

Article

Challenges of Industry 4.0 Technology Adoption for SMEs: The Case of Japan

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Abstract: In the light of several national advanced manufacturing strategies such as Industry 4.0 in Germany or the Made in China 2025 initiative in China, this article examines the challenges of Industry 4.0 adoption of Japanese small and medium-sized manufacturing firms. A technology adoption model for Industry 4.0 is developed and empirically tested with 38 manufacturing companies. The results yield that the market uncertainty of the firm's business is a significant driver for adoption in the short, medium, and long-term. Relative competitive advantage matters in the short term and top management support in the long-term. No support has been identified concerning advanced manufacturing complexity and market transparency of Industry 4.0 solutions.

Keywords: advanced manufacturing; industry 4.0; SME; technology adoption model

1. Introduction

Manufacturing is the backbone of large economies such as the U.S., Europe, China, or Japan. Changing demographics, globalization, scarcity of resources, the challenges of climate change, and mass customization are the megatrends that challenge the future of manufacturing [1]. These changes imply volatile, uncertain, complex, and ambiguous environments for firms and affect them across their strategic environment [2]. Various initiatives emphasized the urgency for advanced manufacturing strategies to tackle those challenges and support economic growth [3].

Industry 4.0 facilitates the balancing act of internal and external complexity by shifting traditional production systems from a structured centralized control to decentralized control. It is a specific deployment of an advanced manufacturing strategy. The core principles of Industry 4.0 are modularization, self-regulation, and digital integration across business functions and within and beyond the organizational boundaries. Industry 4.0 induces product innovation based on the usage of intelligent sensor and actor systems to facilitate context-sensitive production processes and ICT based process innovation to integrate production processes across the value chain, value network, and product lifecycle.

While the manufacturing industry is the backbone of large economies such as the U.S., Europe, China, or Japan, small and medium-sized enterprises (SMEs) are the foundation for manufacturing industries. Small and medium-sized enterprises are very flexible in adapting new technologies and catering niche markets, while large corporates are better on scale efficiencies but slower in adapting innovations [4]. Therefore, it is essential to study the challenges of information technology adoption concerning the concept of Industry 4.0 for small and medium-sized enterprises to accelerate the diffusion of advanced manufacturing.

This article contributes to the body of knowledge in two ways. First, a technology adoption model is presented that accounts for the particularities of Industry 4.0 information technologies, and second, this model is empirically tested, and the results are discussed.

2. Technology Characteristics of Industry 4.0

Industry 4.0 is defined as the “[...] integration of cyber-physical-systems in production and logistics as well as the application of the Internet of Things in industrial processes. This includes the consequences for the value chain, business models, services, and work environment” [5]. While some advanced manufacturing strategies include the usage of new materials, advanced human-machine interaction, assistive (ambient) systems, and factory virtualization, the common element in all definitions is the linkage of physical systems and virtual systems using information and communication technologies for facilitating manufacturing processes.

It consists of two innovation types: product and process innovation. On the product innovation side, it is the integration of cyber-physical systems (CPS) to integrate context-aware and self-adaptive production processes. Using machine learning techniques on higher ICT levels, the monitored data from sensors can be used to control embedded actors to respond to environmental changes (self-regulatory). This is depicted in the stages of the 5C architecture of a CPS, ranging from smart connections to data conversion, cyber integration, cognition, and self-configuration [6]. Based on technology such as the Internet of Things (machine-to-machine communication), Internet of Service (machine-to-human communication), and Internet of People (virtual human-to-human communication), CPS integrates the physical world of productions vertically. Successful implementation of CPS is based on “[...] horizontal integration through value networks, end-to-end digital integration of engineering across the entire value chain, vertical integration, and networked manufacturing systems” [5]. This implies that product and process innovation has to be implemented in combination and not separately.

From a technical perspective, these two elements of the advanced manufacturing strategies, cyber-physical systems, and digital integration of production and business processes are not new in the industrial context. Notably, both parts are the core principles of a so-called Smart Factory. The Smart Factory idea is based on transferring the ubiquitous (wireless) computing to an industrial context [7].

