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Factors affecting the adoption of quality standards in the semiconductor industry: The importance of stakeholder pressures

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ABSTRACT

Standards play a significant role in the semiconductor industry. However, few scholars have focused on gaining a better understanding of standardization in this industry. This study examines a specific aspect of standardization: the adoption of quality standards by companies in The Netherlands' semiconductor industry. Multiple quality standards are available and the uncertainty surrounding that choice is high. There is a need to decrease this uncertainty. This paper attempts to accomplish that by focusing on a Dutch multinational semiconductor company that has adopted quality standards that improve sustainability. This is a typical example of a company affected by uncertainty regarding the quality standards that should be adopted. Based on a literature review and interviews with experts from the company, we develop a list of factors that influence the company's adoption of two quality standards and assign weights to these factors by applying the best-worst method. Our results show that pressure from customers, pressure from big players, management support, and formalization are the most important factors explaining quality standard adoption in The Netherlands' semiconductor industry. Applying these factors and weights can reduce the uncertainty for companies regarding which standards should be adopted, which is the practical implication of our study.

Introduction

The semiconductor industry depends on standards (Khazam & Mowery, 1994; Vanhaverbeke & Noorderhaven, 2001). Standards are *sets of solutions that help address so-called coordination problems* (Grillo et al., 2024). They can be divided into categories, such as standards that guarantee compatibility between systems (e.g., USB and Wi-Fi), variety-reducing standards (e.g., A4 paper size), information and measurement standards (e.g., meters), and standards that specify a minimum quality (e.g., ISO9001) (Blind, 2004). This study focuses on quality standards. Scholars also often distinguish between types of standards based on how they come into existence and the actors involved. They distinguish between *de facto* and *de jure* standards. The former emerge through *market-mediated* processes and are often developed by (consortia of) companies, whereas the latter are discussed in committees or enforced by the government (David & Greenstein, 1990). How standards are entered into forceoften varies across regions (Van de Kaa & Greeven, 2017). This study focuses on *de jure* quality standards developed by committees in The Netherlands.

Scientists investigating standardization often focus on gaining a better understanding of the standardization process. They mainly examine the development of standards within formal organizations (Backhouse et al., 2006; Lemstra et al., 2011), their effects (Wu & de Vries, 2022), the strategies that companies can apply (Gallagher, 2012; Gallagher & Park, 2002; Shapiro & Varian, 1998; Van de Kaa et al., 2011) and the characteristics of the firm (Dai et al., 2024) to achieve dominance with their standards. Few researchers have examined the factors that influence companies' adoption of standards (Van de Kaa, 2023) or their effects (Scott et al., 2017). Most researchers have focused on standardization in the fields of consumer electronics, information technology, and telecommunications. Few researchers have examined standardization in the semiconductor industry (the two exceptions are Khazam and Mowery (1994) and Vanhaverbeke and Noorderhaven (2001)). This study contributes to standardization research by focusing on an aspect that is often under-researched (i.e., the factors that lead to the adoption of quality standards) and on a sector that is scarcely studied (i.e., the semiconductor industry).

The research objective of this study is to present the factors that lead

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to the adoption of quality standards. The research question is: *Which factors affect the adoption of quality standards in the semiconductor industry in The Netherlands, according to experts?* We investigate two standards that support sustainability and cleaner production – ISO 9001 and ISO 13485. We answer the research question by conducting a literature review of the main theories that discuss the factors in the adoption of standards. We then supplement those factors with opinions from experts in the semiconductor industry and rank the factors according to importance using the best-worst method (BWM).

The remainder of this paper is organized as follows. The paper provides an overview of theoretical perspectives concerning standards adoption and then describes the methodology in detail. The results are then presented. The paper concludes with a discussion, implications, and suggestions for future research.

