# WHAT DRIVES INDUSTRY 4.0 ADOPTION? AN EXAMINATION OF TECHNOLOGICAL, ORGANIZATIONAL, AND ENVIRONMENTAL DETERMINANTS

CHRISTIAN ARNOLD
Friedrich-Alexander University Erlangen-Nürnberg (FAU), Chair of Industrial Management,
Lange Gasse 20, 90403 Nürnberg, Germany
christian.arnold@fau.de (Corresponding)

JOHANNES W. VEILE
Friedrich-Alexander University Erlangen-Nürnberg (FAU), Chair of Industrial Management,
Lange Gasse 20, 90403 Nürnberg, Germany
johannes.veile@fau.de

KAI-INGO VOIGT
Friedrich-Alexander University Erlangen-Nürnberg (FAU), Chair of Industrial Management,
Lange Gasse 20, 90403 Nürnberg, Germany
kai-ingo.voigt@fau.de

## ABSTRACT

Industry 4.0 refers to a novel production approach characterized by an entirely digitized and connected industrial value creation (Kagermann et al. 2013). This is associated with several benefits, e.g., increased resource efficiency, higher degrees of customization, and novel business models (Bauernhansl 2014; Kagermann et al. 2013; Rehage et al. 2013). Nevertheless, manufacturing companies show differences regarding adoption intensity and extent (Schmidt et al. 2015). Hence, it is the purpose of this paper to examine, which factors determine the adoption of Industry 4.0 in German manufacturing companies.

This study relates to technology adoption literature. Previous studies in this field revealed significant differences between different companies regarding the adoption of new technologies (Schmidt et al. 2015). In this context, renowned literature identified various factors that determine the adoption of different technologies by manufacturing companies. Since to date, there are no academic studies that examined relevant factors determining the adoption of Industry 4.0 as a comprehensive concept, this represents a clear research gap.

To address this gap, the technology-organization-environment framework of DePietro et al. (1990), which has been successfully employed in several previous IT adoption studies, is applied. In total, the applied model contains nine constructs. A quantitative study was carried out among German manufacturing companies using a survey questionnaire as an instrument for gathering data. The final sample consists of 197 usable responses. The developed hypotheses were tested using a logistic regression.

This study reveals valuable insights with regard to relevant adoption factors in the context of Industry 4.0. In particular, the results show that relative advantage associated with Industry 4.0, support by a company's top management, and high levels of competition positively influence Industry 4.0 adoption, while environmental uncertainty is the only determinant that negatively affects Industry 4.0 adoption. The study further reveals no significant influence of perceived challenges, firm size, absorptive capacity, and perceived outside support. In doing so, this study provides the first analysis of factors that determine the adoption of Industry 4.0. Further research is still recommended as only German manufacturers were analyzed and there was no differentiation between small and large companies. Additionally, there are still various other potentially influencing factors, which are not addressed by this study.

The results show important managerial implications for companies at the threshold of implementing Industry 4.0 in their company. By revealing relevant factors that influence the adoption of Industry 4.0, this paper provides managers with valuable insights regarding important aspects to look at. This study is among the first to analyze relevant adoption determinants especially for Industry 4.0. In this course, several factors stemming from three perspectives, i.e., technology, organization, and environment, are examined in one study. The results give a first indication about relevant determinants influencing Industry 4.0 adoption behavior of manufacturing companies.

**Key words:** Industry 4.0; Industrial Internet of Things; German manufacturing companies; Technology adoption; Quantitative research

## INTRODUCTION

Industry 4.0 represents a novel paradigm of industrial value creation that aims at addressing the arising challenges that manufacturing enterprises have to deal with. Among others, those companies have to face shortened technology and innovation cycles, the necessity of bringing highly customized products in accordance with the cost of a large-scale production, and intensified competition originating in Asia, in particular (Bauer *et al.*, 2014; Bauernhansl, 2014; Dais, 2014). At its core, Industry 4.0 enables the real-time capable, intelligent, horizontal, and vertical connection of people, machines, and objects by employing cyber-physical systems and the internet (Bauer *et al.*, 2014). The equipment of machines and products with embedded systems like actuators, sensors, and microcomputers provides them with intelligence, resulting in a so-called smart factory. This autonomous factory enables a flexible and efficient execution of production and results in increased resource efficiency (Rehage *et al.*, 2013), higher degrees of customization (Kagermann *et al.*, 2013), highly profitable business models (Bauernhansl, 2014), and job designs suitable for future employee requirements (Hirsch-Kreinsen and Weyer, 2014; Spath *et al.*, 2013).

Although Industry 4.0 is associated with the aforementioned benefits, several studies have revealed differences regarding adoption intensity and the extent to which it is adopted (McKinsey, 2015; Schmidt *et al.*, 2015). Considering previous research in the field of technology management, similar observations are conspicuous for various technologies, since companies' technology adoption depends on several determinants. For instance, Chang *et al.* (2008) reveal factors that influence the adoption of enterprise resource planning (ERP) systems, Peltier *et al.* (2012) examine, which factors determine the decision of small businesses to implement technologies, and Sila (2013) analyzes the implementation factors of e-commerce technologies. With reference to Industry 4.0, Arnold *et al.* (2015) examine adoption factors of embedded systems, Reyes *et al.* (2016) study radio-frequency identification (RFID) adoption, and Oettmeier and Hofmann (2017) ascertain determinants of additive manufacturing technology adoption. Nevertheless, to date, there are no academic studies on the relevant factors that determine the adoption of Industry 4.0 as a comprehensive concept.

