# Exploring the Adoption of the International Information Security Management System Standard ISO/IEC 27001: A Web Mining-Based Analysis

Mona Mirtsch, Jan Kinne, and Knut Blind

***Abstract*—In the light of digitalization and recent EU policy initiatives, information is an important asset that organizations of all sizes and from all sectors should secure. However, in order to provide common requirements for the implementation of an information security management system, the internationally well-accepted ISO/IEC 27001 standard has not shown the expected growth rate since its publication more than a decade ago. In this article, we apply web mining to explore the adoption of ISO/IEC 27001 through a series of 2664 out of more than 900 000 German firms from the Mannheim Enterprise Panel dataset that refers to this standard on their websites. As a result, we present a "landscape" of ISO/IEC 27001 in Germany, which shows that firms not only seek certifications themselves but often refer on their websites to partners who are certified instead. Consequently, we estimate a probit model and find that larger and more innovative firms are more likely to be certified to ISO/IEC 27001 and that almost half of all certified firms belong to the information and communications technology (ICT) service sector. Based on our findings, we derive implications for policy makers and management and critically assess the suitability of web mining to explore the adoption of management system standards.**

***Index Terms*—Adoption, information security, management system standards, standards, web mining.**

## I. Introduction

In addition to the advantages of digitalization, the growing connectivity also entails risk with regard to information security [1]–[3]. Security breaches have, therefore, become a global concern, with a value at risk arising from direct and indirect attacks of USD 5.2 trillion between 2019 and 2023 [4]. To achieve information security and reduce the risk of security breaches, organizations must take appropriate measures to protect their information assets and ensure business continuity [5]. The international management system standard ISO/IEC 27001 assists organizations in developing and maintaining an information security management system (ISMS) on the organizational level [6] and "remains one of the most effective risk management tools for fighting off the billions of attacks that occur each year" [1].

After implementing this management system, firms can additionally seek certification to ISO/IEC 27001 to provide confidence to stakeholders that risks are adequately managed [7]. Certification against (preferably international) standards, such as ISO/IEC 27001, is increasingly moving into the focus of policy makers in the light of recent European initiatives. While the Directive on security of network and information systems (NIS-Directive EU 2016/1148) targets operators of essential services in critical infrastructures and digital service providers, the Regulation on information and communications technology (ICT) cybersecurity certification (EU 2019/881 - Cybersecurity Act) sets up a European cybersecurity certification framework for ICT products, ICT services, and ICT processes.

However, apart from the number of valid certificates, which are published in the context of the annual ISO Survey (2018), surprisingly little is known about the adoption of ISO/IEC 27001. According to Castka and Corbett [8], research is often neglected in the early stages of management system standards, probably due to the limited data available. While initial studies often focus on the motives and impacts of adoption, usually based on firm-level data and interviews or surveys, later studies on diffusion often determine diffusion patterns based on macrolevel data [8]. According to Rogers [9], adoption is the decision of an adopting unit (such as firms) "to make full use of an innovation as the best course of action available." Diffusion, on the other hand, being the aggregation of individual (in our case firm) decisions, involves a time aspect and is defined as "the process in which an innovation is communicated through certain channels over time among the members of a social system" [9].

Existing studies on ISO/IEC 27001 analyze the adoption mainly from a theoretical perspective [10]–[12], based on

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surveys with the pitfalls of low response rates [13]–[17] or based on case studies [18]. To the best of our knowledge, no studies have empirically investigated the adoption of ISO/IEC 27001 at the national level.

To help fill this gap, the aim of our article is twofold. First, to explore the adoption of ISO/IEC 27001 in Germany, not only by taking into account firms certified to ISO/IEC 27001, but also adopting this standard in other ways. Second, to identify drivers for the certification to ISO/IEC 27001 in Germany. Therefore, we introduce a new method to analyze the adoption of management system standards using web scraping and web mining. Web mining describes the application of data mining techniques to uncover relevant data characteristics and relationships (e.g., data patterns, trends, and correlations) from previously web scraped unstructured web data [19]. We do so by using data from the Mannheim Enterprise Panel (MUP) as the firm database, and then categorize web scraped firms using their website texts and conduct multivariate analyses based on firm characteristics and a deep-learning-based product innovator probability indicator [20].

The remainder of this article is structured as follows. Section II discusses the literature on ISO 9001 and ISO 14001 as well as existing studies on ISO/IEC 27001. Based on the assumption that management system standards are organizational innovations [21]–[23], we present the Technology-Organization-Environment (TOE) framework as an applicable innovation adoption model [24] for firms adopting ISO/IEC 27001. Section III describes the research methodology starting with web mining as a data collection process. Section IV presents the results of the manual categorization of firms that refer to ISO/IEC 27001 on their websites. Using a probit model, we estimate determinants of firm-specific characteristics (firm size, age, innovativeness, and sector affiliation) for the certification to ISO/IEC 27001. In Section V, we discuss our findings and derive a number of managerial implications and recommendations for standards development organizations and policy makers. In our conclusion, we summarize our findings, outline the limitations of our article, and discuss the suitability of web mining to explore the adoption of ISO/IEC 27001 and management system standards in general, including the need for further research.

## II. Literature Background

### A. Literature Review on the Adoption of Management System Standards

Management system standards, also referred to as meta standards [25], "help organizations improve their performance by specifying repeatable steps that organizations consciously implement to achieve their goals and objectives [...]" [26]. Thereby, organizations can decide whether to implement a management system standard or additionally seek certification through the attestation by an independent third party, also sometimes referred to as registration [27].

Certificates can help organizations signal attributes [28], [29], and hence decrease information asymmetries, one aspect of market failures according to Akerlof [30]. As shown by Terlaak and King [31], the certification to management system standards, such as ISO 9001, is particularly beneficial when there is a high information asymmetry between producers and buyers.

As highlighted by Castka and Corbett [8], in their review of the adoption and diffusion of management system standards (focusing on ISO 9001 and ISO 14001), many studies emphasize on who adopts a standard, why, how and when. The decision to adopt a management system standard is driven by internal or external reasons [8]. The benefits of certification include regulatory compliance [32], meeting customer requirements [33], internal improvements [34], [35], access to markets [36], and innovation performance [37]. Although the motives for seeking certification to ISO 9001 and ISO 14001 are quite similar, the adoption of the latter is often determined by the regulatory environment [38].

DiMaggio and Powell [39] argued that firms are driven by coercive, mimetic, and normative isomorphism, which make organizations similar over time. The desire to improve performance drives the first movers, whereas the second movers are more driven to improve their image [40]. Therefore, according to Naveh *et al.* [40], first movers benefit more from implementing a managerial practice, such as ISO 9001, from their own experience, whereas second movers can benefit by learning from the experiences of others. In this context, the later adoption can be explained by the "bandwagon effect," where previous adopters either reveal information about the value of the adoption or increase the value of the adoption and thereby set off bandwagons [41].

In the case of ISO 14001, Delmas and Montes-Sancho [42] noted that mandatory forces (e.g., derived from regulation) dominate in the early adoption phase, whereas normative pressures and trade-related aspects are more prevalent in the later phase. This effect is evidenced by Arimura *et al.* [43] in relation to ISO 14001, who also recommended government assistance programs to encourage the adoption of ISO 14001 for addressing public objectives.