A Smart Factory is a “[...] Factory that context-aware assists people and machines in execution of their tasks [...] by systems working in background, so-called Calm-systems and context-aware applications” [8]. A Smart Factory masters the complexity challenge by modularization of its components and self-regulating mechanics based on context-aware applications. A self-adaptive system, such as the Smart Factory, addresses the complexity issue by automatically modifying itself in response to changes in its operating environment. A Smart Factory is robust and increases production efficiency by enabling communication flows among humans, machines, and resources, just like communication flow in social networks [5].

The key implication of linking production processes with business functions using context-aware systems is the ubiquitous real-time availability and analysis of data for self-regulatory behavior [9]. Other authors refer to the Smart Factory concept as Industrial Internet, Intelligent Manufacturing, Digital Factory, Ubiquitous Factory, or Factory 4.0 [10,11].

The technological enablers for deploying cyber-physical systems and ICT-integrated production-business processes are advanced technologies in Big Data Analytics, Cloud Computing, Internet of Things, and virtualization/simulation technologies for education and assistance [2,12]. However, not all enablers have reached a certain readiness level [13]. Due to the uncertainty of economic rents involved with each technological readiness level, SMEs will adopt mature technologies, likely adopt technologies that reached the evaluation stages and hesitate to adopt technologies in its infancy. Specifically, maturity models for small-and-medium-sized enterprises should be different from multinational-enterprises due to their specific requirements [13].

3. Technology Adoption Models

A list of models, tailored to the particular product and process innovation characteristics and the SME context, is added to the annex of this article. General concepts differentiate between the adoption perspective of an organization and an individual, where this study takes the firm's view.

Roger's innovation diffusion theory (IDT) states that potential adopters evaluate the following technical characteristics to assess the adoption of an innovation: first, the relative advantage of the innovation compared to the competition and its compatibility with the existing infrastructure are the most significant adoption determinants [14]. Second, in terms of complexity and trialability, a firm also evaluates the external organizational context to suppliers, customers, or governmental authorities in terms of efficiency gains or possible constraints from the adopted innovation [15].

The Technology, Organization and Environment framework (TOE) [16] is a widely accepted framework [17] which identified three constructs that are vital to adopt an innovation: (1) availability, best practices, and equipment, (2) firm size, communication processes and managerial structure, and (3) industry characteristics, market characteristics, and technology support.

Following the arguments by Scott [18], institutional environments such as business partners or competitors shape organizational structures and actions, which leads to the inter-organizational model (IO) based on the constructs of (1) perceived benefits, (2) organizational readiness, and (3) external pressure. Raymond [19] underlines this approach and postulates that IDT and TOE frameworks "[...] need[s] to be enriched when the innovation relates to complex technologies with an inter-organizational locus of impact, for which adoption decisions are linked (e.g., when imposed by business partners) and when the innovation is adopted by organizations" [19].

This has been implemented by Chau and Tam [15], where the authors propose a model based on the TOE framework and added product-specific characteristics to study the adoption of open (software) system standards: (1) external environment e.g., market uncertainty, (2) organizational technology such as complexity of IT infrastructure, satisfaction with existing system, formalization on system development & management, and (3) open system characteristics like perceived benefits, perceived barriers, interoperability, and interconnectivity.

While Iacovou et al. [20] incorporated inter-organizational aspects, Chatterjee et al. [21] argued that the adoption of specific information and communication technologies are guided by intra-organizational cooperation. Following the argumentation by Swanson [22], the adoption decision must be coordinated. This is reflected in their model, which incorporates top management factors such as beliefs towards innovation, participation in the adoption process, and strategic investment rationale.