Hence, the present paper aims to address this research gap by pursuing the following research question: Which factors determine the adoption of Industry 4.0 in manufacturing companies? To answer this question, we applied the technology-organization-environment (TOE) framework of DePietro *et al.* (1990) and conducted a quantitative research design based on a sample of 197 German manufacturing companies.

By doing so, we identified four significant Industry 4.0 adoption determinants from all three dimensions of our framework, i.e., factors referring to Industry 4.0 itself, the respective organization, and the organization's environment. To be more precise, the significant factors are: relative advantage, top management support, competition, and environmental uncertainty.

The remainder of the paper is structured as follows: In the next section, we propose the chosen research framework and our hypotheses. Afterwards, the employed methodology is described before the results are presented. Then, the findings are discussed, and finally, the conclusion contains limitations, perspectives for future research, and managerial implications.

## RESEARCH FRAMEWORK AND HYPOTHESES

### Technology-organization-environment framework

The research framework applied for our study, i.e., the TOE framework, considers three dimensions that impact technology adoption simultaneously. Firstly, the framework includes characteristics specific to the technology under examination. Secondly, it incorporates aspects concerning the adopting organization. Thirdly and lastly, it takes the organization's external environment into account. The TOE is among the most frequently employed frameworks in the context of technology adoption research (Baker, 2012; Sila, 2013). It has been successfully employed in several IT adoption studies, including RFID adoption (Wei *et al.*, 2015), e-business adoption (Zhu and Kraemer, 2005; Zhu *et al.*, 2003), e-commerce adoption (Rodríguez-Ardura and Meseguer-Artola, 2010), electronic data interchange (Iacovou *et al.*, 1995; Kuan and Chau, 2001), and information systems (IS) (Thong, 1999).

In addition to the strong empirical support of the TOE framework, it allows for the integration of other popular adoption theories like Rogers' (1995) innovation diffusion theory or the technology acceptance model of Davis *et al.* (1989) (Baker, 2012; Oettmeier and Hofmann, 2017; Wei *et al.*, 2015; Zhu *et al.*, 2003). Furthermore, the TOE framework is rather generic and allows for the utilization of various factors, thereby making it highly adaptable to different research contexts. This is a valuable advantage over other models since unified theories consider specific technology characteristics only in an insufficient manner (Baker, 2012; Vilaseca-Requena *et al.*, 2007). For these reasons, we apply the TOE framework in our study to examine our object of investigation.

### Predicting factors related to the technological context

In this section, we introduce Industry 4.0 adoption determinants referring to the technological perspective of the TOE framework. They include relative advantage, perceived challenges, and compatibility. In the following, the reasons for including these three factors are discussed.

*Relative advantage*

A variety of studies have used relative advantage to explain technology adoption. Relative advantage is "the degree to which an innovation is perceived as being better than the idea it supersedes" (Rogers, 1995, p. 212). Vowles *et al.* (2011) examine the determinants of voice over internet protocol (VoIP) adoption in Australian companies and found relative advantage to be a significant predictor. Jurison (2000) conducted a longitudinal study on adoption of office IS. According to his results, the perceived relative advantage is positively associated with a rapid adoption and diffusion. Although many scholars found relative advantage to be significantly positive related to technology adoption, some authors could not find a significant correlation. Wei *et al.* (2015), for instance, studied the adoption of RFID technology by Chinese companies and found relative advantage to be positively but not significantly related to RFID implementation. Nevertheless, in a literature review of 51 studies on organizational IT adoption, Jeyaraj *et al.* (2006) revealed that relative advantage is among both the most frequently used predictors and the best predictors in terms of significance. We argue that relative advantage is also a motivating factor for Industry 4.0 adoption as companies only implement new technologies if benefits exceed potential negative effects. In this context, Industry 4.0 is, among others, associated with increased resource efficiency, flexibility, and customization (Kagermann *et al.*, 2013). Therefore, we propose the following hypothesis:

H1. Relative advantage is positively related to Industry 4.0 adoption.

*Perceived challenges*

In addition to potential benefits for implementing companies, Industry 4.0 comes with several challenges that deter companies from implementing this new value creation paradigm (Erol *et al.*, 2016). In particular, manufacturing companies have to adequately qualify employees, ensure IT security, adjust their business models, adapt internal and external communication, and deal with an unsure legal framework and missing standards (Bradley *et al.*, 2014; Chen, 2012; Kagermann *et al.*, 2013). Consequently, we argue that perceived challenges associated with Industry 4.0 have the potential to prevent manufacturers from adoption and are therefore of particular importance. Thus, we add perceived challenges to our research framework and propose the following hypothesis:

H2. Perceived challenges are negatively related to Industry 4.0 adoption.

*Compatibility*

Compatibility is defined as “the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters” (Rogers, 1995, p. 224). Implementing IS, to which Industry 4.0’s underlying systems can be assigned, might easily fail, if they are not compatible with the company’s culture (Yusuf *et al.*, 2004). Compatibility is accordingly included in various technology adoption studies. Chang *et al.* (2008) examined the adoption of ERP systems by analyzing the usage behavior. They found compatibility to have a significant positive effect and explain this by the fact that people within an organization are more likely to use a new technology, if it fits to the organization. Waarts *et al.* (2002) also studied relevant factors determining the adoption of ERP systems. They likewise revealed a high significance of the compatibility of the new ERP system with already existing systems and equipment. We argue that this positive relationship between a technology’s compatibility and its adoption also holds true for Industry 4.0. Companies may be more likely to implement this new value creation approach and its underlying systems and processes if they fit the existing processes. Therefore, we propose the following hypothesis:

H3. Compatibility is positively related to Industry 4.0 adoption.