Theoretical perspectives on standards adoption

Hashem and Tann (2007) distinguished between the five phases in innovation adoption, which they argue can also be applied to standards adoption. First, awareness will arise about the existence of the standard, and, often, at this stage, the company will look for more detailed information about the standard so that it can be better understood. In the second phase, the company forms an opinion of the standard by estimating the effect of its adoption. Third, the standard is evaluated by assessing the advantages and disadvantages of its adoption. In the fourth stage, called the *adoption stage*, the decision is made to choose whether to implement or reject the standard. Finally, if the standard is adopted, actual and continued use might be set in. This study focuses on the fourth stage, i.e., the decision to implement the standard, which is referred to as standard adoption in this paper. The fields and factors involved are discussed in the following subsections.

Adoption of innovations

Innovation adoption focuses on the legitimization of innovative behavior and the adoption, diffusion, and acceptance of innovation (Van Oorschot et al., 2018). Researchers have studied the factors affecting innovation adoption. For example, Rogers (2003) distinguished among an innovation's (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability. The perceptions of these five characteristics influence an individual's decision to adopt innovation. An innovation that has a relative advantage, is compatible, not complex, testable, and observable, and will be adopted more rapidly than other innovations.

While researchers studying the adoption of innovations examine which aspects lead to consumer adoption of innovations, researchers interested in the adoption of standards examine which aspects lead to the adoption of standards. These scholars show that the factors that explain innovation adoption can also be used to explain the adoption of standards (Ezingeard & Birchall, 2005; Moratis & Widjaja, 2014; Zhou et al., 2011). For instance, in the context of standards, relative advantage refers to the potential benefits of implementing the standard in a company in terms of, for example, the structure that it brings (Moratis & Widjaja, 2014); observability refers to, for example, whether it is possible to test the standard before a decision is made to adopt it (Hovav & Schuff, 2005). Finally, complexity refers to whether the standard is understood by its users; when standards are not comprehensible, chances that they will be adopted are lower as was shown by Alkraiji et al. for the case of health data standards (Alkraiji et al., 2013).

Network economics

Some markets are characterized by increasing returns to adoption, which implies that the value of a given technology increases once more users adopt that technology. Network effects are among the causes of these increasing returns on adoption (Farrell & Saloner, 1985; Katz & Shapiro, 1985). We can distinguish between direct and indirect network effects. Direct network effects play a role when products are physically connected. A classic example is a mobile phone network, which increases in value as more users utilize the network since users are able to reach more people. Indirect network effects play an important role in platform-based markets. The platform's value increases as more complementary goods become available. An example of a gaming console can explain this phenomenon since gaming consoles increase in value as more games become available.

Because of the existence of network effects, users tend to adopt a technology that is adopted by the majority of the market, as the value accrued from network effects is higher for that technology. Therefore, when >50 percent of the market adopts a certain technology, the bandwagon effect often occurs, whereby companies follow each other in their adoption choices. Network effects are also common in markets based on compatibility standards; scholars who study factors for standard adoption often mention network effects as important drivers of adoption. As this study focuses on quality standards, the relevance of network effects is deemed lower. However, when a standard is compatible with other standards used within a company, this can contribute positively to its adoption, as argued by Hashem and Tann (2007).

Neo-institutional theory

Neo-institutional theorists focus on how firms' behavior is affected by the context in which they operate. For example, Di Maggio and Powell explored the concept of institutional isomorphism and defined three types of external pressures that may act upon companies and affect their behavior: coercive, mimetic, and normative pressures (DiMaggio & Powell, 1983). Organizations might be dependent on other organizations that exert coercive pressures that direct toward a certain path. Normative pressures originate from institutions, such as professional or industry associations, which define the norms that firms should follow. Mimetic pressures are defined as firms' tendencies to copy the successful actions of other firms and significant competitors when faced with uncertainty.

Scholars focusing on standards adoption and neoinstitutional theory emphasize how actors are forced to adopt a standard because of external pressures. Scholars argue that companies adopt standards because other actors in their value chains force them to do so (i.e., coercive pressure). These actors include, for example, (non-)governmental organizations, customers, big players, and suppliers. Companies also follow the adoption choices of other, mostly larger actors (mimetic pressures) or have an intrinsic motivation to adopt standards (normative pressures). Several scientists have focused on these three types of pressures to explain why quality standards are adopted (Kedzior et al., 2020; Wijen, 2014; York et al., 2018; Zhou et al., 2011).