4. Method

For the development of the technology adoption model, Industry 4.0 is defined as the digital integration of the production system with the company's business functions using self-regulatory sensor-actor networks (CPS) in combination with information and communication technologies. The constituting constructs are: (1) the usage of technologies which continuously monitor processes from inbound logistics, production and outbound logistics to regulate the respective processes autonomously depending on changes in the environment, (2) the real-time availability and analysis of the monitored data to other business functions such as administration, research and development, service, marketing and sales and, (3) the usage of software system for automatic data exchange between business functions such as administration, research and development, service, marketing and sales. For the sake of ease use in a survey, these elements are summarized as self-adaptive technologies and digitalized processes in the individual survey items.

On the one hand, a CPS is considered as product innovation due to its technological foundation. On the other hand, the aligned software-oriented information technologies are considered process innovation because they combine, align, and integrate the CPS components with the existing business processes. This study follows the approach of Fichman and Kemerer [23] and Chau and Tam [15], where the authors highlight that a complicated technological innovation, such as Industry 4.0, should add innovation specific adoption characteristics in addition to the traditional ones. Therefore, the research model builds on the TOE framework and incorporates independent variables from other models to match the context of small and medium-sized enterprises and the characteristics of the

innovations. The dependent variable is a construct of adoption intention and the early stages of technology assimilation as defined by the Guttman scale.

Specific characteristics, which stifle or foster the adoption of advanced manufacturing by SMEs, are highlighted in the study by Wischman et al. [12]. Although the study looks at the broader context of Industry 4.0 in Germany, the factors are assumed to be transferable to the defined advanced manufacturing context in this article because the core elements are identical. According to Wischmann et al. [12], the main hurdles for SMEs to adopt Industry 4.0 are based on (1) financial constraints, (2) an immature IT to support a smooth integration of Industry 4.0 technologies, (3) lack of top management support to lead and digital vision and provide the necessary budget, (4) lack of skills of the workforce, or (5) resistance due to technological uncertainty and immature standards and protocols. The institutional theory is incorporated in this model because, based on the determinants of Swanson's framework [22], Industry 4.0 is a core business function innovation [21]. This study includes only intra-organizational factors and excludes inter-organizational factors because, contrary to EDI, the interconnectivity of firms is not a necessity for cyber-physical systems and data exchange within the organization (Figure 1).

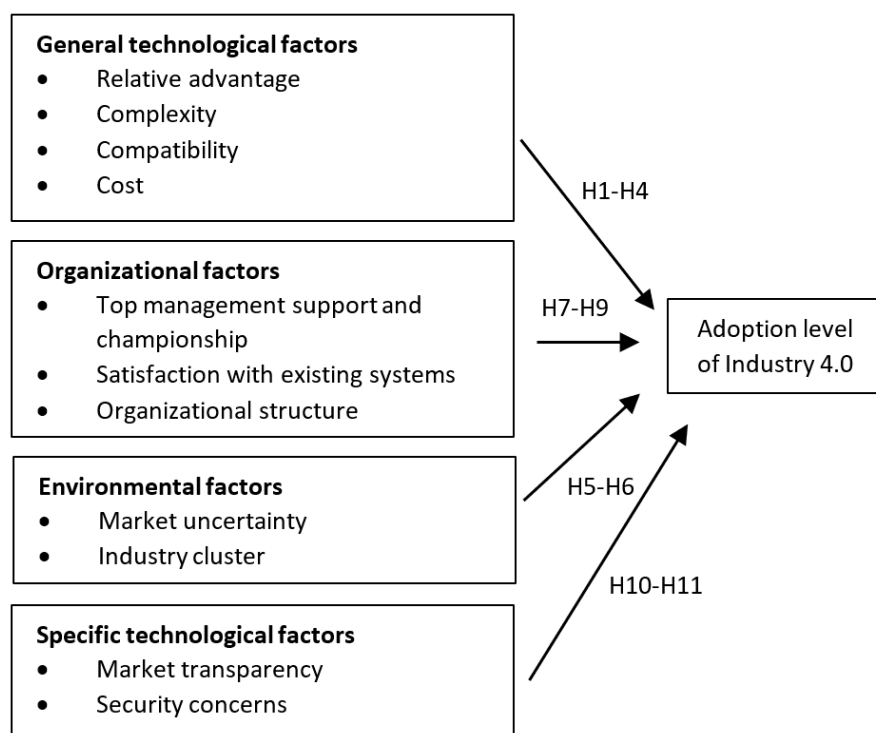


Figure 1. The Industry 4.0 Adoption Model proposing the hypotheses from H1 to H11.