**Predicting factors related to the organizational context**

In addition to technology-related factors, the TOE framework considers adoption determinants that originate in the adopting organization itself. Therefore, we include three factors related to the organizational perspective, i.e., firm size, top management support, and absorptive capacity.

*Firm size*

The size of a company has been proven to influence the adoption of new technologies in various studies. This is evidenced by Jeyaraj *et al.*'s (2006) review of relevant technology adoption studies. They learned that an organization's size is among the most often utilized IT adoption factors and represents a significant predictor in most cases. Gomez and Vargas (2009), who analyzed the adoption of multiple process technologies by Spanish manufacturers, found firm size to have a significantly positive impact on the decision to adopt new technologies. They argue that large companies have more resources available, resulting in a higher ability to both finance an investment and absorb losses associated with risky investments. Similarly, Ko *et al.* (2008) and Patterson *et al.* (2003) follow the line of reasoning that larger organizations do not only have more financial resources than smaller companies, but that they also have a higher risk capacity, which is required for investments in new, risky technologies. Since the implementation of Industry 4.0 is associated with novel intelligent and connected facilities as well as the adaptation of processes, large investments in IT and machines are required. Consequently, we propose the following hypothesis:

H4. Firm size is positively related to Industry 4.0 adoption.

*Top management support*

In his examination of factors affecting the adoption of B2B e-commerce technologies, Sila (2013) included the independent variable top management support since a positive commitment toward a new technology is critical for a successful implementation. This is particularly true for interorganizational systems (Grover, 1993), including Industry 4.0. Reyes *et al.* (2016) are in line with Sila (2013) arguing that the adoption of RFID requires large investments. This in turn requires involvement and support of top management as a prerequisite for a successful implementation. Vowles *et al.* (2011) analyzed VoIP adoption and found a significant positive influence of a so-called champion, who uses his/her power to support an innovation. Jeyaraj *et al.* (2006) also reveal that top management support is among the best IT adoption predictors in terms of significance. In our opinion, since the implementation of Industry 4.0 is accompanied by extensive organizational consequences and substantial investments (Kagermann *et al.* 2013), support of top management is an important factor for successful Industry 4.0 adoption. Therefore, we propose the following hypothesis:

H5. Support of top management is positively related to Industry 4.0 adoption.

*Absorptive capacity*

The absorptive capacity of a company is defined as its "ability to recognize the value of new information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990, p. 128). Cohen and Levinthal (1990) emphasize the particular importance of absorptive capacity for successful innovation implementation in an environment characterized by uncertainty. Since Industry 4.0 represents a new paradigm of value creation for manufacturing companies with substantial uncertainty, absorptive capacity is a critical success factor in the context of Industry 4.0 adoption. Previous studies examined absorptive capacity as a predicting factor for technology adoption. Wei *et al.* (2015) revealed a significant positive relationship between a company's absorptive capacity and RFID adoption in China. According to them, prior experiences of related technologies foster the early recognition of the value of new technologies. Vowles *et al.* (2011), who analyzed VoIP adoption, found that the capability to absorb information about innovations is significantly positively related to the VoIP adoption. Arvanitis and Hollenstein (2001) showed that absorptive capacity is a significant determinant for the application of advanced manufacturing technologies. As Industry 4.0 can be regarded as a combination of several advanced manufacturing technologies, we propose the following hypothesis:

H6. Absorptive capacity is positively related to Industry 4.0 adoption.

**Predicting factors related to the environmental context**

Lastly, the TOE framework comprises determinants related to an organization's environment. Consequently, we included three respective factors in our research framework, i.e. competition, environmental uncertainty, and perceived outside support.

*Competition*

With regard to IT adoption determinants involving the environment, competition is one of the best predicting factors (Jeyaraj *et al.*, 2006). In most studies, a positive relationship between competition and technology adoption has been revealed. Zhu *et al.* (2003) argue that the adoption and implementation of new technologies allows companies to change the rules of competition and outperform rivals. Therefore, high levels of competition lead to an increased adoption of new technologies. According to Gatignon and Robertson (1989), strong competition motivates companies to watch narrowly competitive moves of rivals. Consequently, innovations are quickly adopted to avoid falling behind. Vilaseca-Requena *et al.* (2007) analyzed the adoption of e-commerce in Spain and reason that there is a positive influence of a more complex competitive environment because of the perceived pressure to change the rules of competition. Thus, companies increasingly deploy e-business to gain advantage over competitors. On the contrary, Rodríguez-Ardura and Meseguer-Artola (2010) revealed a significant negative correlation between the pressure from a company's competitive environment and the adoption of e-commerce technologies. They explain this result by the fact that companies operating in a business environment characterized by low competition can allocate more resources for the development of innovations like e-commerce. Despite this opposing finding, we follow the majority and argue that competition leads to Industry 4.0 adoption. This is reasonable because manufacturing companies currently have to face increased competition and Industry 4.0 is regarded as a possible response to this challenge (Bauer *et al.*, 2014). Consequently, we propose the following hypothesis:

H7. Competition is positively related to Industry 4.0 adoption.