Standardization

According to standardization scholars, the process of standardization can be roughly subdivided into three stages: development of a standard (which often occurs in standards development organizations), selection of a standard (which often occurs in a market involving standards battles), and adoption of a standard. Researchers who explore the development of standards focus on, for example, the benefits of joining standards development organizations (Axelrod et al., 1995), the politics involved in developing standards (Backhouse et al., 2006), the motives behind standardization in general (Blind & Mangelsdorf, 2016), and how the standardization process can become more responsible. Scholars who focus on the selection of standards have investigated strategies that may be applied by companies to be successful in standards battles and set *de facto* standards. These scholars highlight the importance of quickly building an installed user base (Shapiro & Varian, 1998, 1999). Scholars have investigated the strategies that can be applied to increase the

installed base and point to strategically pricing a standard (Liu, 2010), choosing an optimal point in time to enter the market (Schilling, 1998, 2002), and increasing the availability of complementary goods (Hill, 1997; Schilling, 1999). Complementary assets in the form of financial resources and reputation are required (Gallagher & Park, 2002).

This study focuses on the third stage: the adoption of standards. Standardization scholars who focus on this stage have utilized one or more of the above-mentioned three perspectives to explain the adoption of standards. For example, Hovav et al. (2004) integrated network economics theory and the diffusion of innovation theory to better understand the adoption of standards for the Internet. Hashem and Tann (2007) primarily drew on the diffusion of innovation literature to better understand the adoption of ISO 9001 standards. These scholars also stressed the relevance of organizational characteristics such as centralization, formalization, and organization size (Mirtsch et al., 2021) which make an organization more inclined to adopt a standard. In addition, Chan and Chong (2012) studied the determinants of the adoption of standards for supply chain management integration by utilizing insights from the adoption of innovation literature and institutional theory and found that management support in the form of commitment from top management is an important driver for the adoption of standards. Recently, a thorough literature study on factors for the adoption of standards was performed (Van de Kaa 2023) which resulted in the most complete framework to date; 18 factors were divided into the following five categories: (1) characteristics of the standard, (2) external pressures, (3) characteristics of the firm, (4) environmental factors, and (5) the standards organization's characteristics and strategies. The first three categories are relevant to the current study and are utilized in the accompanying theoretical framework.

Methods

To answer our research question, *which factors affect the adoption of quality standards in the semiconductor industry in The Netherlands, according to experts?*, following earlier research (Hoogerbrugge et al., 2023), we conducted two phases of study (see Fig. 1). In Phase 1, we determined the relevant factors for the adoption of standards by reviewing the literature on the adoption of standards and identifying the relevant determinants of the adoption of quality standards (Chan & Chong, 2012; Hashem & Tann, 2007; Lee & Xia, 2006; Liu et al., 2018). We also interviewed five industry experts (experts 1–5 in Table 1). In these interviews, interviewees explicitly or implicitly mentioned the determinants of adopting standards. When a determinant was mentioned in one of the four articles that we read, or by at least one industry expert, it was considered a relevant factor in the adoption of standards. In this process, we were open to new factors introduced by experts. Following this approach, we also compiled a comprehensive list of factors that included the determinants that have already been discussed in the literature, as well as the determinants that were not discussed in the literature but that experts found relevant.

This study was conducted at a multinational semiconductor company (Company X). The company was established in 2004 and is active in Europe and Asia. It specializes in developing mechatronic products for the in-house semiconductor industry, which may eventually be installed in the larger machines of larger semiconductor firms, such as ASML. This company has adopted over 300 standards; therefore, it can be assumed that its employees have sufficient knowledge of standard adoption. All interviewed experts were employees of Company X. They were selected using the three criteria mentioned by Shanteau et al. (2002): experience, certification, and social acclamation. All experts were selected using the criterion certification; at a minimum, they had a Bachelor of Sciences degree. Furthermore, Expert 1 was selected by means of the criterion expertise (an expert is someone with many years of experience, which in our study is 30 years of work experience or more). Expert 1 identified other experts (social acclaims). Thus, in summary, we considered someone to be an expert if they had at least a Bachelor of Sciences degrees, although most held an Master of Sciences degree. Furthermore, we selected Expert 1 as this expert had >30 years of work experience, while the other recommended people were considered experts because Expert 1 designated them.

