 – Research model of this paper

Methodology

The purpose of this study is to test the hypotheses stated above and thereby investigate the effect of openness on the digital maturity. To test these hypotheses we conduct survey research. Surveys are well suited when the theory of the examined phenomenon is rather mature and when hypotheses are to be tested (Forza, 2002; Malhotra and Grover, 1998).

Both concepts, openness and process innovations are explored fields in the research. However, their interaction is not yet sufficiently explained. Using explanatory surveys enables us to find relationships among the two variables.

Data collection and sampling

We conduct and use the second round of the Swiss Manufacturing Survey. This annual study aims at identifying developments and structural changes of the Swiss manufacturing landscape. It should support economy, science and politics to analyse trends. The questionnaire focuses on firms with at least one manufacturing location in Switzerland.

We developed the questionnaire in close cooperation between the ETH Zurich and the University of St. Gallen based on an initial literature review as well as input from industry experts. Peer researchers and senior academics reviewed the draft and further tested it with a purposive sample of manufacturing firms. All feedback shaped the questionnaire in numerous rounds. The survey was distributed to Swiss manufacturing firms between November 2017 and February 2018 via personal emails. Reminders were sent after four weeks. We received 184 usable responses, which were analysed and served as a foundation for this study. All participants are provided with a customized report.

In fact, primarily publications that have a holistic perspective on digital technologies have been considered in order to identify relevant technologies. We selected the following 12 digital technologies and technological concepts: additive manufacturing, augmented reality, Big Data analytics, blockchain, cloud computing, drones, identification solutions (RFID, NFC, etc.), machine learning, machine-to-machine communication, mobile devices on shop-floor level (e.g. tablet, smartphone), robotics, as well as digital twin for processes (Neugebauer *et al.*, 2016; Schwab, 2016; Gartner Inc., 2017; Hänisch, 2017; Hofmann and Ruesch, 2017). These digital technologies serve as the basis for the digital maturity levels. However, the “field of digital transformation is too broad to enable the use of a maturity model in its prescriptive functionality" (Berghaus and Back, 2016, p. 3). In this paper, we apply a descriptive maturity model to explain the coherence of digital technologies and open process innovation. The maturity in terms of these technologies ranges from the perception of "irrelevant" (1) over "under surveillance" (2), "research and development" (3), "prototype implemented" (4), "first applications" (5) to "fully implemented" (6) on a 6-point Likert scale.

Data analysis

We exclude unanswered questions and answers stating "I do not know" from the analysis phase. Thereafter, we derive our main variables we are interested in, namely the independent variable *openness* and dependent variable *digital maturity*. For the independent variable, we consider the three external sources of process innovation of the survey: other companies, universities, and consultants. We calculate the variable of openness by the mathematical mean of the three sources. For the dependent variable digital maturity, we take the answer of the Likert scale from zero to six for each technology. We calculate the overall digital maturity by the mathematical mean of the maturity from the different technologies.

We define two control variables, *size* and *production strategy*. The size is a binary variable. If the company's total amount of employees is above the average of the sample the variable is zero if not it is one. Production strategy is a categorical variable that can take the characteristics make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO), or engineer-to-order (ETO). Table 1 visualizes the list of variables.

Table 1 – Variable definition

Variable	Operational Definition	Type	Value
Process Openness	Mean value of the answers to how intense the company sources knowledge from the sources: other companies, universities and consultancies for process innovation	Independent	1-7
Digital Maturity	Mean value of digital maturity of the regarded technologies	Dependent	1-6
Size	Smaller or larger than the avg. firm size of the sample	Control	1 = small; 0 = large
Production Strategy	Production strategy mainly used by the company	Control	MTS, ATO, MTO, ETO

For a first analysis, we will perform a linear regression to predict the effect of the overall openness on the overall digital maturity. In case we find evidence for it, we will continue analysing clusters of technologies, which have similar effects. We use factor analysis to identify these different clusters. Factor analysis helps to identify underlying dimensions within a larger number of variables. For each of the clusters we calculate the average maturity. The analysis of the eigenvalues suggests to use three factors. Table 2 shows the resulting clusters and the factor loadings of their components. The first cluster consists of robotics, machine-to-machine communication, identification solutions, mobile devices, machine learning, and additive manufacturing. In the second cluster the technologies big data, Blockchain, and cloud computing are put in. The last cluster consist of augmented reality, digital twin of the processes and drones.

Table 2 – Factor analysis of technology clusters

Technology	Factor Loadings		
	Cluster 1	Cluster 2	Cluster 3
Robotics	0.8		
Machine-to-machine Communication	0.6		
Identification and Communication	0.5		
Mobile Devices	0.4		
Machine Learning	0.4		
Additive Manufacturing	0.3		
Big Data Analysis		0.7	
Blockchain		0.6	
Cloud Computing		0.6	
Augmented Reality			0.8
Digital Process Twin			0.3
Drones			0.3

We then use linear regression to predict the effect of the cluster's openness on the digital maturity of the specific cluster of the company. Finally, we develop our model by including the control variables for each of the clusters. All calculations are executed in R.

Findings

The linear regression between the overall average maturity and openness reveals a significant correlation with a p-value lower than 0.05. We find that an increase of openness by one unit relates to an increase of the digital maturity by 0.27. The model can thereby explain 19% of the variation (R-squared = 0.19). Adding the control variable size reduces the effect of openness to 0.2 but increases explained variation to 0.23. Being a small company reduces maturity by 0.33. Finally, for model 3, we include the production strategy as well, which has, however, no significant impact on the overall model.