*Environmental uncertainty*

Environmental uncertainty is characterized by "fluctuating prices, unpredictable competitor actions, unreliability of inbound supplies, rapid change in production processes, rapid change in customer preferences, volatile levels of demand, and/or quick product obsolescence" (Dröge and Germain, 1998, p. 28). Wei *et al.* (2015) find a significant negative relationship between environmental uncertainty and the adoption of RFID technology. With regard to their results, they point out that a positive relationship would be expected, based on previous studies. The deviation of their results can be explained by the fact that they examined Chinese companies, which are more risk averse than Western companies and tend to avoid high investments. Contrary to that and in accordance with the prevailing view, Patterson *et al.* (2003) argue that companies facing high environmental uncertainty have a greater motivation to adopt advanced, value chain spanning information technologies that foster a fast and reliable share of data and production schedules. As a result, these companies improve the exchange of information and data and are able to manage uncertainty between organizations. Although they focus on supply chain technologies, their line of reasoning applies to Industry 4.0 as well since the interconnection of entire supply chains is an inherent part of Industry 4.0 (Obermaier, 2016). Therefore, we propose the following hypothesis:

H8. Environmental uncertainty is positively related to Industry 4.0 adoption.

*Perceived outside support*

With perceived outside support, we understand it to include every activity conducted by organizations external to the company that helps it to decide whether or not to adopt Industry 4.0. Previous studies have showed the relevance of perceived outside support for innovation and technology adoption. Cragg and King (1993), for instance, analyzed motivators for implementing IS in small firms and came to the conclusion that expert consultations have a strong influence. Yap *et al.* (1992) similarly showed that external expertise in terms of consultations and vendor support has a significantly positive effect on the successful implementation of IS in small businesses. Waarts and van Everdingen (2005) and Waarts *et al.* (2002) examined the adoption of ERP systems. In both studies, supplier activities proved to be a significant adoption predictor. Likewise, Vowles *et al.* (2011) argue that suppliers can influence VoIP adoption by offering information, education, and trials. According to Oettmeier and Hofmann (2017), such outside support facilitates a company's efforts to reduce uncertainties about a new technology and therefore to better assess its potential. As Industry 4.0 is still subject to uncertainty at this juncture, we argue that this rationale is also suitable for Industry 4.0. Thus, we propose the following hypothesis:

H9. Perceived outside support is positively related to Industry 4.0 adoption.

**Dependent variable**

The dependent variable of our model is Industry 4.0 adoption. Adoption is part of the innovation-decision process, which consists of five steps: (1) obtaining knowledge about an innovation or technology, (2) building an attitude toward the technology, (3) deciding whether to adopt the technology or not, (4) implementing the technology in the company, and (5) confirming the technology during future use (Rogers, 1995). In relation to adoption, diffusion has to be differentiated. While technology adoption refers to the decision and initial implementation, technology diffusion concerns the subsequent spread of a technology within an organization (Hall and Khan, 2003). Hence, Industry 4.0 adoption refers to the first implementation of this novel production approach into a company, but does not require the entire production to be changed subsequently.

The following Figure 1 shows our research framework consisting of the three dimensions of technology, organization, and environment. Additionally, the illustrated framework includes the positive/negative relationship between each determinant and the adoption of Industry 4.0, as proposed above.