4.1. General Technological Factors

4.1.1. Complexity

Complexity is the degree to which the technologies are perceived as challenging to understand and use [24,25], and it is typically negatively correlated with adoption [25]. The lack of knowledge is the second major obstacle for Industry 4.0 adoption for SMEs [12]. Complexity can be measured in terms of number and diversity of relationships and number and diversity of elements within a given. Cyber-physical systems consist of multiple specialized heterogeneous devices and operate in a changing environment. In combination with data analysis and ICT integration with business functions, product innovation is considered to be complex. Technological communication standards and protocols must be established to guarantee a smooth integration of data exchange across business functions. The orchestration of multiplicity of hardware and software is a complex task [25]. Based on established measures by Premkumar and Roberts [25] and Jeon et al. [26] the indicator is operationalized as:

- The skills required to use self-adaptive technologies and digitalized processes are too complex for our employees.
- Integrating self-adaptive technologies and digitalized processes in our current work practices will be very difficult.

Hypothesis H1. *The lower the perceived complexity of the advanced manufacturing technologies, the more likely they will be adopted.*

4.1.2. Compatibility

Compatibility is the degree to which technological innovation can be easily integrated with the existing infrastructure and processes [24]. If the innovation is compatible with current practices and technological infrastructure, adoption is more likely, according to Cooper and Zmud [27]. The shift from centralized controlled production to decentralized (self-adaptive) controlled production is a substantial change for the organization. According to Premkumar and Roberts [25], it is essential for small businesses that the changes are compatible with the organizational culture. Otherwise, it may result in resistance. Chatterjee et al. [21] highlight, in the context of e-business, that higher technological compatibility of the innovation with the existing system implies higher adoption capability of the organization. Old production systems are strong inhibitors to adopt Industry 4.0. Based on these measures, this indicator is operationalized as:

- The changes introduced by self-adaptive technologies and digitalized processes are consistent with the firm's existing beliefs/values.
- The self-adaptive technologies and digitalized processes are compatible with existing IT infrastructure.
- The self-adaptive technologies and digitalized processes are compatible with the firm's existing experiences with similar systems.

Hypothesis 2 (H2). *The greater the perceived compatibility of the advanced manufacturing technologies with current infrastructure, values, and beliefs, the more likely they will be adopted.*

4.1.3. Relative Advantage

Relative advantage is the degree of additional benefit for the organization from adopting the innovation compared to the status quo, according to Roberts [24]. A recent study by Commerzbank [28] on the impact of the digital trend on manufacturing firms revealed that firms tend to accelerate ICT integration to establish new business models and innovations to counter the competitive pressure and short product life cycles. Relative advantages are referred to in recent models as a perceived benefit [20]. Roger's and Iacovou's model indicate both that understanding the relative advantage increases the likelihood of adoption. Therefore, advanced manufacturing is expected to be able to give organizations a better competitive advantage. Based on established measures by Iacovou et al. [20], Premkumar and Roberts [25], Hsu et al. [29], Gibbs and Kraemer [30] and Oliveira and Martins [31], the indicator is operationalized as:

- Self-adaptive technologies and digitalized processes will allow us to better respond to customer needs.
- Self-adaptive technologies and digitalized processes will allow us to cut costs in our operations.
- Implementing self-adaptive technologies and digitalized processes will increase the profitability of our business.
- Self-adaptive technologies and digitalized processes provide timely information for decision making.