The motivation to seek certification may also depend on the sector in which the firm operates. Singh *et al.* [44] found that manufacturers are more likely to focus on developing export potential and reducing costs, whereas service providers tend to meet external expectations, such as from customers or government agencies. In addition, internationally active firms are more likely to adopt standards and be certified [45], especially when export markets are affected by EU regulations [33].

However, the adoption of a management system standard and particularly seeking certification is time consuming and costly, especially regarding the costs for external auditors [46]. These costs involve the setting up of a management system, the involvement of consultants, and, in the case of additional certification, the cost of external auditing [47]. These costs vary by firm size and sector, ranging from $10 000 to $200 000 for ISO 14001 [48]. In terms of time invested, the average duration of certification to ISO 9001 is 12 months [44]. Since these investments could outweigh the benefits [49], firms might adopt a management system standard but not seek a third-party attestation (certification).

Once firms have already invested in the adoption of a standard, this can also change their decision-making process when adopting an additional standard [50]. Therefore, a firm's experience

in implementing a management system standard could spur the implementation of another management system standard [32], [51], [52]. However, the implementation of a previous management system standard could also hinder the adoption of another management system standard, if it is not fully complementary to the previously adopted standard [32]. Tuczek *et al.* [52], who also referred to Castka and Corbett [8], pointed out that this "coupling effect" is not sufficiently investigated in the context of the adoption of standards.

Firms are increasingly making use of integrated management systems that cover the aspects of quality (ISO 9001), environment (ISO 14001), energy (ISO 50001), occupational health and safety (OHSAS 18001 or ISO 45001), and, also, information security (ISO/IEC 27001) [53]. The aim of integrating compatible management system standards is to reduce administrative burden [54] and costs, e.g., when combined audits and multiple certifications can be obtained. Furthermore, organizations can use the meta structuring of standards similar to the structuring of technologies as a way to deal with the multiplicity of standards, as Gey and Fried [55] showed in the case of a software company.

Previous studies have investigated the adoption of international standards, e.g., by counting valid certificates. However, little attention has been paid to the various forms of adoption (i.e., implementation versus certification) [56] and to the actors and activities to promote the diffusion of organizational standards, which Stamm [57] has recently termed as *diffusion work*. By introducing four modes of standard diffusion along the dimensions direct/indirect and explicit/implicit, namely concrete diffusion (I), broad diffusion (II), selective diffusion (III), and ideational diffusion (IV), Stamm [57] emphasized on the role of consultants to connect activities of standards developing organizations, governments, business associations, and academics. The analysis of this *diffusion work* is particularly suitable for earlier stages, in which the mimetic behavior is not largely evident [57], and from the perspective of the policy stage, since the adoption of the standard does not necessarily immediately follow the creation of the standard.

### *B. Literature Review on ISO/IEC 27001*

Spurred by the success of ISO 9001 and ISO 14001, ISO/IEC 27001 was initially published at the end of 2005 by the International Organization of Standardization (ISO) together with the International Electrotechnical Commission (IEC) and technically revised with the second edition of ISO/IEC 27001:2013. This standard was reviewed and confirmed in 2019, and hence this version remains current.

The underlying ISO/IEC 27000 series is based on the British Code of Practice BS 7799 (see Disterer [6] for the development of this standard), which currently comprises over 40 international standards, including information security controls (ISO/IEC 27002), cloud security (ISO/IEC 27017 and ISO/IEC 27018), and investigation of incidents (ISO/IEC 27043) (ISO, 2019). As the best-known standard within this family, ISO/IEC 27001 [1] "provide[s] requirements for establishing, implementing, maintaining, and continually improving an information security management system" [7]. Within the ISO/IEC 27000 series, information security is

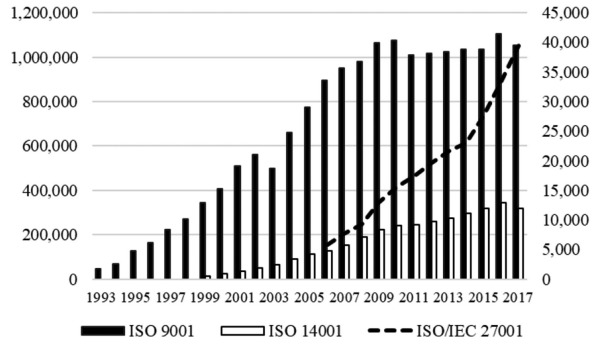


Fig. 1. Evolution of ISO 9001, ISO 14001, and ISO/IEC 27001 over time in terms of valid certificates worldwide. Source: [60].

defined as "preservation of confidentiality [ …], integrity [ …] and availability [ …] of information" [58].

Information security, therefore, differs from concepts such as ICT security (limited to information stored or transmitted using ICT) and cybersecurity (extending information security by including noninformation-based assets), although these terms are often used interchangeably (though indeed overlap—see [59] for details).

Fig. 1 shows the diffusion of the three common management system standards with ISO 9001 and ISO 14001 (bars with the left *y*-axis) and ISO/IEC 27001 (dashed lines with the right *y*-axis) from the year in which they became certifiable or corresponding data from the ISO survey [60] are available.

Looking at the number of valid certificates according to the annual ISO survey, ISO/IEC 27001 has shown high growth rates in recent years (e.g., +19% in 2017), but still remains on a comparatively low absolute level (with less than 40 000 valid certificates at the end of 2017), especially compared to other common management system standards, such as ISO 9001 with more than one million valid certificates and ISO 14001 with roughly 360 000 valid certificates in 2017 [60]. This also applies to these management system standards in the early years, when more than 660 000 certificates for ISO 9001 and almost 240 000 certificates for ISO 14001 were valid a decade after their publication [61]. Furthermore, digitalization has been expected to spur the adoption of ISO/IEC 27001. Since firms increasingly store their information based on ICT and governments and suppliers more and more require firms to ensure information security, it has been expected that ISO/IEC 27001 would also be adopted apart from the IT sector [10]. These aspects led to expectations for a higher adoption rate of ISO/IEC 27001 globally [11].

Therefore, previous studies on ISO/IEC 27001 often focused on the reasons for the (low) adoption of ISO/IEC 27001 by firms, alongside the impact of this management system standard as well as the means to increase adoption [10], [11]. Based on case studies in the U.K. and in the Netherlands, Van Wessel and de Vries [18] found that firms adopt ISO/IEC 27001 and ISO/IEC 27002 both for internal reasons (quality enhancement, cost reductions, and increasing the company's risk profile) and for external reasons (meeting legal or customer requirements and improving image). However, firms, especially small and medium-sized enterprises (SMEs) [12], often do not implement information security standards due to high costs and the lack of evidence that the benefits outweigh the costs [62].