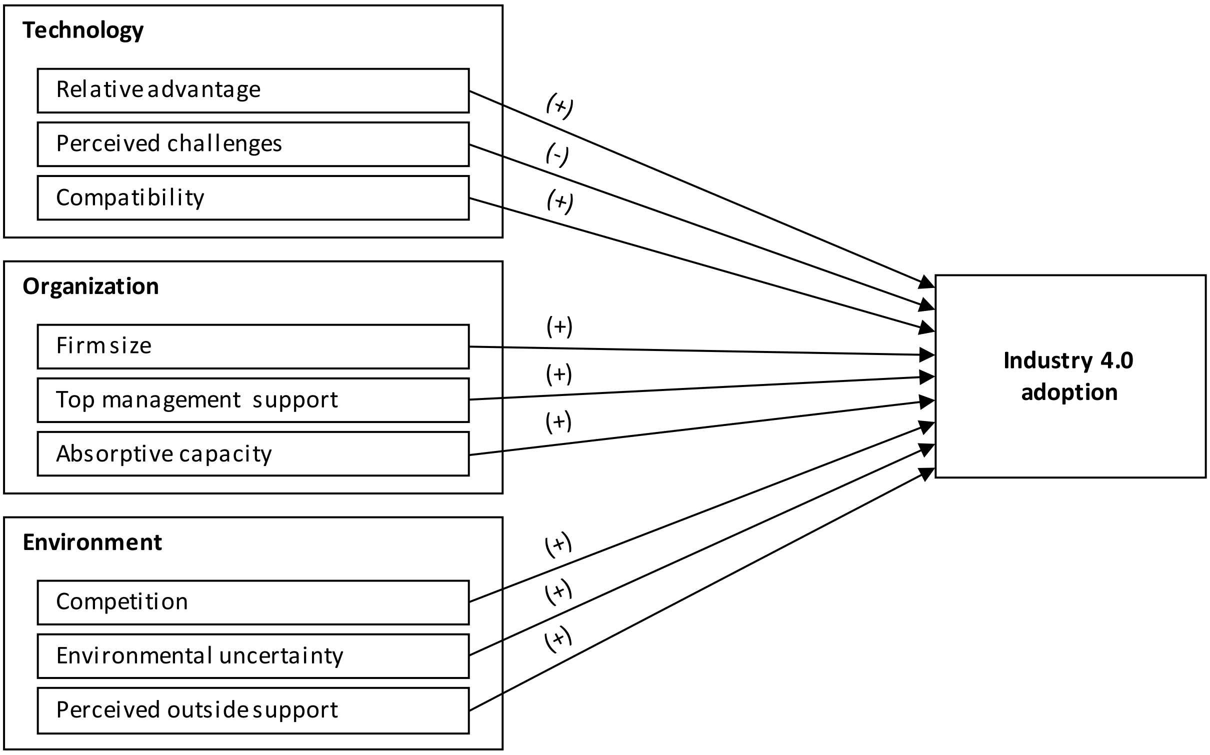


*Figure 1: Research Framework*

## METHODOLOGY

A cross-sectional field survey was conducted to collect data about Industry 4.0 adoption among German manufacturing companies. The German market was chosen for several reasons. Firstly, the term 'Industry 4.0' originally appeared in Germany. Secondly, the German manufacturing industry is a global leader and has always been a pioneer in terms of implementing innovative technologies (Breznitz, 2014). Lastly, the manufacturing sector is the most important one for the German economy in terms of employees and contribution to the GDP (Federal Bureau of Statistics, 2016), which justifies examining this industry in particular.

Data were gathered by means of an electronic survey based on 'Unipark', an academic online survey software. Therefore, a list of German manufacturing companies was obtained from the bisnode database that comprises German companies of all industries and sizes. Manufacturing companies were identified and subsequently contacted via e-mail and telephone from January until March 2017. The applied questionnaire consists of closed-ended questions. Section A contains demographics about the respective company, followed by a dichotomous question about the dependent variable, i.e., whether the company has already adopted Industry 4.0 or not. Non-adopters were additionally asked if an adoption is planned in the medium term. Section B comprises questions regarding the items that measured the eight factors hypothesized in order to determine Industry 4.0 adoption in areas other than firm size. They all consist of a Likert-Scale reaching from 1 (strongly disagree) to 5 (strongly agree). Section C emphasizes personal data about the respondent. The items applied to measure the constructs were borrowed from prior technology adoption studies and were modified to fit our purpose where appropriate. This procedure increases content validity (Ramsey *et al.*, 2008). Table 1 shows the constructs, related items, if they are directly adopted or modified, and their sources.

*Table 1: Constructs and items of this study*

| Constructs | Items | Origin | Source |
|---|---|---|---|
| Relative advantage | (1) Industry 4.0 adoption is associated with cost reduction. | Modified | Chau and Tam, 2000 |
| | (2) Industry 4.0 adoption is associated with increased resource efficiency. | Modified | |
| | (3) Industry 4.0 adoption is associated with increased production flexibility. | Modified | |
| | (4) Industry 4.0 adoption is associated with job design oriented toward employee needs. | Modified | |
| | (5) Industry 4.0 adoption is associated with the offering of customized solutions. | Modified | |
| Compatibility | (1) Industry 4.0 fits our company well. | Adopted | Oettmeier and Hofmann, 2017 |
| | (2) The implementation of Industry 4.0 technologies would require few firm-specific adaptations. | Adopted | |
| | (3) The physical integration of Industry 4.0 technologies into our company would be unproblematic. | Adopted | |
| | (4) We could integrate the software necessary for Industry 4.0 with little effort into our existing IT landscape. | Adopted | |
| Perceived challenges | (1) Industry 4.0 adoption is associated with adequate employee qualification. | Modified | Chau and Tam, 2000 |
| | (2) Industry 4.0 adoption is associated with unsure legal circumstances. | Modified | |
| | (3) Industry 4.0 adoption is associated with Industry 4.0-specific business model adaptations. | Modified | |
| | (4) Industry 4.0 adoption is associated with necessary guaranteeing of IT security. | Modified | |
| | (5) Industry 4.0 adoption is associated with internal communication and coordination among departments and locations. | Modified | |
| | (6) Industry 4.0 adoption is associated with supply chain spanning communication with external organizations. | Modified | |
| | (7) Industry 4.0 adoption is associated with establishment of standards. | Modified | |
| Top management support | (1) Our top management is likely to invest funds in Industry 4.0. | Adopted | Sila, 2013 |
| | (2) Our top management is willing to take risks involved in the adoption of Industry 4.0. | Adopted | |
| | (3) Our top management is likely to be interested in adopting Industry 4.0 in order to gain competitive advantage. | Adopted | |
| | (4) Our top management is likely to consider the adoption of Industry 4.0 as strategically important. | Adopted | |

*Table 1: Continued*

| Constructs | Items | Origin | Source |
|---|---|---|---|
| Absorptive capacity | (1) Searching for relevant information regarding our industry is part of employees' daily tasks.<br>(2) Corporate management motivates employees to employ information sources internal to our industry.<br>(3) Corporate management expects employees to deal with information external to our industry. | Adopted<br>Adopted<br>Adopted | Flatten *et al.*, 2011 |
| Competition | (1) Competition in our sector is "cut throat".<br>(2) Our customers tend to look for new services all the time.<br>(3) In our kind of business, customers' preferences for services and products change quite a bit over time.<br>(4) An industry move to utilize Industry 4.0 would put pressure on my firm to do the same. | Modified<br>Adopted<br>Modified<br>Modified | Ramsey *et al.*, 2008 |
| Environmental uncertainty | (1) The evolution of Industry 4.0 is unpredictable.<br>(2) The net payoffs of using Industry 4.0 remain uncertain. | Adopted<br>Adopted | Wei *et al.*, 2015 |
| Perceived outside support | (1) There is a sufficient number of experts that could help us to implement Industry 4.0.<br>(2) We could get outside support to help us troubleshooting with little effort. | Adopted<br>Adopted | Mole *et al.*, 2004 |

Ten companies participated in a pilot test of the survey to assure comprehensibility and content validity (Cooper and Schindler, 1998). Feedback resulted in slight adjustments of the phrasing of a few questions. The final survey link was sent to 2,750 German manufacturing companies. As a result, we received 362 questionnaires, representing a response rate of 13.2%. After a data-cleaning procedure, which eliminated incomplete values, a total of 197 usable questionnaires were left, constituting a final 7.2% response rate.