Hypothesis 3 (H3). *The greater the perceived relative advantage of the advanced manufacturing technologies, the more likely they will be adopted.*

4.1.4. Cost

Tornatzky and Klein [14] state that technologies that are perceived to be low in cost are more likely to be adopted. Also, Premkumar and Roberts [25] highlight that for small businesses, the cost of hardware/software is a severe inhibitor for adoption. The study by Wischmann et al. [12] revealed that lack of resources, both financial and human resources, is the major obstacle for small and medium-sized companies. Based on established measures by Premkumar and Roberts [25] and Jeon et al. [26], the indicator is operationalized as:

- The costs of adoption of these self-adaptive technologies and digitalized processes are far greater than the benefits.
- The cost of maintenance and support of these self-adaptive technologies and digitalized processes are very high for our business.
- The amount of money and time invested in training employees to use these self-adaptive technologies and digitalized processes is very high.

Hypothesis 4 (H4). *The smaller the perceived cost/benefit ratio of the advanced manufacturing technologies, the more likely they will be adopted.*

4.2. Environmental Factors

4.2.1. Market Uncertainty

External organizational factors like megatrends or economic fluctuations affect the way business is conducted. Market uncertainty stems from all technological, social, ecological, and political areas such as technological disruptions, degree of competition, volatility in demand, uncertain supply, and political [15]. This market uncertainty induces tension to the outer and inner complexity of a firm, which as to be balanced [2]. Self-adaptive systems such as the Smart Factory facilitate the balancing act [10]. The authors explain how cyber-physical systems support mass customization and handle market uncertainties. Therefore, it is assumed that a higher degree of market uncertainty is positively correlated with the likelihood of adopting advanced manufacturing technologies. In other studies, this construct is represented by competitive pressure [25,26], perceived industry pressure [32], or competition intensity [29]. Based on established measures by Chau and Tam [15], this indicator is operationalized as:

- The market for firms' products/services is stable.
- The competition of firms' products/services is stable.
- The demand for firms' products/services is stable.
- The degree of loyalty of their major customers is stable.
- The frequency of price-cutting in the industry is stable.

Hypothesis 5 (H5). *The higher the market uncertainty for the company's business, the more likely the advanced manufacturing technologies will be adopted.*

4.2.2. Industry Cluster

Since the first industrial revolution, it has been observed that firms tend to cluster in specific geographic regions. While this has been driven by the availability of resources in the first place and the need to secure them, this changed with the second industrial revolution when the infrastructure (power and transportation) allowed firms to settle independently of large cities. With the rise of automation and machinery-based manufacturing, access to the labor market, and close proximity to suppliers became more critical [33]. This clustering of firms creates externalities such as reduced labor cost or knowledge spillover because, in a reciprocal way, it attracts more people to the region, which in turn reduces the cost of labor [34]. However, the degree of those positive externalities depends on

the affinity of the firm to the existing cluster. A cluster of similar manufacturing SMEs (similar/same industry) will benefit from a large specialized workforce to a greater extent than SMEs from different industries due to labor pooling and sharing of inputs. In the Marshall-Arrow-Romer model [35], this is described as externalities due to specialization, where this leads to knowledge spillovers, and if similar firms collocate in one region (cluster), it fosters innovation due to competition.

On the other hand, in Jacob's model [36], SMEs from different industries strive for innovation due to knowledge spillovers based on different labor skills in high-tech industries [34]. In addition to industry affinity externalities, whether based on specialization or diversification, Alacer and Chung [37] highlight the importance of firm size on the agglomeration effects. Large firms typically experience a higher knowledge drain than SMEs, which benefit from it (knowledge gain). Based on this argumentation, the indicator for this construct is defined as:

- The company resides in a geographic, industrial area.
- The companies within the geographic, industrial area stem from many diversified industries.