Existing studies show that the adoption of ISO/IEC 27001 or other ISMS standards neither leads to less frequent or severe security breaches nor to positive economic impacts through certification against ISO/IEC 27001 [11], [63]–[65]. Therefore, the motives for adopting this standard differ significantly from those for adopting other management system standards such as ISO 9001, the positive economic impact of which has been demonstrated in several studies [8]. However, Barlette and Fomin [11] point out that it is difficult to quantify the benefits of the adoption since ISO/IEC 27001 can be considered as a means to avoid potential losses rather than gaining immediate profits. As a specific positive economic effect, the implementation of ISO/IEC 27001 might result in lower insurance premiums [5].

Other possible reasons for the low adoption include the consideration of competing ISMS standards [11] and the fact that firms outsource their "information-related business" to other countries, e.g., the Far East [10]. However, Fomin *et al.* [10] found no statistical evidence for the latter, as the number of valid certificates in India, for example, was no higher than in the U.K., which is still the case [60]. Fomin *et al.* [10] also concluded (inter alia) that it is worth investigating the need perceived by firms to seek certification instead of just adopting this standard.

Benslimane *et al.* [66] examined the role of certification of IT personnel and ISMS standards, such as ISO/IEC 27001. Looking at online job postings, they found that organizations value work experience and personnel certifications related to IT security more than knowledge of IT security standards. These findings indicate that firms can implement ISMS requirements [66] without fully complying with or being certified to the management system standard.

A limited number of studies conducted surveys investigating motives, obstacles, and impact of ISO/IEC 27001 [14]–[17]. However, the number of respondents were comparably low ranging from 4 and 20 firms per survey also due to the limited number of valid certificates in countries such as Finland, Saudi Arabia, and Bosnia and Herzegovina, where the surveys were conducted. A recent study among Portuguese firms (with 25 participating companies) showed that more than half of these certified firms belong to the IT sector [67]. As regards the implementation and certification process, it took between 6 and 12 months for the firms to obtain ISO/IEC 27001 certification, which in most cases cost more than €50 000 (including costs for personnel, technical equipment, and external consultancy [67]).

In order to increase the adoption of ISO/IEC 27001, most scholars place focus on the legal environment [10], [68]. From an institutional perspective, governmental intervention may be necessary, as a standard requires a certain adoption rate that triggers further adoption across other organizations, i.e., the bandwagon effect, which is not (yet) evident for ISO/IEC 27001 [68].

### C. Theoretical Framework to Analyze Drivers for Certification to ISO/IEC 27001

The Schumpeterian definition of innovation [69] already goes beyond the narrow focus on technical innovations. One type of innovation is organizational innovation such as the implementation of management system standards as intraorganizational procedural innovation according to Armbruster *et al.* [22]. This approach is supported by Hashem and Tann [23] who stated that the introduction of ISO 9001 is an innovation and applied the TOE framework of Tornatzky *et al.* [24] to investigate key determinants of the adoption of the ISO 9000 standard series of Egyptian manufacturers [23].

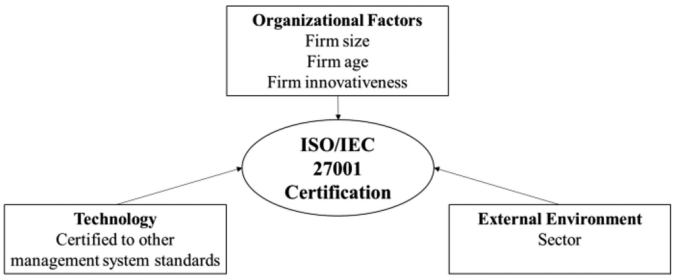


Fig. 2. Conceptual model based on [23] and [24].

The TOE framework describes how the adoption of innovations is influenced by three aspects in the context of firms. It comprises the following.

1) The Technological context, which includes both internal and external technologies relevant to the firm.
2) The Organizational context, which features firm-specific factors, such as scope, size, and the managerial structure.
3) The Environmental context, which comprises surrounding factors, such as industry, competitors, and governmental influence.

According to Oliveira and Martins [70], the TOE framework has already been used to empirically validate factors that influence the adoption, such as electronic data interchange (EDI) [71], radio frequency identification (RFID) [72], and enterprise resource planning (ERP) systems [73].

For our article, we therefore examine the influence of selected factors on the adoption of ISO/IEC 27001 on firm level, as shown in our conceptual model in Fig. 2 based on the TOE model. As the depth or quality of implementation of management system standards may vary [8], [74], we focus on firms that have implemented this ISO/IEC 27001 standard and additionally received a certificate. We consider this as an indicator of making full use of ISO/IEC 27001.

We have *chosen firm size, firm age,* and *firm innovativeness* as organizational factors, as these factors were identified in previous studies as relevant factors for the analysis of the certification to management system standards [8], [23], [33], [43], [75], [76] or IS innovation adoption on firm level in general [70], [77].

In the technological context, "current practices" can determine the adoption of innovations [70], especially in terms of their compatibility with the new practice [77]. We, therefore, consider *certified to other management system standards* a "current practice" since certification to one management system standard is often linked to the certification to other management system standards [32], [51].

Taking into account that ISO/IEC 27001 is strongly associated with the IT sector [60], [61], we selected the *sector* as an external environmental factor for our study.

## III. Methodology

### A. Web Mining for Innovation Indicators

Web mining based on previously web scraped websites has proven itself to be applicable in many research areas [78], [79]. In economic research, firm websites are a particularly interesting area of the World Wide Web. Firms use their websites to present themselves as well as their products and services. The information found on these websites can be used to assess firms' products, services, credibility, achievements, key personnel decisions, strategies, and relationships with other firms [80]. Surveying firms through their websites, rather than conducting interviews, questionnaires, or using other traditional methods, offer clear advantages (coverage, granularity, cost, and timeliness), but it is also associated with its own challenges (data collection, harmonization, and data quality) [19].

There are only a few existing studies that analyze the usability of web-based innovation indicators. These studies either use web content mining or web structure mining [81]. The latter is the analysis of connections between entities (e.g., firms) via the hyperlink structure of websites. Katz and Cothey [82] used this approach in a case study on European and Canadian education institutions. They find that their method is suitable for measuring the degree of recognition of a nation's or province's web presence they receive from other nations and provinces. The authors emphasize the importance of reproducible and accurate indicators capable of dealing with the constantly changing properties of the Internet.

In web content analyses, texts and other website contents are analyzed. This approach is taken by the following studies: Youtie *et al.* [83] used web mining to explore the transitions from discovery to commercialization of 30 nanotechnology SMEs. Arora *et al.* [84] used a similar approach to analyze entry strategies of SMEs commercializing emerging graphene technologies. Both study approaches are capable of identifying different innovation stages. Applying a keyword technique to explore the R&D activities of 296 UK-based enterprises, Gök *et al.* [80] found that web-based indicators provide additional insights compared to patent and literature-based innovation indicators. In addition, they emphasize that web mining has another advantage as a research method. The act of surveying a subject using web scraping and web mining does not cause particular problems, such as altering the behavior of the study object in response to being studied. The authors conclude "[…] that web mining is a significant and useful complement to current methods, as well as offering novel insights not easily obtained from other unobtrusive sources" [80]. However, they raise the criticism that obtaining information from website data is more difficult and that caution is required when generating web-based indicators. Information on websites is generally more related to innovation output than to input. In addition, websites are self-reported, and firms do not publish any new information on their websites at equal frequencies. Beaudry *et al.* [85] used a keyword technique to generate innovation indicators of Canadian aeronautic, space, and defense as well as nanotechnology-related firms based on the text on their websites. They found a significant correlation between their web-based and traditional innovation indicators.