Since non-response is a potential source of bias that has to be addressed (Fowler, 1993), we compared data between early and late respondents. For this test, we employed size in terms of revenues and ten randomly selected items. The results of the Mann-Whitney test shows no significant difference between early and late respondents, indicating the absence of non-response bias (Ramsey *et al.*, 2008).

**RESULTS**

Results indicate that most respondents are at least at a senior manager level (60.4%) and are well educated, as 70.1% graduated from university and 9.1% even hold a PhD. Further, most companies operate in the machine engineering sector (26.4%), reflecting its strong position in the German economy. Regarding Industry 4.0 adoption, 48 companies (24.4%) had already adopted this new manufacturing paradigm, while the remaining 149 companies have not yet adopted it. Among non-adopters, more than half of them (n = 82) intend to adopt Industry 4.0 in the medium term. Table 2 summarizes demographics of the sample.

*Table 2: Demographics of respondents (n = 197)*

| Variables | Frequency | Variables | Frequency |
|---|---|---|---|
| Industry 4.0 Adoption | | Gender | |
| Adopted | 24.4% | Male | 86.3% |
| Not adopted | 75.6% | Female | 7.6% |
| Revenues (in million EUR) | | Year of birth | |
| 0-10 | 30.5% | 1940s | 0.5% |
| 10-50 | 30.5% | 1950s | 14.5% |
| 50-100 | 10.7% | 1960s | 35.2% |
| 100-250 | 6.6% | 1970s | 22.2% |
| 250-500 | 4.6% | 1980s | 16.1% |
| 500-1,000 | 1.0% | 1990s | 2.0% |
| 1,000-5,000 | 4.1% | Educational level | |
| 5,000-10,000 | 0.5% | Apprenticeship | 12.7% |
| 10,000-50,000 | 4.6% | University degree | 70.1% |
| >50,000 | 4.1% | PhD degree | 9.1% |
| Industry sector | | Length of service with company | |
| Machine engineering | 26.4% | 1-10 years | 49.7% |
| Plant engineering | 7.6% | 11-20 years | 19.2% |
| Automotive | 8.6% | 21-30 years | 17.1% |
| Electrical equipment | 11.2% | 31-40 years | 5.0% |
| Metal products | 14.7% | Job position | |
| Electronics | 10.7% | Executive board | 13.7% |
| Rubber & plastics | 5.1% | Top management | 21.8% |
| Chemical products | 5.1% | Senior management | 24.9% |
| | | Middle management | 17.7% |
| | | Employees with managerial responsibility | 7.6% |
| | | Employees without managerial responsibility | 11.2% |

In order to test our model, three steps were conducted. Firstly, the validity of the applied constructs was assessed by applying a factor analysis. Secondly, Cronbach's alpha was calculated for each construct to evaluate the reliability of each construct included in our research framework. Lastly, a logistic regression was conducted to assess the impact of the independent factors on Industry 4.0 adoption.

A confirmatory factor analysis was conducted with SPSS 24. An initial run resulted in all items loading on their intended factors. The only exception was compatibility, in which items did not load as expected. Consequently, these items were dropped. As shown in Table 3, all items in the final analysis loaded perfectly on predicted factors with values higher than 0.5 as suggested in the literature (Hatcher, 1994). In order to assess construct reliability, Cronbach's alpha was calculated. As shown in Table 3, all constructs meet the required cut-off value of 0.7 (Nunnally, 1978). The only exception is competition with a value of 0.66, which is also acceptable in explorative studies (Nunnally, 1978).

*Table 3: Rotated component matrix*

| | **Relative advantage (RA)** | **Perceived challenges (PC)** | **Top management support (TMS)** | **Absorptive capacity (AC)** | **Competition (COM)** | **Environmental uncertainty (EU)** | **Perceived outside support (POS)** |
|---|---|---|---|---|---|---|---|
| Cron-bach's α | 0.86 | 0.80 | 0.92 | 0.81 | 0.66 | 0.74 | 0.79 |
| RA1 | 0.762 | | | | | | |
| RA2 | 0.756 | | | | | | |
| RA3 | 0.722 | | | | | | |
| RA4 | 0.708 | | | | | | |
| RA5 | 0.701 | | | | | | |
| PC1 | | 0.789 | | | | | |
| PC2 | | 0.716 | | | | | |
| PC3 | | 0.698 | | | | | |
| PC4 | | 0.685 | | | | | |
| PC5 | | 0.646 | | | | | |
| PC6 | | 0.548 | | | | | |
| PC7 | | 0.536 | | | | | |
| TMS1 | | | 0.803 | | | | |
| TMS2 | | | 0.799 | | | | |
| TMS3 | | | 0.797 | | | | |
| TMS4 | | | 0.769 | | | | |
| AC1 | | | | 0.807 | | | |
| AC2 | | | | 0.802 | | | |
| AC3 | | | | 0.801 | | | |
| COM1 | | | | | 0.734 | | |
| COM2 | | | | | 0.663 | | |
| COM3 | | | | | 0.661 | | |
| COM4 | | | | | 0.512 | | |
| EU1 | | | | | | 0.795 | |
| EU2 | | | | | | 0.696 | |
| POS1 | | | | | | | 0.883 |
| POS2 | | | | | | | 0.851 |