Hypothesis 6 (H6). *The higher diversity in an industry cluster, the more likely the advanced manufacturing technologies will be adopted.*

4.3. Organizational Factors

4.3.1. Top Management Support and Championship

According to Chatterjee et al. [21], top management championship is an important factor for assimilating information technologies, such as Web technologies, because it defines institutional norms and values how the company perceives the innovation. If the top management believes in the innovation and actively shapes the vision and strategy, this serves as a strong signal to the organization to overcome obstacles in the assimilation process. The significance of top management beliefs and active participation has been demonstrated in various studies [21]. Thus, top management support is positively related to adoption [25]. This is supported by Wischmann et al. [12], which highlight that the lack of a digital vision by the top management is an inhibitor to implement Industry 4.0. Based on established measures by Chatterjee et al. [21], this indicator is operationalized as:

- The top management is likely to invest funds for self-adaptive technologies and digitalized processes.
- The top management is willing to take risks in the adoption process of self-adaptive technologies and digitalized processes.
- The top management is likely to be interested in adopting the self-adaptive technologies and digitalized processes.
- The top management is likely to consider the adoption of the self-adaptive technologies and digitalized processes as strategically important.
- The top management has articulated a vision or strategy for the organizational use of self-adaptive technologies and digitalized processes.

Hypothesis 7 (H7). *The higher the top management support and championship for advanced manufacturing technologies, the more likely they will be adopted.*

4.3.2. Satisfaction with the Existing System

The shift from centralized production to decentralized (self-adaptive) production is a substantial change for the organization. As highlighted by McGaughey and Snyder [38], human resistance to change was one major factor that hampered the success of computer integrated manufacturing in the 1990s. Resistance to change or motivation for change stems from two sources: lack of skills or satisfaction with the existing system. Because a lack of skills is already covered by the complexity

construct, this construct follows the argument by Rogers [24] that a low satisfaction level with the existing system is perceived as a performance gap and will motivate the organization to improve performance. Based on established measures by Chau and Tam [15], this indicator is operationalized as:

- The existing production system serves the needs of the company.
- The existing IT system serves the needs of the company.
- The cost/performance of the production system satisfies the top management.
- The cost/performance of the current IT system satisfies the top management.

Hypothesis 8 (H8). *The higher the satisfaction with the existing system, the less likely the advanced manufacturing technologies will be adopted.*

4.3.3. Organizational Structure

The effect of organizational structures such as centralization (degree of organizational hierarchy) and decision-making processes is debatable according to Kimberly and Evanisko [39]. A centralized organizational structure can be positively or negatively correlated with technology adoption behavior. In the context of advanced manufacturing technologies, this study follows the argument by Chatterjee et al. [21]: To successfully implement a complex technology, which affects multiple organizational entities, the needed intensity of interactions and collaborations among the managers of these entities is a critical factor in the adoption of advanced manufacturing technologies. Thus, it is expected that a decentralized organizational structure with flatter decision structures will be associated with the adoption of new technologies. Based on these established measures this indicator is operationalized as:

- The company decision making is highly concentrated at top management levels.
- The company extensively utilizes cross-functional work teams for managing the day to day operations.
- The company has reduced the formal organizational structure to integrate operations more fully.

Hypothesis 9 (H9). *The more decentralized the organization, the more likely the advanced manufacturing technologies will be adopted.*

4.4. Specific Technological Factors

4.4.1. Market Transparency for Advanced Manufacturing Technologies

Market transparency refers to the availability of information and solutions to implement the technologies. It is reflected in governmental efforts to promote information, establish public-partnerships, and establish measures to compare technologies solutions of different providers. A highly fragmented market, with various isolated solution providers, with every one having its standard, implies an immature industry.

Thus, market transparency is a proxy for technological maturity. Small and medium-sized companies are more likely to adopt mature Industry 4.0 technologies than an immature one. The study by Wischmann et al. [12] also highlights that a lack of user-transparency, technological standards, and availability of solutions are severe obstacles for small and medium-sized enterprises. Based on this argument, the following indicators are proposed:

- Information about products and services on self-adaptive technologies and digitalized processes are widely available.
- The market for self-adaptive technologies and digitalized processes is transparent concerning product and service features.
- The market for self-adaptive technologies and digitalized processes is transparent concerning product and service costs.