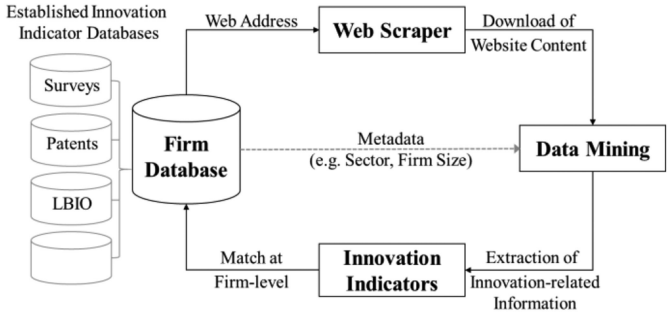


Fig. 3. General analysis framework for generating web-based innovation indicators. Source: [19].

Nathan and Rosso [86] combined the UK administrative microdata, media, and website content to develop experimental measures for innovation in SMEs. The authors used proprietary data gathered by a data firm that uses website and media content to model lifecycle events of firms such as new product and service launches. They were able to identify three times more product/service launches than patent applications from SMEs. Nathan and Rosso [86] concluded that web-based indicators are a useful complementary measure to existing metrics as they reveal additional information. Moreover, they found that previous patent activities are related to a firm's current launch activities and that tech SMEs are much more likely to launch new products or services than nontech SMEs. Studies on web-based innovation indicators have thus confirmed that firm websites are an interesting and rich data source for examining the innovation activity of firms and science, technology, and innovation systems in general.

### B. Data Collection and Sample

Kinne and Axenbeck [19] proposed a generally applicable framework for studying firm websites based on established firm databases (see Fig. 3). Starting from the firms' website addresses, a web scraper queries the websites and downloads their content (e.g., texts). In a subsequent data mining step, which can be enriched with available firm metadata (e.g., for data mining model preselection), the so-called innovation-related information is extracted and transferred to firm-level innovation indicators. In the final step, these new innovation indicators are matched back to the firm database at the firm level. This last step also established a link between the new indicators and the traditional ones (e.g., patents) that can be used for validation.

In this article, we apply the web mining approach as described in Fig. 3 to identify and analyze German companies that mention the ISO/IEC 27001 standard on their websites.

Therefore, we use the Mannheim Enterprise Panel (Mannheimer Unternehmenspanel—MUP) from 2019 as a basic dataset. The MUP is based on a firm data pool of Germany's largest credit rating agency (Creditreform e.V.) and, as a panel firm database, comprises all economically active firms located in Germany and the associated metadata (e.g., sector, firm size, and location) [87].

In the beginning of 2019, the MUP comprised 2 497 412 firms that were definitely economically active at that time and 1 155 867 corresponding website addresses (URLs). With these 1 155 867 URLs, we were able to successfully scrape texts from 912 850 firm websites using the open-source ARGUS web scraping tool [19]. Referring to the findings of Kinne and Axenbeck [19], we downloaded a maximum of 25 webpages per website (the median number of webpages per firm website in Germany is 15). We also used ARGUS' options to download preferably German language webpages and those with shorter URLs. The latter follows the idea that the most general information about a firm can be found on its top-level webpages (e.g., "firm-name.com/about-us"). Based on the results of a comprehensive study performed by Kinne and Axenbeck [19], it can be expected that the coverage of our sample of scraped website texts will differ systematically between sectors and firm types; only a small fraction of very young and very small firms (smaller than five employees and younger than two years) will be included. Sparsely populated regions and certain sectors, such as agriculture, are also less well covered. Medium-sized and larger firms are expected to be almost fully covered, especially in technology-intensive sectors, such as mechanical engineering [19].

The web scraping process described above resulted in approximately 47 GB of raw text data for the 912 850 firms. To identify firms that mention ISO/IEC 27001 on their websites, we used a simple keyword search. Taking into account the possible writing options for the individual management system standard, we have included all combinations of DIN (the German Institute for Standardization), ISO and IEC with 27000 and 27001 and tagged all firm websites with at least one occurrence of at least one of the search string combinations.

### C. Methodology to Analyze the Adoption of ISO/IEC 27001 in Germany

The first step of the analysis focused on the number of firms that refer to ISO/IEC 27001 on their websites. In a subsequent step, we categorized the firms according to the reason why they refer to ISO/IEC 27001 on their website, assuming that not all firms are certified, but refer to this management system standard for other reasons. To ensure a correct manual categorization of the firms in this sample, the webpages of these firms were analyzed in detail per firm using predefined codes (e.g., firm is certified, adopts a standard without certification, offers consulting or certification services, and any other reference) and two additional codes derived during the coding process (firms employing certified IT specialists and firms that are not certified themselves but refer to certified business partners). This coding was conducted by three persons and all certified firms were independently validated by another person to ensure consistent results.

### D. Methodology to Analyze Driving Factors for ISO/IEC 27001 Certification in Germany

For our following statistical analysis, we use the variables as described in Table I. We rely on the firm data in the MUP, which are available to 50% in terms of firm size, to 94% in terms of firm age, and to 99% in terms of affiliation to the sector of all web scraped firms. Furthermore, a firm-level product innovator probability is available for 82% of all web scraped firms.

TABLE I
DESCRIPTION OF VARIABLES

| Model variable | Description |
|---|---|
| *Dependent variable* | |
| Certification to ISO/IEC 27001 | 1 if a firm obtained a certificate for ISO/IEC 27001, 0 otherwise. Derived from web mining and subsequent manual firm categorization |
| *Independent variables* | |
| Firm Size | Logarithm of number of the firms' employees. Derived from MUP firm data base |
| Firm Age | Logarithm of years since founding date. Derived from MUP firm data base |
| Innovation Probability | Probability (0.0 to 1.0) that the firm is a product innovator. Derived from a deep learning model |
| Sector | Sector affiliation using NACE classification Derived from MUP firm data base [20] |

This prediction is based on the firm's website text and a deep learning model trained on the websites of firms surveyed in the German Community Innovation Survey (CIS) (see [20] for more details). In particular, traditional firm-level indicators from a questionnaire-based innovation survey (German CIS) were used to train an artificial neural network classification model on labeled (product innovator/no product innovator) web texts of surveyed firms. Subsequently, this classification model was applied to the web texts of hundreds of thousands of firms in Germany to predict whether they are product innovators or not. The authors compared these predictions to firm-level patent statistics, survey extrapolation benchmark data, and regional innovation indicators. The results showed that this approach produces reliable predictions and has the potential to be a valuable and highly cost-efficient addition to the existing set of innovation indicators, especially due to its coverage and regional granularity [20].