Table 1
Overview of interviewees.

Expert	Background	Position	Years of work experience
Expert 1	Industry	Manager operations	34
Expert 2	Industry	Manager standardization and process development	30
Expert 3	Industry and academia	Production and development manager	25
Expert 4	Industry and academia	Director	27
Expert 5	Industry and academia	Director	24
Expert 6	Industry	Manager operation	30
Expert 7	Industry and academia	Procurement manager	19
Expert 8	Industry	Manager	29
Expert 9	Industry	Director	28
Expert 10	Industry	Production manager	6

Table 1 lists the selected experts. During Phase 1, we interviewed Experts 2, 3, 4, and 5. Each interview was unstructured, meaning that no predefined list of questions was used. The experts did not provide a list of determinants from the literature, which made them unbiased when explaining the principal reasons for adopting quality standards.

In Phase 2, we used the best-worst method (BWM), which is a multi-criteria decision-making method (MCDM), to identify the weights of the determinants. This method was introduced by Rezaei (2015) and is explained below. We choose this method over other MCDM methods because it results in more reliable results (Rezaei, 2015). BWM has been applied in various studies and sectors, including energy (Ridha et al., 2024), healthcare (Chen & Ruan, 2024), and information technology (Kapoor et al., 2024). The participants were asked to choose a discrete set of decisions. The optimal weights of the criteria can then be determined, with the vectors functioning as the input for an optimization model (Rezaei, 2020). BWM provides more reliable answers than other MCDM methods because it requires less data and is simpler (Rezaei, 2015, 2020). Applying this method results in a consistency ratio that, when closer to zero, implies that the answers of the experts are more reliable. In our study, Experts 1–10 conducted the BWM. This was done during face-to-face interviews, during which the method was visualized.

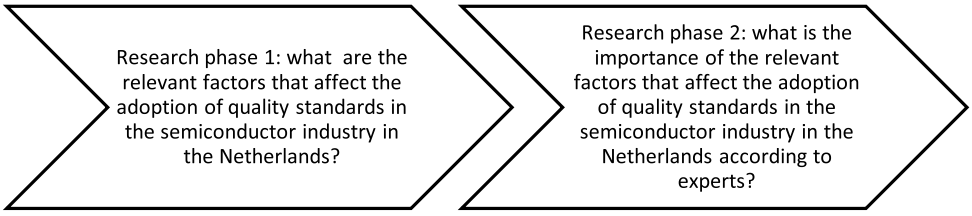

Fig. 1. Diagram of the two phases of the study.

The steps of BWM are as follows:

Step 1: The relevant criteria are distilled $\{c_1, c_2, \ldots, c_n\}$; these are the relevant factors for quality standard adoption that emerged in research phase 1.
Step 2: The experts assessed the most and least preferred criteria for adopting quality standards.
Step 3: The preferred criterion is compared with the other criteria. The preference for the most preferred criterion over all other criteria was determined using a number between 1 and 9. This results in the best-to-others vector:

$$B - O = (a_{B1}, a_{B2}, \ldots, a_{Bn})$$

Step 4: The other criteria are compared with the least preferred criterion. The preference for all other criteria over the least preferred criterion was determined using a number between 1 and 9. This resulted in an others-to-worst vector:

$$O - W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$$

Step 5 – optimal weights are calculated by solving the following problem:

$$\min \xi$$

$$s.t.$$

$$\left|w_B - a_{Bj} W_j\right| \leq \xi, \text{ for all } j$$

$$\left|w_j - a_{jw} W_w\right| \leq \xi, \text{ for all } j$$

$$\sum_j W_j = 1$$

$$W_j \geq 0, \text{ for all } j$$

The solution to this problem results in optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and a consistency ratio ξ^*.