- Information on standards and protocols for self-adaptive technologies and digitalized processes is widely available.

Hypothesis 10 (H10). *The higher the market transparency, the more likely advanced manufacturing technologies will be adopted.*

4.4.2. Security Concerns of Advanced Manufacturing Technologies

Cyber-physical systems and its digital integration along the business function share are a unique feature with e-business security concerns. Firms conducting Internet-based e-business have less control over data as in legacy systems. Also, the integration along the value chain implies the diffusion of core corporate data, and even if its access restricted, its several physical access points for fraud usage as increased.

These security concerns are even more prevalent in the context of self-regulating factories. According to Bauer et al. [2], information security based on confidentiality, integrity, and availability is a prerequisite or even the decisive factor in adopting Industry 4.0 technologies. Based on established measures by Zhu et al. [40], this indicator is operationalized as:

- The company is very concerned about the security and privacy of data and transactions using self-adaptive technologies and digitalized processes.
- Our trading partners are very concerned about the security of data and privacy using self-adaptive technologies and digitalized processes.

Hypothesis 11 (H11). *The higher the security concerns, the less likely advanced manufacturing technologies will be adopted.*

4.5. Dependent Variable

Advanced manufacturing technologies are currently in its evaluation stage for scale based industrial applications, and many public-private initiatives have just recently been planned or have just been set up to promote prototypes and technology champions [41]. Thus, it is way too early to investigate general adoption stages.

Therefore, this study follows first the approach by Tsai et al. [42] and investigates the general intention to adopt advanced manufacturing strategies and subsequently includes only the early stages of technology assimilation based on the Guttman scale in Fichman and Kemerer [23]. On a five-point Likert scale ranging from strongly agree to disagree the intention to adopt is measured according to Tsai et al. [42]:

- The company is seriously contemplating to adopt self-adaptive technologies and digitalized processes within one to three years from now.
- It is critical for the company to adopt self-adaptive technologies and digitalized processes within one to three years from now.
- My firm is likely to adopt self-adaptive technologies and digitalized processes within one to three years from now.

5. Results

A survey has been sent out to 38 selected manufacturing SMEs in Japan according to the relative representation. The descriptives of the firms are presented in Table 1. The company sizes range between 10 (12 firms), 50 (13 firms), 100 (eight firms), and more than 200 employees (five firms).

Table 1. Manufacturing Industries.

Industry	Number of Firms
Automated Equipment and Robots	2
Basic Metals	2
Computer, Electronics and Optical Products	4
Control Equipment	2
Electrical Equipment	4
Fabricated Metal Products	1
Machinery and Equipment	9
Motor vehicles, trailers, and semi-trailers	1
Non-metallic mineral products	1
Transport Equipment	1
Paper Products	1
Pipes and Pumps	1
Mold Manufacturing	1
Precision Manufacturing	5
Other Manufacturing	3

The survey has been translated to Japanese and back to English to ensure semantic consistency. The survey consists of the statements described in the previous section, and the interviewees indicated to which extent, on a five-point Likert scale, they agree or disagree with each statement.

The model is evaluated for reliability, convergent validity, and discriminant validity. The Construct reliability is assessed by computing Cronbach's alpha. Cronbach's alpha is a measure to check the internal consistency of a construct based on the average correlations between the construct items (Table 2). Cronbach's alpha should be above 0.7. If the Cronbach's alpha value is below 0.7, this is an indicator that the items measure different concepts, or the items are not understandable/are ambiguous. Therefore, only the constructs Complexity, Compatibility, Relative Advantage, Market Uncertainty, Top Management Support, Market Transparency, and the dependent variables are considered. Based on the remaining constructs a principal component analysis (correlation matrix, varimax) is used to assess the convergent and discriminant validity. The Compatibility construct had to be dropped because of too many over-loadings and insignificance (loading > 0.5).