## IV. RESULTS

### A. Results of the Adoption Analysis of ISO/IEC 27001 in Germany

Out of the 1.15 million web scraped firms, a total of 47 919 firms refer to one of the management system standards, which corresponds to about 4.15% of all scraped firms. Most firms refer to ISO 9001, followed by ISO 14001, ISO 50001, and ISO/IEC 27001. This also corresponds to the ranking of valid ISO certificates published in Germany in 2017 as part of the ISO survey (see Table II).

As a first finding, only in the case of ISO/IEC 27001, the number of firms referring to this standard on their website is larger than the number of valid certificates according to the ISO survey [60]. Since firms can obtain more than one certificate

TABLE II
COMPARING CERTIFIED FIRMS OF MUP SAMPLE WITH VALID CERTIFICATES IN GERMANY

| | *# firms (MUP)* | *# certificates (Germany)* | *Relation:* |
|---|---|---|---|
| ISO 9001 | 35,706 | 64,658 | 0.55 |
| ISO 14001 | 6,789 | 10,176 | 0.67 |
| ISO 50001 | 2,760 | 8,314 | 0.33 |
| ISO/IEC 27001 | 2,664 | 1,339 | 2.00 |

Source: [60].

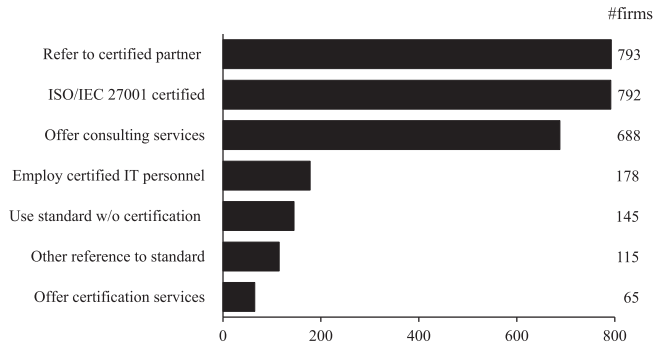


Fig. 4. Firm categorization of 2664 firms referring to ISO/IEC 27001 on their websites.

per management system standard (e.g., for different branches or organizational units within one firm), our comparison can, however, only serve as a rough proxy. Furthermore, firms can refer to the management system standards on their websites for other reasons than being certified.

Fig. 4 shows the results of manually categorizing the reasons why firms refer to ISO/IEC 27001 on their websites. In general, it should be noted that firms can belong to several categories, e.g., a consulting firm offering services in connection with ISO/IEC 27001 can also be certified to ISO/IEC 27001.

In total, 29.7% of the firms refer to ISO/IEC 27001 on their websites because they are ISO/IEC 27001 certified. A relatively small proportion (5.4%) stated that they have adopted a standard, but are not officially certified, although they often claim on their websites to seek certification in the future. Total 6.7% of firms employ certified IT personnel without having obtained a certificate for the firm's ISMS. However, the highest proportion of 29.8% of firms was not certified themselves but referred to a certified partner. Many firms referring to ISO/IEC 27001 offer consultancy (25.8%) or certification services (2.4%) related to ISO/IEC 27001. Overall 4.3% of all firms have referred to ISO/IEC 27001 for other reasons, e.g., to provide news about this management system standard.

For the companies certified to ISO/IEC 27001, we have also investigated the likelihood that firms will be certified to other international management system standards as technological context factor (see Fig. 2). Therefore, we have manually visited their websites and have searched for a different management system certificate. As a finding, a large proportion of firms certified to ISO/IEC 27001 is also certified to ISO 9001, followed by ISO 14001 and ISO 50001, as shown in Table III.

TABLE III
OBSERVED CO-OCCURRENCES OF REFERENCES TO MANAGEMENT SYSTEM STANDARDS IN ABSOLUTE AND RELATIVE TERMS

| | *ISO 9001* | *ISO 14001* | *ISO 50001* |
|---|---|---|---|
| ISO/IEC 27001 | 339 (42%) | 111 (14%) | 52 (7%) |

TABLE IV
SECTOR AFFILIATION OF ISO/IEC 27001 CERTIFIED FIRMS VERSUS NONCERTIFIED MUP FIRMS

| | *Certified MUP firms* | | *Non-certified MUP firms* | | *Difference* |
|---|---|---|---|---|---|
| | Obs. | % | Obs. | % | in % points |
| ICT services | 338 | 43.00 | 34,051 | 3.75 | +39.25 |
| Other services | 58 | 7.38 | 54,990 | 6.06 | +1.32 |
| Consulting | 53 | 6.74 | 49,634 | 5.47 | +1.27 |
| Financial services | 52 | 6.62 | 26,352 | 2.90 | +3.72 |
| Management services | 44 | 5.60 | 21,005 | 2.31 | +3.29 |
| Retail | 32 | 4.07 | 93,971 | 10.36 | -6.29 |
| Engineering services | 31 | 3.94 | 37,315 | 4.11 | -0.17 |
| Public utility | 28 | 3.56 | 7,902 | 0.87 | +2.69 |
| Personal services | 24 | 3.05 | 34,660 | 3.82 | -0.77 |
| Wholesale | 24 | 3.05 | 55,917 | 6.16 | -3.11 |
| Transport/logistics | 19 | 2.42 | 19,828 | 2.19 | +0.23 |
| Creative services | 17 | 2.16 | 29,485 | 3.25 | -1.09 |
| Leisure services | 11 | 1.40 | 22,313 | 2.46 | -1.06 |
| Construction | 9 | 1.15 | 99,233 | 10.94 | -9.79 |
| Electronics/optics | 6 | 0.76 | 4,654 | 0.51 | +0.25 |
| All other | 40 | 5.10 | 316,148 | 34.84 | -29.74 |
| **Sum** | 786 | 100% | 907,458 | 100% | |

Out of the 792 ISO/IEC 27001 certified firms, 30% are certified to one additional standard, 9% against two further standards, and 5% against all three other management system standards.

### *B. Results on the Analysis of Driving Factors for ISO/IEC 27001 Certification in Germany*

*1) Descriptive Statistics:* In terms of sector affiliation, almost half (43%) of all ISO/IEC 27001 certified firms offer ICT services, which is significantly higher than approximately 4% of all firms in the MUP data sample offering ICT services (see Table IV). ISO/IEC 27001 certified firms providing consultancy and financial services are also overrepresented as well as public utilities compared to noncertified firms in the MUP database. The results also show that ISO/IEC 27001 certification is not very common in "traditional" sectors, such as construction, retail, or manufacturing.