Results

The two most prominent standards adopted by Company X are ISO 9001 and ISO 13485, both of which are quality management standards used by the company to set up its production processes. The interviewees were asked which factors led to the adoption of these two standards. Standards from the ISO 9000 family are among the most pervasive and influential quality standards (Van de Kaa & De Vries, 2015). Company X adopted this standard more than two decades ago; later, the company adopted ISO 13485. The standard is based on the ISO 9001 standard. ISO 13485 is specifically relevant to companies that produce, develop, design, install, and service medical devices, which are among the main areas in which Company X specializes.

Phase 1 yielded 15 factors, grouped into three categories using the Technology Organization Environment (TOE) framework developed by Tornatzky and Fleischer (2007). In this framework, a firm's context for adopting innovation is subdivided into three environments: organizational, technological, and external. Various scholars have used this framework to analyze innovation adoption. However, this can also explain the adoption of standards (Hashem & Tann, 2007). We used the TOE framework's technological environment to group the factors from the diffusion of innovation theory; we used the TOE framework's external environment category to group the factors from the neoinstitutional theory. The third TOE environment, the organizational environment, was used to group the organizational determinants. Table 2 presents all relevant determinants found in the literature and/or those mentioned by experts during the interviews. The table also lists the source(s) of each factor. Based on the interviews, *coercive pressure*s from neoinstitutional theory were subdivided into five separate factors. These are factors from 1.1 to 1.5 in Table 2.

In Phase 2, we determined the weights of the factors. The final weights are listed in Table 3. The three columns on the right-hand side represent the local average weight, global average weight, and ranking. Local weights are the average weights assigned to categories and factors, whereas global weights are obtained by multiplying the category weights by the factor weights. The global weight was used to determine the importance of the factor; the higher the global weight, the more important the factor. The results indicate that the four key factors are *pressure from customers* (0.16), *management support* (0.13), *pressure from big player(s)* (0.12), and *formalization* (0.10). Table 4 presents the input-based consistency ratios and associated threshold values. Most comparisons were lower than or close to their associated threshold values, which indicated sufficient consistency. We ran a separate analysis during which we only considered the consistent results; during this analysis, the top four factors did not change, but their relative rankings did change. The rankings were as follows: *management support* (0.15), *formalization* (0.14), *pressures from customers* (0.10), and *pressure from big player(s)* (0.09).

Discussion

Interpretation of the findings

This section interprets the results in relation to our research question (*Which factors affect the adoption of quality standards in the semiconductor industry in The Netherlands, according to experts*). We also interpret the results in relation to the existing literature on standards adoption. According to experts, customer pressure is among the most important factors for standard adoption. As one of the experts mentioned, without an ISO 9001 certificate, they will not obtain assignments from other organizations. Another expert indicated that the company is, in principle, forced to implement the ISO 9001 standard, because if it did not do so, customers could switch to a competitor. Essentially, the adoption of ISO 9001 would increase the credibility of the company among customers, and thereby, customers would choose that company. However, this expert added that his organization would always look critically at what a standard would bring.

The experts also rated the pressure from (a) big player(s) as a crucial factor. Once a major company in the value chain has adopted a certain quality standard, other companies feel the urge to adopt the same standard as a requirement for conducting business. More companies may follow, after which it may become an unwritten rule in the value chain that the quality standard is a must-have for conducting business. This phenomenon can also be observed in compatibility standards such as MS-DOS, the predecessor of the Windows operating system. Once IBM adopted this as the standard operating system for its personal computers, other companies followed (Van de Kaa et al., 2011).