Table 3 – Results of the linear regression

Variables	Model 1				Model 2	Model 3
	Digital Maturity				Digital Maturity	Digital Maturity
	All	Cluster 1	Cluster 2	Cluster 3	All	All
Constant	1.55***	1.95***	1.32***	1.04***	1.89***	1.96***
Process Openness	0.27***	0.31**	0.24***	0.17**	0.20***	0.22***
Size					-0.33***	-0.30***
Production Strategy						
MTS (default)						
ATO						-0.02
MTO						-0.10
ETO						-0.24
R^2	0.19	0.12	0.08	0.08	0.23	0.25
Adjusted R^2	0.18	0.11	0.07	0.07	0.22	0.22

***p<0.001; **p<0.01; *p<0.05

As the results for the overall average are significant, we continued to investigate model 1 for the different clusters of technologies. Reviewing the clusters, we find a significant correlation between process openness and each cluster's digital maturity. The highest slope is thereby recorded in the first cluster with an increase of 0.31 per one-unit increase in openness and an R-square value of 0.12. Following is the second cluster, in which a one-unit increase of openness results in an increase of the digital maturity of 0.24 (R-square of 0.08). The lowest impact is seen at the third cluster with an increase of 0.17 and R-square value of 0.08. The resulting regressions are illustrated in Figure 2. For every identified cluster (C1, C2, C3) process openness has a different slope and thus a different effect on the digital maturity of the respective cluster.

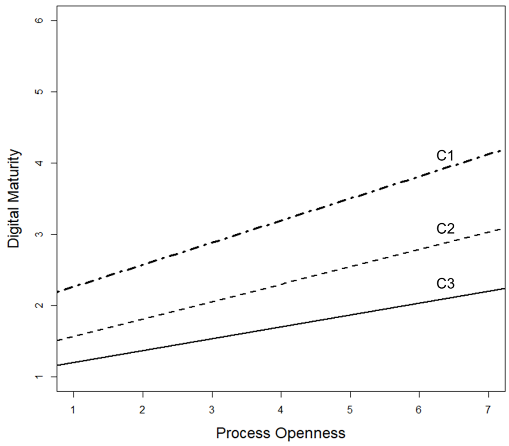

Figure 2 – Effect of openness on the digital maturity

Discussion

The positive relationship between openness and process innovation is in line with the literature. Reichstein and Salter (2006) showed that openness has a positive effect on process innovations of a firm. We find this still holds true for the digital innovations in production. Openness in process development correlates in our study with the digital maturity of a firm. We can therefore support the first hypothesis. This paper adds insights to that effect by further separating the effect of openness on different technological clusters.

The strongest effect of openness was identified in cluster 1, followed by cluster two and three. The clusters found in the analysis above are not identical with the ones suggested by the World Economic Forum (2017), namely connectivity and computing, physical transformation, human-machine interfaces, as well as analytics and intelligence. The first identified cluster relates mostly with the technologies physical transformation (e.g. additive manufacturing) and connectivity and computing (e.g. M2M communication). The second cluster relates well with the analytics and intelligence category of the WEF. The third cluster finally resembles the human-machine interface. Hence, we find clusters with varying potential of openness and can verify hypothesis 2. However, these technology clusters are a mix from the given classification by the WEF. It is therefore useful to regard other digital technology classifications from the literature. Obermaier (2016), for example, derived the classification (1) internet and communication technology, (2) automation and manufacturing technology, (3) human-machine interfaces, (4) embedded systems and analytics, as well as (5) sensors and actuators.

Applying the classification of Obermaier (2016), our technology cluster 1 composes automation and manufacturing technologies. Robotics, M2M, identification technologies, machine learning, or mobile devices directly support the automation of processes and systems. For instance, advanced machine learning abilities allow the automated control and actions of machines. In addition, additive manufacturing is a typical manufacturing technology for physical production of goods. In contrast, our cluster 2 comprises the three technologies (big data, blockchain, cloud computing), which belong to embedded systems and analytics. Technology cluster 3 includes technologies with focus on human-machine interfaces. In particular, augmented reality solutions as well as digital twin are obvious technologies to enhance operations by visualization. In addition, drones can be used on the one hand for transportation operations, but on the other hand as monitoring systems for various activities such as quality control and thus are a kind of human-machine interfaces.

Another explanation for the three clusters is the maturity of the technologies. All technologies in cluster 1 are on a high maturity level, as they are employed either in manufacturing (e.g. robotic, identification technologies) or commercial use (e.g. mobile devices) for several years. Technologies in cluster 2 are less mature compared to cluster 1. Finally, most technologies in cluster 3 are on a development stage. Currently, augmented reality, digital twin and drones are not wider applied in manufacturing processes. Although different projects and isolated use cases have shown the potential benefits of these technologies, it was not possible to roll them out on a larger scale.

The effect of the control variables is further of interest. In our sample we find a negative effect of being a small company on the digital maturity. One explanation for this might be that this cluster requires higher investments and thus it is generally more difficult for smaller companies to reach a higher state. A second explanation ca be that smaller companies already bought some equipment in this area and are not further investing to reach a higher level. Larger organizations, however, could have the budget to further reinvest and stay on the frontline of technology. This, however, needs to be further explored in consecutive studies. The production strategy is further not found significant on the effect of openness.

Conclusion

Opening up to outside knowledge sources in order to improve a firm's product development is a known and established practice. In contrast, using openness for innovating processes has received very little research (Bogers et al., 2017). This research fills this gap by providing a better understanding of how open process innovation relates to digitalization of manufacturing. We find that a higher openness in process innovation is related with a higher degree of digital maturity. We further identify clusters of various extent of the effect.

For practitioners, the results of the study encourage an active engagement with outside knowledge sources to improve their own manufacturing processes. Closing down the curtains and relying solely on the own competencies can hurt long-term competitiveness in the age of digitalization.

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