To differentiate between firms providing ICT services and other firms, we present the following descriptive statistics for all firms (all sectors), and in a second step, we focus just on

TABLE V
FIRM CHARACTERISTICS OF ISO/IEC 27001 CERTIFIED FIRMS VERSUS NONCERTIFIED MUP FIRMS

| All Sectors | | |
|---|---|---|
| *Mean* | *Certified MUP firms* | *Non-certified MUP firms* |
| Firm Size*** | 76 (229.27) N=596 | 23 (483.61) N=458,933 |
| Firm Age*** | 17 (14.03) N=768 | 24 (42.44) N=858,902 |
| Innovation probability*** | 0.57 (0.20) N=774 | 0.25 (0.16) N=749,580 |
| **ICT Service Sector** | | |
| *Mean* | *Certified ICT service firms* | *Non-certified ICT service firms* |
| Firm Size*** | 61 (129.11) N=274 | 15 (78.82) N=16,896 |
| Firm Age*** | 17 (12.53) N=333 | 14 (18.33) N=33,050 |
| Innovation probability*** | 0.62 (0.18) N=331 | 0.49 (0.21) N=27,266 |

*Notes:* Standard deviation in parentheses. $N$ = Number of observations. Significance from the $t$-test: $^{*}\ p < 0.10$; $^{**}\ p < 0.05$; and $^{***}\ p < 0.01$.

the companies that are attributed to ICT services, as they are responsible for almost half of all certifications. In both cases, the results of the descriptive statistics on firm size, firm age, and innovation probability presented in Table V reveal significant differences between the firms certified to ISO/IEC 27001 and noncertified firms.

Taking into account firms of all sectors, first, the certified firms with 76 employees are more than three times as large as the average noncertified firm in the MUP. Second, and in contrast, certified firms aged 17 years are on average seven years younger than the average of noncertified firms. Third, the innovation probability of 57% is twice as high as the average innovation probability of noncertified firms.

Surprisingly, when focusing on firms attributed to ICT services, the average age is the same as for all ISO/IEC 27001 certified companies. Certified ICT service firms are still larger than noncertified ICT service firms with 61 employees compared to 15 employees. Aged 17 years, however, they are also older than noncertified firms in the ICT service sector aged 14 years. After all, firms in the ICT service sector have a product innovation probability of almost 50%, i.e., almost twice the probability of all noncertified firms. However, certified firms in the ICT sector have an even higher product innovation probability with 62%.

Summarizing the findings from the analysis of the descriptive statistics, we can see a positive relationship between firm size and the probability of certification. A positive correlation with firm age can only be observed within the ICT service sector. Furthermore, innovativeness increases the likelihood of certification, while the high proportion of certified firms belonging to the ICT service sector (see Table V) indicates that this sector is strongly linked to certification against ISO/IEC 27001.

TABLE VI
PROBIT ESTIMATION RESULTS

| *Independent variables* | *Certification to ISO/IEC 27001 MUP total* | *Certification to ISO/IEC 27001 ICT Service Sector* |
|---|---|---|
| Firm Size (in logs) | 0.179*** (0.00078) | 0.238*** (0.00986) |
| Firm Age (in logs) | -0.057** (-0.00025) | 0.011 (0.00046) |
| Innovation Probability | 1.564*** (0.00679) | 0.624*** (0.02591) |
| Sector Dummies | Yes (base: ICT service sector) | |
| Constant | -3.249*** | -2.992*** |
| Observations | 345,607 | 14,333 |
| Model Chi-square | 2063.20*** | 252.43*** |

*Notes:* The table displays the coefficients of all observations in the MUP and ICT service sectors and the marginal effects of each in brackets. A correlation matrix of the variables is provided in Table VIII and the probit estimation results for the sector dummies in Table X $^{*}p < 0.10$.$^{**}\ p < 0.05$.$^{***}p < 0.01$.

TABLE VII
SECTOR AFFILIATION OF TÜV RHEINLAND ISO/IEC 27001 CERTIFIED FIRMS

| | Observations | Percent |
|---|---|---|
| ICT services | 123 | 47.13 |
| Other services | 23 | 8.81 |
| Public utility | 17 | 6.51 |
| Consulting | 13 | 4.98 |
| Management services | 12 | 4.60 |
| Financial services | 10 | 3.83 |
| Health & social services | 9 | 3.45 |
| Electronics/optics | 8 | 3.07 |
| Engineering services | 7 | 2.68 |
| Personal services | 6 | 2.30 |
| All other | 33 | 12.64 |
| **Sum** | **261** | **100** |

*2) Probit Model:* Finally, we run a probit model. Our probit models test the probability of the event (= certification to ISO/IEC 27001) as a dependent variable and the independent variables as shown in Table I.

The results of our two probit models are shown in Table VI. In the general model, which covers all MUP firms, significant results are shown for all explanatory variables. First, the likelihood to be certified to ISO/IEC 27001 increases significantly with firm size. Second, older firms are significantly less likely to be certified to ISO/IEC 27001. Third, firms with a higher innovation probability are more likely to be certified to ISO/IEC 27001. Finally, firms operating in the ICT service sector are more likely to be ISO/IEC 27001 certified than firms operating in any other sector as shown in Tables VII and X.

Consequently, we run a second probit regression model just for the firms active in the ICT service sector. Here, too, the firm size is significantly positively associated with the likelihood of being certified to ISO/IEC 27001. However, the age of firms in this sector does not significantly explain the likelihood of

certification. Finally, firms in the ICT service sector with a higher innovation probability are more likely to be certified to ISO/IEC 27001. In addition, this relationship is stronger than in the sample of all firms based on the marginal effects shown in brackets.

Since only a very small proportion of the firms in the MUP sample are ISO/IEC 27001 certified (less than 0.1%), we encounter the problem of a small sample bias. In our search for rare events, we, therefore, apply the method proposed by King and Zeng [89] and run a corrected logit estimate for our independent variables firm size, firm age, and innovation probability. The corrected logit estimates provided in Table IX confirm the results of our probit models.

### C. Validation

To validate our findings and to avoid a single source bias, we relied on another independent dataset. Therefore, we have manually analyzed the ISO/IEC 27001 certified firms of the German certification body TÜV Rheinland, which publishes their valid certification[1]. In this certification database, we have identified 358 valid certificates of 261 German firms that are certified to ISO/IEC 27001.

First, we examined which sector these firms belong to. Second, we analyzed whether these firms publish their certificates on their websites, and if not, whether they publish a logo instead. Third, we analyzed how many certified firms would have been identified using our web scraping.

We found a similar sector breakdown (see Table VII) as our web mining results (see Table IV), which confirms that most ISO/IEC 27001 certified firms offer ICT services, followed by other services. Firms belonging to the public utility sector (e.g., energy providers) rank higher in this sample compared to our web mining sample, but this could also indicate a certain affiliation of this sector to this particular certification body.

Out of the 261 ISO/IEC 27001 certified firms, 39 firms (equaling 15%) did not publish a written reference to an ISO/IEC certification on their websites, one-third of them offering ICT services. Out of these 39 firms, 5 firms displayed a logo instead, representing less than 2% of the 261 firms.

Since our web scraper only searched for the top 25 webpages per firm, our web scraper would have identified 44% of these certified firms that are included in the MUP. This finding shows that the remaining ISO/IEC 27001 certified firms would have only be identified with a higher scraping effort, i.e., more webpages per company. Our manual analysis, furthermore, revealed that especially larger firms do not display their certificates on the top 25 webpages, but at lower level webpages—e.g., on the webpages of specific products or news pages.