Pressure from customers and big players is an example of coercive pressure. Organizations in this industry are surrounded by an institutionalized environment and forced by others to adopt the same standards in that environment (DiMaggio & Powell, 1983; Meyer & Rowan, 1977). Coercive pressure is also important when adopting quality standards that were reported in the literature (Georgiev & Georgiev, 2015; Guler et al., 2002; Hashem & Tann, 2007; Jajja et al., 2019; Kedzior et al., 2020; York et al., 2018). Furthermore, many researchers have mentioned the pressures relevant to the adoption of standards in general (Ezingeard & Birchall, 2005; Henderson et al., 2011; Van de Kaa 2023). Our study provides further evidence of the importance of coercive pressure in the adoption of standards.

Table 2
Relevant factors for quality standards adoption.

	Category/factor	Explanation	Source(s)
1.	Pressure from (external) stakeholders	The extent to which external pressures result in companies adopting certain standards.	Experts 1, 2, 3, 4, 5
1.1.	Pressures from the government	The extent to which firms adopt standards as they are pressured into doing this by the government. For example, standards may be imposed by the government in which case standards adoption has to take place.	Experts 3, 4, 5
1.2.	Pressure from non-governmental organizations	Pressures from organizations that do not reside in the semiconductor industry (e.g., ISO)	Expert 4
1.3.	Pressures from customers	Pressures exerted by customers demanding that certain standards be applied.	Expert 1, 4
1.4.	Pressures from (a) big player(s)	Pressures exerted by large parties (e.g., ZEISS, ASML, Thermo Fischer) with whom the focal organization cooperates and who demand that certain standards be applied.	Experts 1, 2, 4, 5
1.5.	Pressure from suppliers	Pressures exerted by technology providers in the focal organization's value chain with which it collaborates and who demand that certain standards be applied.	Expert 4
1.6.	Mimetic pressures	The extent to which companies feel pressured to copy the choices made by other companies so that they are taken more for granted.	Expert 4
1.7.	Normative pressures	The extent to which companies adopt standards because they feel that this is a good decision. This can be because they have been taught so or adopting the standard is in line with their values.	Expert 3, 4, 5
2.	Organizational characteristics	Organizational characteristics that ensure that an organization opts for a certain standard.	(Hashem & Tann, 2007).
2.1.	Management support	The extent to which the management of an organization supports the decision to adopt the standard.	(Chan & Chong, 2012; Liu et al., 2018).
2.2.	Centralization	The degree to which decision-making activities and powers are concentrated. A higher centralization increases the chances that the standard is adopted.	(Hashem & Tann, 2007; Zmud, 1982).
2.3.	Formalization	The extent to which procedures and rules are incorporated in the organization. A highly formalized organization is likely to adopt quality standards because it certifies its orderly way of working.	(Hashem & Tann, 2007; Zmud, 1982).
2.4.	Organization size	Large organizations have more resources available than smaller organizations, which facilitates standards adoption.	(Hashem & Tann, 2007; Lee & Xia, 2006).
3.	Perceived characteristics of quality standards	The characteristics that the standard complies with according to the company.	
3.1.	Relative advantage	The benefits that adopting the standard will bring to the company	(Hashem & Tann, 2007; Rogers, 2003).
3.2.	Compatibility	The extent to which the standard is interoperable with other standards. The more the standard is compatible with existing standards that are used in the company, the higher the chance that an organization will adopt that standard.	(Hashem & Tann, 2007; Rogers, 2003).
3.3.	Complexity	The extent to which a standard is understood and the extent to which it is challenging for the company to adopt the standard. The higher the complexity of the standard, the lower the chance that it will be adopted.	(Hashem & Tann, 2007; Rogers, 2003)).
3.4.	Observability	The visibility of the standard.	(Hashem & Tann, 2007; Rogers, 2003).

In addition, experts rated management support and formalization as crucial factors in the adoption of quality standards. From the literature on market-based standardization, we know that commitment from top management is an important prerequisite for the adoption of standards. In the standards battle for multi-channel audio sounds, the consortium behind the widely adopted standard (AC-3) was committed to the standard, which, in part, led to its large-scale adoption (Van de Kaa & De Vries, 2015). However, for the competing consortium, the Moving Pictures Expert Group (MPEG), one of the companies, Philips, did not gain full support because of conflicting interests, thus reducing the overall commitment to the standard within the consortium, partly leading to the failure of MPEG-2.