For the last step of data analysis, a logistic regression was conducted. We preferred a logistic regression over a discriminant analysis, because the dependent variable is dichotomous, fewer assumptions are required, and logistic regressions are more robust than discriminant analyses (Dattalo, 1995). The chi-square test was significant (Omnibus $\chi^2$ = 54.264, df = 8, p = 0.000) and Nagelkerke R2 (= 0.467) proved satisfactory. Furthermore, the Hosmer and Lemeshow test showed a satisfactory goodness-of-fit ($\chi^2$ = 6.189, df = 8, p = 0.626), indicating no significant difference of the proposed model compared to a perfect one (Chau and Tam, 1997).

Regarding hypothesized adoption factors, the results are displayed in Table 4 and show four significant determinants. Relative advantage, top management support, and competition each have a significant positive effect on Industry 4.0 adoption, which are all in line with our expectations. Hence, hypotheses 1, 5, and 7 are supported. Environmental uncertainty also has a significant effect, which is negative and therefore opposite our proposed positive correlation. Thus, hypothesis 8 cannot be supported. No significance can be revealed for perceived challenges, firm size, absorptive capacity, and perceived outside support. Consequently, hypotheses 2, 4, 6, and 9 have to be rejected. Additionally, we controlled for industry sector. As we did not find a significant correlation between any industry sector and Industry 4.0 adoption, we can assume that industry affiliation does not play a role regarding the adoption of Industry 4.0.

*Table 4: Results of logistic regression*

| Variables | B | Exp(B) | S.E. | Wald | Sig. | Hypothesis |
|---|---|---|---|---|---|---|
| Relative advantage | 1.535 | 4.641 | 0.378 | 16.495 | 0.000 | supported |
| Perceived challenges | -0.118 | 0.889 | 0.295 | 0.159 | 0.690 | rejected |
| Firm size | 0.109 | 1.116 | 0.095 | 1.338 | 0.247 | rejected |
| Top management support | 0.656 | 1.927 | 0.291 | 5.068 | 0.024 | supported |
| Absorptive capacity | 0.482 | 1.620 | 0.307 | 2.463 | 0.117 | rejected |
| Competition | 0.772 | 2.164 | 0.322 | 5.737 | 0.017 | supported |
| Environmental uncertainty | -0.816 | 0.442 | 0.275 | 8.808 | 0.003 | opposite the prediction |
| Perceived outside support | 0.187 | 1.205 | 0.270 | 0.479 | 0.489 | rejected |

**DISCUSSION**

In the following section, the results are discussed in detail. Regarding technology-related factors, our study shows that relative advantage of Industry 4.0 has a highly significant positive effect on the adoption decision. Moreover, this factor represents the most influential determinant. This indicates that benefits associated with Industry 4.0 play the most important role when deciding whether or not to adopt this new production approach. The significance of this construct is consistent with our expectation and confirms the findings of previous studies that examined the effect of a technology's benefits on technology adoption (Jurison, 2000; Vowles *et al.*, 2011; Waarts *et al.*, 2002).

The second technology-related factor, perceived challenges, has no significant influence on the adoption of Industry 4.0. This contradicts our expectation but reflects the fact that we did not find any technology adoption study identifying challenges to have an impact on the adoption decision. This indicates that companies tend to have faith in Industry 4.0's benefits rather than being deterred by potential challenges. One explanation might be the fact that German manufacturers have always been pioneers in implementing innovative technologies (Breznitz, 2014). Consequently, they are used to facing associated challenges and and have learned to overcome them.

With reference to the organizational perspective, firm size is not a significant predictor of Industry 4.0 adoption. This is surprising, as in previous technology adoption studies, size usually proved to be a significant determinant (Gomez and Vargas, 2009; Ko *et al.*, 2008; Mole *et al.*, 2004). An explanation for this deviation might be rooted in our sample. As shown in Table 2, the majority of the respondents are rather small companies and only very few can be characterized as large. Although this reflects the distribution among German manufacturers, which are typically small and medium-sized enterprises (Federal Bureau of Statistics, 2016), the comparably small portion of large companies in the sample could lead to the result that size has no significant influence on Industry 4.0 adoption.

The second significant organizational adoption determinant is top management support. Although this factor has the weakest positive influence, the results emphasize that involvement and active support of a company's executives is of particular importance regarding Industry 4.0 adoption. This finding is in accordance with our expectation and previous findings. Vowles *et al.* (2011) identified influential persons within a company, like top managers, who make use of their power to push technology implementation. Similarly, Reyes *et al.* (2016) came to the same conclusion. According to them, support of top management ensures that required financial resources are appropriately allocated to successful implementation of new technologies in a company.