## V. Discussion

### A. Discussion on the Adoption of ISO/IEC 27001 in Germany

The initial finding of our web mining revealed that double the number of firms refer to ISO/IEC 27001 on their websites as valid certificates according to ISO (2018) are available in Germany. Our manual categorization, however, showed that out of the 2664 firms identified, only 792 firms are certified to ISO/IEC 27001, which now represents roughly 60% of all valid certificates. This finding shows that many firms refer to this management system standard in relation to ISO/IEC 27001 for reasons other than being certified. Therefore, the manual categorization of all firm websites in our ISO/IEC 27001 analysis has helped to create a "landscape" of the adoption of ISO/IEC 27001 (see Fig. 5) including a demand side and a supply side to gain a better understanding of the ISO/IEC 27001 adoption in Germany.

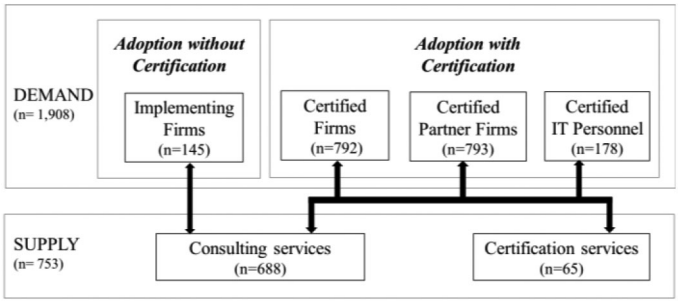


Fig. 5. ISO/IEC 27001 "landscape" of German firms.

On the demand side, the landscape does not only include certified firms, which is often the case with previous studies about management system standards using ISO survey data. Firms can also adopt this management system standard without seeking certification for themselves, which we refer to as implementing firms. The results show a comparatively small number of firms that have not (yet) received a certificate but have only adopted the standard. Referring to a study by Irish managers, which stated that 12% of firms use standards, such as ISO/IEC 27001, but only 2% are certified [90], it could have been expected that more firms had implemented the standard instead of being additionally certified. However, it may not be worthwhile to communicate on the website, if firms have implemented a standard without a formal attestation.

The landscape also shows the important role of IT personnel, as discussed above by Benslimane *et al.* [66], as it also implements security practices in firms according to the ISO/IEC 27001 standard, which can also serve as a signal to stakeholders. For example, IT personnel may have obtained certificates such as Information Security Officer or Auditor according to ISO/IEC 27001 (e.g., [91] as an example).

A key finding of our explorative research is the possibility to refer to partners (such as cloud computing providers or data centers) that are certified. This option shows the main difference between ISO/IEC 27001 and the other management system standards, as it is possible to outsource information security to some extent, which is unlikely for quality, environmental, and energy management. It is, therefore, possible that outsourcing will not take place in the Far East, for example, as discussed by Fomin *et al.* [10], but to IT service providers within Germany or Europe. This could also be spurred by the General Data Protection Regulation (GDPR), which entered into force in May

[1][Online]. Available: www.certipedia.com

2018. Although ISO/IEC 27001 certification should not be seen as a tool to signal GDPR compliance, ISO/IEC 27001 can help to comply with the GDPR [92]. In order to elaborate this effect of "indirect certification" theoretically, one can apply theories about networking and, in particular, brand leveraging and co-branding, concepts that traditionally originate from marketing and, in particular, consumer research [93]. In our case, firms can be "embedded" in a network and gain reputation and trust by claiming an alliance with a partner who is certified, as shown by Hu *et al.* [94], in the case of technical standard alliances.

The "landscape" (see Fig. 5) also includes the supply side of ISO/IEC 27001, by involving certification bodies and consultants as important actors in the diffusion work [57] of this management system standard. The large number of consultants active in the field of ISO/IEC 27001 and providing knowledge of this standard indicates, first, a need for firms to use consulting firms for the implementation of ISO/IEC 27001. Second, it indicates that firms may implement this standard with the help of consultants rather than to be officially certified. This can also help explain the low adoption of ISO/IEC 27001 in Germany given the low number of valid certificates [60], although on average almost 30% of all German companies claim to have a formally defined ICT security policy that takes into account the confidentiality, integrity, and availability of their data and ICT systems [95].

### *B. Discussion on Driving Factors for ISO/IEC 27001 Certification in Germany*

Our regression analysis revealed that larger and more innovative firms, most of them belonging to the ICT service sector, are more prone to ISO/IEC 27001 certification.

The significant size effect supports the findings of previous studies on other management system standards [33], both for all firms and for ICT service providers. Obviously, certification costs present a problem for smaller companies that may not be compensated by the benefits of achieving certification to ISO/IEC 27001 [12]. Since the firm size is often correlated with firm age [96], we expected a positive effect that is only the case for ICT service firms (see Table V), though not significant (see Table VI). Therefore, different organizational factors and IT skills may lead to differences in the perception of firms in terms of information security and related investments, apart from size, age, and innovativeness, which should be subject to future research.

Our findings have several implications for managers, policy makers, and standard development organizations. From a managerial perspective, it shows that firms can make use of ISO/IEC 27001 either in terms of implementation versus certification (1), the use of certified IT personnel (2), and the reference to a certified partner (indirect certification) (3) without having to bear the time and cost for certification. Therefore, depending on their individual objectives, firms should critically examine whether it is worthwhile to seek certification (e.g., as a competitive advantage or because stakeholders require an independent attestation) or not. In some cases, the implementation of ISO/IEC 27001 might be a good start to increase the overall level of information security, including employee awareness, without bearing the immediate costs for certification.

From a policy perspective, our findings have an impact when policy makers decide to make use of ISO/IEC 27001 to increase the overall level of information security in firms. First, the significant firm size effect may require action. Policy makers could, for example, spur the diffusion of ISO/IEC 27001 among SMEs by providing incentives to firms that seek services, e.g., from consultants, to implement an ISMS according to ISO/IEC 27001. Second, the benefits for smaller firms implementing an ISMS according to ISO/IEC 27001 may not be sufficiently known or measurable for smaller companies. Therefore, standards development organizations could publish practical guidance documents, in particular, to help SMEs apply the ISO/IEC 27000 series, as proposed by the European Commission in its recent rolling plan for ICT standardization [98]. Third, it is worth investigating whether independent third-party certification is required or whether a self-declaration of conformity might be useful to achieve the respective goal. Finally, looking closely at the ISO/IEC 27001 certified firms, they most often belong to the ICT service sector. Hence, the question arises as to whether the concentration of certifications among ICT service firms is sufficient for an overall adequate level of information security because they provide services to companies throughout the entire economy, or whether we have a significant gap here. This might be true, in particular, for manufacturing firms, particularly in view of the increasing connectivity related to Industry 4.0, which may require further actions from policy makers.

## VI. Conclusion

For the first time, we used web mining as a data source and method to examine German firms in the MUP database with a website with reference to ISO/IEC 27001 in this article.

A manual categorization of all firms with ISO/IEC 27001 reference on their websites enabled the development of an ISO/IEC 27001 "landscape", as outlined in Fig. 5, covering both the demand side (firms making use of this management system standard) and the supply side of this management system standard (firms providing services related to ISO/IEC 27001).