The remaining five components explain 72% of the variance and have significant loadings in their respective parts and are uncorrelated across the components. Heteroskedasticity, the variance of the error term, has been tested with the Breusch-Pagan/Cook-Weisberg, yielding a $\chi^2 = 0.18$. This means that the variance of the error terms does not change with the observations.

After the determinants have been validated, the regression analysis is performed on the adjusted model. A linear regression analysis is performed for the three scenarios of short-term (one year), medium-term (two years), and long-term (three years) adoption intention.

Table 2. Cronbach's Alpha.

Technology Adoption Construct	Cronbach's Alpha
Relative Advantage	0.86
Complexity	0.74
Compatibility	0.79
Cost	0.64
Top Management Support and Championship	0.79
Satisfaction with Existing Systems	0.5
Organizational Structure	0.82
Market Uncertainty	0.69
Industry Cluster	0.34
Market Transparency	0.88
Security Concerns	0.67

The final regression model is shown in Figure 2. The regression shows that Market Uncertainty (of the company's business) is a significant driver for adoption intention in the short, medium, and long-term. Also, while the Relative Advantage matters in the short-term, strong indicators for adoption intention in the long-term are Top Management Support of a company. No support has been identified for the other constructs. This indicates that the adoption of advanced or smart manufacturing for SMEs is market-driven, whether there is a strong need to change and build a strong relative competitive advantage or not. This is facilitated in the long-term by the top management. Therefore, this study highlights that the adoption of Industry 4.0 technologies and processes is primarily driven by external factors and less by internal drivers. This is aligned with the results obtained in [43], where the authors highlight that Industry 4.0 in SMEs is typically related to Cloud Computing to improve operational efficiency and only to a smaller degree used in real business cases for digital transformation.

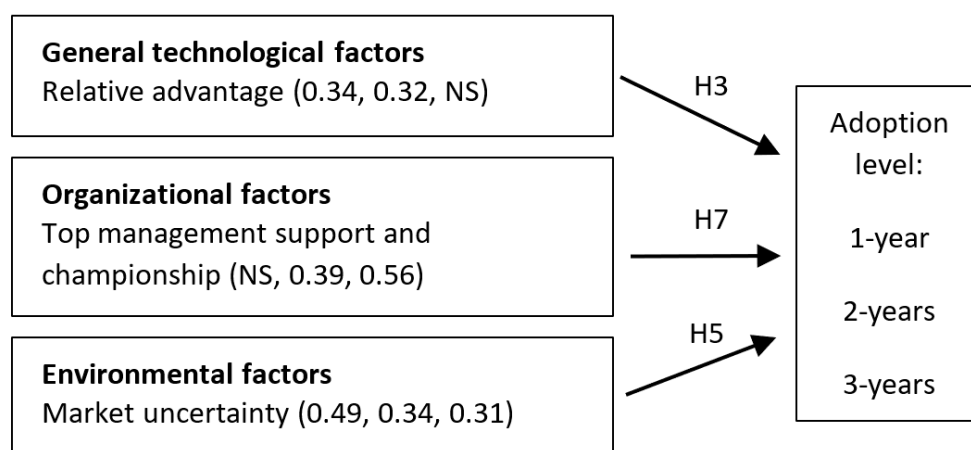


Figure 2. The resulting Industry 4.0 Adoption Model. NS= No support. The number in brackets shows the beta coefficients for one, two, and three years adoption levels.

The consequences of external pressure as the main driver has advantages and disadvantages. Especially for small and medium-sized enterprises, it could lead to late adoption of Industry 4.0, because compared to mass markets catered by large enterprises, niche markets are less competitive. Thus, external pressure signals could be misinterpreted or necessary technology adoption could be deferred. However Industry 4.0 standards and protocols have not reached a unified maturity level, thus being a late adopter could refrain SMEs to tap into additional costly investments. Especially in the light of interoperability challenges [44] and unsolved cyber-security concerns [45], late adoption for SMEs might be beneficial.

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