Absorptive capacity did not have a significant influence on Industry 4.0 adoption. This contradicts both our proposed hypothesis and prior studies (Ramsey *et al.*, 2008; Wei *et al.*, 2015). Nevertheless, Vowles *et al.* (2011) found at least partial insignificance on condition that the dependent variable was differentiated between respondents, which implemented VoIP and respondents who had never heard of VoIP. Since this is the only study we found, which finds no significant correlation, our results are a little bit surprising as we assume that all respondents who filled out the questionnaire have heard about Industry 4.0. A reason for this might be the fact that, due to their pioneering position, German manufacturing companies apply comprehensive technology scouting, independently from being an Industry 4.0 adopter or non-adopter (Kiel *et al.*, 2015). Hence, our sample companies might all possess a comparably high absorptive capacity, which therefore cannot act as a differentiator between adopters and non-adopters.

Regarding the third dimension of our research model, i.e., environment, the companies' competition has a significant positive impact on Industry 4.0 adoption, supporting our proposed hypothesis. This finding is in line with most previous technology adoption studies, which argue that competitive pressure urges companies to apply new technologies in order to gain a competitive advantage (Vilaseca-Requena *et al.*, 2007; Zhu *et al.*, 2003). A similar line of reasoning can be given for Industry 4.0. Manufacturers face increased competition, particularly from new entrants from Asia (Kagermann *et al.*, 2013). As Industry 4.0 is supposed to be a new production approach to cope with this challenge (Bauer *et al.*, 2014), competitive pressure might lead to increasing Industry 4.0 adoption.

Environmental uncertainty also has a significant influence on Industry 4.0 adoption. Contrary to the previous factors, it has a negative effect and contradicts our proposition. This is surprising since the line of reasoning is similar to that of competition, which has a positive effect. We expected increasing environmental uncertainty to foster Industry 4.0 adoption in order to improve information flows and therefore reduce uncertainty. It is probable that the uncertainty perceived by the sample companies cannot be reduced by an enhanced flow of information. The source of uncertainty might instead be the unknown further development of Industry 4.0, e.g., regarding standards. Hence, the less companies feel sure about future standards, the less likely they are to engage in Industry 4.0 adoption.

Lastly, perceived outside support was tested and found to have no significant effect on Industry 4.0 adoption. Either manufacturers seem not to be willing to draw on external support or such support does not exist. In particular, the former reason corresponds to previous research revealing that German manufacturers rarely build on external organizations. Arnold *et al.* (2016) show that external partners play a subordinate role in terms of Industry 4.0-triggered adjustments of a company's business model. This aversion to integrating external organizations into the business model seems to apply to the support from outside with reference to Industry 4.0 adoption as well.

## CONCLUSION AND IMPLICATIONS

In summary, the results indicate that factors from all three perspectives, i.e., technology, organization, and environment, have a significant influence on the adoption of Industry 4.0. In particular, relative advantage, top management support, and competition positively affect Industry 4.0 adoption. Environmental uncertainty, in contrast, has a negative effect. Among these determinants, relative advantage has the strongest impact. This is particularly interesting against the background that perceived challenges associated with Industry 4.0 have no significant influence, indicating that benefits play a substantially more important role for the adoption decision.

This study enhances existing research on technology adoption as well as on Industry 4.0 in several ways. Various factors that already proved to be significant in previous examinations were assessed by applying the pervasive TOE framework of DePietro *et al.* (1990). In this course, we were able to extend the validity of earlier results. The three determinants of relative advantage, top management support, and competition, which proved to have a significant positive effect on the adoption of a multitude of technologies so far, affect Industry 4.0 adoption in the same way. Moreover, environmental uncertainty, which proved to have also a significant positive influence in prior studies, shows a negative impact on Industry 4.0 adoption. Firm size, absorptive capacity, and perceived outside support do not seem to affect the adoption of Industry 4.0, although they have proven to do so in the context of other technologies. Perceived challenges were tested for the first time as a potential adoption predictor but do not play a noteworthy role, at least for our sample. Especially with regard to Industry 4.0 research, our findings provide novel insights. Previous research dealt with potential effects of Industry 4.0 implementation from several perspectives, but failed to examine relevant factors influencing the adoption decision.

The findings also provide valuable insights for managers. Firstly, top management support shows a significant positive influence on Industry 4.0 adoption. Therefore, companies that plan to implement Industry 4.0 in their industrial value creation should involve the executive board and ensure appropriate support. Secondly, the absence of significance with regard to perceived challenges associated with the adoption of Industry 4.0 should not lead to a negligence of those challenges. Nevertheless, they should also not be overemphasized, and should be assessed appropriately, particularly against the background of potential benefits. Thirdly, when facing increasing competitive pressure, manufacturers are well advised to consider adopting Industry 4.0. Otherwise, these companies might fall behind competitors who invest in Industry 4.0 in order to achieve a competitive advantage. Lastly, environmental uncertainty, particularly in terms of lacking standards, prevents the adoption of Industry 4.0. Therefore, we recommend manufacturers to participate in respective committees and organizations to drive the establishment of standards.

Despite this study’s contributions, there are some limitations. The sample consists only of German manufacturing companies. Since Industry 4.0 is also relevant for other companies, e.g., service providers and companies from other countries, future studies should consider respective companies. Especially a sample with foreign companies would allow for the analysis of potential cultural influences. Furthermore, this study includes firm size as an independent variable but does not differentiate between small and large companies. Since it is probable that different factors determine Industry 4.0 adoption in small and large companies, future research should differentiate between companies’ sizes. Regarding the influencing factors analyzed in this study, they represent only a small portion of all potential adoption determinants. Therefore, future studies should consider other factors that proved to be significant in previous studies as well, e.g., organizational structure, or factors that are newly defined specifically for the Industry 4.0 context.

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