The implications of our findings can lead to a better understanding of the reasons for the (low) adoption of ISO/IEC 27001. First, the small number of valid certificates reported in the ISO survey is not necessarily due to the low adoption rate of the standard. Firms can also benefit from either implementing the management system standard without seeking certification or by using certified IT personnel. Second, firms make use of certified partners to which they refer on their websites, a phenomenon that we term "indirect certification." These partners (mostly cloud suppliers and data centers), therefore, have a multiplier effect by providing information security to a larger number of firms.

Our web mining based analysis of firms that refer to ISO/IEC 27001 on their websites showed that this method can be used in combination with a manual firm-by-firm evaluation to gain a better understanding of the drivers for certification to ISO/IEC 27001. We have shown that firm size, innovativeness, and affiliation to the ICT service sectors are potential drivers

for ISO/IEC 27001 certification. In particular, smaller firms seek less certification than larger firms, which may call for the need for supporting SMEs in implementing ISO/IEC 27001 and seeking certification.

From a legal perspective, certification against ISO/IEC 27001 is voluntary for firms per se. However, this could change in the near future not only in the light of the NIS-Directive but also of the latest EU Cybersecurity Act. In addition, firms can adopt ISO/IEC 27001 to demonstrate compliance with the principles of technical and organizational measures to protect information for the purpose of the GDPR [99]. Thereby, the results of this article can help to derive more substantial recommendations for the application of this management system standard, e.g., if a mandatory certification for firms in specific sectors or alternative measures to increase the adoption of ISO/IEC 27001 are discussed.

From a methodological perspective, web mining of firm websites supplements the traditional methods of standard adoption research, which are often based on surveys and are qualitative in nature, or in the case of diffusion research based on national macrodata.

However, web mining and this article are not without limitations. As far as the applicability of the method is concerned, our web scraping first covered only the top 25 webpages per website. A previous study showed that the median number of subweb pages per website of German firms is 15, but this number of webpages is also strongly correlated with the size of the firm [19]. This suggests that our rather low per-website scraping limit can induce a bias against larger firms, which we also found in our validation, indicating that German ISO/IEC 27001 certified firms may be even larger than our empirical results suggest. For future web mining studies, we therefore suggest either using a higher scraping limit for all firms or adjusting the scraping limit according to the available firm size information.

Second, our analysis assumes that all firms certified to ISO/IEC 27001 would announce this on their websites. However, firms are not obliged to do so, and some sectors, such as ICT services or electronics, may be more prone to the presentation of their certificates on their websites than other sectors [67]. Therefore, firms active in the health or tourism sector may see a lower value for their goal of publishing their certificates and hence there may be a distortion in certain sectors.

Third, our web mining (by keywords only) cannot distinguish whether firms are certified or otherwise refer to this management system standard. Therefore, only a combination of web mining and manual analysis allowed a suitable categorization. In order to make use of this method to a greater extent, further automation would be needed using a web scraper. This could include the recognition of images to identify certificates, or the use of neural networks to predict whether a firm is certified to a particular management system standard.

Finally, the positive relationship of firm drivers for ISO/IEC 27001 certification does not necessarily imply causality. Further research is needed to examine the drivers and barriers to the adoption of ISO/IEC 27001. As a first step, our categorized firms that are certified to ISO/IEC 27001 or have adopted this standard (without certification) can be used to analyze the context in which firms refer to the use of ISO/IEC 27001 on their website as a motive for adoption and further sector segmentation. This analysis could also be extended to firms that refer to certified partner firms to examine the drivers for this type of "indirect certification". Additional methodological approaches, such as interviews and surveys, are needed to theoretically support these correlations and to identify further drivers and barriers in connection with ISO/IEC 27001 certification. Our identified firms can therefore serve as a sample.

Our approach of defining certifications based on management system standards as organizational innovation itself opens up a new research field to investigate the relationship between product innovation and certifications in the context of international management system standards as organizational innovations [22]. This raises the question of timing, i.e., whether product innovations trigger certification to management system standards as organizational innovations [97] or vice versa. However, this question cannot be answered by the available cross-sectional data but requires time-series data.

## APPENDIX

See Tables VIII–Table X

TABLE VIII
CORRELATION MATRIX OF THE VARIABLES

| | *Firm Size* | *Firm Age* | *Innovation probability* | *ISO/IEC 27001 certified* |
|---|---|---|---|---|
| Firm Size | 1.000 (1.000) | | | |
| Firm Age | 0.337* (0.329*) | 1.000 (1.000) | | |
| Innovation probability | -0.042* (0.266*) | -0.146* (0.033*) | 1.000 (1.000) | |
| ISO/IEC 27001 certified | 0.026* (0.117*) | -0.007* (0.044*) | 0.050* (0.069*) | 1.000 (1.000) |

*Notes:* The table shows the pairwise correlation coefficients of all observations in the MUP. ICT sector service coefficients are in brackets.
* $p < 0.01$.

TABLE IX
CORRECTED LOGIT ESTIMATES

| *Independent variables* | *Certification to ISO/IEC 27001 MUP total* | *Certification to ISO/IEC 27001 ICT Service Sector* |
|---|---|---|
| Firm Size (in logs) | 0.398*** | 0.553*** |
| Firm Age (in logs) | -0.287*** | 0.062 |
| Innovation Probability | 5.804*** | 1.415*** |
| Constant | -8.923*** | -6.188 *** |
| Observations | 374,145 | 14,333 |

*Notes:* The table displays the coefficients of all observations in the MUP and ICT service sectors applying rare event logistic regression.
* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

TABLE X
PROBIT ESTIMATION RESULTS FOR SECTOR DUMMIES

| *Sector* | *Coefficient* | *Marginal effect* |
|---|---|---|
| Automobile trade/repair | -1.232*** | -0.00653 |
| Automotive manuf. | -1.076*** | -0.00641 |
| Chemicals | -1.152*** | -0.00648 |
| Construction | -0.946*** | -0.00625 |
| Consulting | -0.460*** | -0.00474 |
| Creative services | -0.601*** | -0.00540 |
| Education | -1.274*** | -0.00656 |
| Electrical engineering | -0.995*** | -0.00632 |
| Electronics/optics | -0.975*** | -0.00629 |
| Engineering services | -0.627*** | -0.00549 |
| Financial services | -0.383*** | -0.00427 |
| Health & social services | -1.487*** | -0.00664 |
| Interest groups | -1.090*** | -0.00642 |
| Leisure services | -0.613*** | -0.00544 |
| Management services | -0.158** | -0.00224 |
| Mechanical engineering | -1.569*** | -0.00666 |
| Media | -0.646*** | -0.00556 |
| Metalware | -1.203*** | -0.00651 |
| Mining | -0.427 | -0.00455 |
| Other manufacturing | -1.041*** | -0.00637 |
| Other services | -0.444*** | -0.00465 |
| Personal services | -0.540*** | -0.00514 |
| Public utility | 0.002 | 0.00004 |
| Real estate business | -0.748*** | -0.00586 |
| Repair/installation | -0.731*** | -0.00582 |

*Notes:* The table displays the coefficients and marginal effects based on the ICT service sector. $^{*}\ p < 0.10$. $^{**}\ p < 0.05$. $^{***}\ p < 0.01$.

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