Intel, the main company behind the HomeRF standard (a competitor of Wi-Fi), also promoted other standards, reducing their overall commitment to HomeRF. This is one of the reasons why this standard was unsuccessful (Van de Kaa et al., 2015). We also show that commitment is important for the adoption of quality standards. Furthermore, formalization was found to be important in our research. This is in line with the research performed by Moratis and Widjaja (2014) and Xu et al. (2012) who showed that standards are more easily implemented when they are compatible with a firm's infrastructure.

Limitations

This section discusses the three limitations of this study. First, the sample had one main limitation, i.e., that we interviewed experts from only one company. This inherently results in findings that may not apply to other companies in the semiconductor industry. However, because the company has adopted over 300 standards, it can be assumed that experts in the company have sufficient knowledge of standard adoption. Furthermore, as Table 1 shows, most of the interviewed experts had been working in this industry for a considerable amount of time, and most of them also had work experience outside Company X. Furthermore, their qualitative statements showed overlapping insights. In addition, we found that the four most important factors did not change after adding the findings of experts 6, 7, 8, 9, and 10. This indicated that a sufficient number of interviews were conducted.

Second, the experts mainly operated in management positions, which might also bias the results. As explained in Section 'Methods', all experts were selected by means of certification and they should have operated at the managerial level as managers or directors. However, it may have been better to use a broader sample in this regard.

Third, experts did not always provide sufficiently consistent answers.

Table 3
Results of the BWM analysis.

Categories & factors	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	Local average weight	global weight	**ranking**
Pressure from (external) stakeholders	0.65	0.72	0.82	0.29	0.65	0.68	0.17	0.14	0.64	0.58	0.53		
1. Pressures from government organizations	0.27	0.27	0.04	0.24	0.03	0.07	0.13	0.03	0.20	0.06	0.13	0.07	5
2. Pressure from non-government organizations	0.11	0.06	0.04	0.24	0.06	0.06	0.03	0.06	0.13	0.06	0.08	0.04	9
3. Pressures from customer(s)	0.17	0.30	0.39	0.24	0.41	0.26	0.20	0.36	0.22	0.41	0.30	0.16	1
4. Pressures from big player(s)	0.17	0.15	0.39	0.14	0.18	0.35	0.20	0.36	0.13	0.15	0.22	0.12	3
5. Pressure from supplier(s)	0.05	0.10	0.04	0.04	0.06	0.04	0.08	0.08	0.02	0.06	0.06	0.03	14
6. Mimetic pressures	0.02	0.06	0.04	0.07	0.18	0.04	0.05	0.05	0.22	0.06	0.08	0.04	10
7. Normative pressures	0.22	0.07	0.04	0.02	0.09	0.17	0.32	0.06	0.08	0.22	0.13	0.07	6
Organizational characteristics	0.23	0.10	0.10	0.54	0.27	0.26	0.29	0.78	0.27	0.31	0.31		
8. Management support	0.55	0.57	0.04	0.55	0.40	0.39	0.47	0.14	0.54	0.56	0.42	0.13	2
9. Centralization	0.05	0.14	0.31	0.27	0.05	0.14	0.10	0.05	0.24	0.16	0.15	0.05	8
10. Formalization	0.33	0.23	0.49	0.09	0.40	0.39	0.26	0.58	0.04	0.22	0.30	0.10	4
11. Organization size	0.07	0.07	0.16	0.09	0.15	0.08	0.17	0.23	0.18	0.05	0.12	0.04	11
Perceived characteristics of quality standards	0.13	0.18	0.08	0.17	0.08	0.06	0.54	0.08	0.09	0.11	0.15		
12. Relative advantage	0.05	0.48	0.57	0.54	0.39	0.61	0.49	0.24	0.04	0.57	0.40	0.06	7
13. Compatibility	0.28	0.25	0.25	0.07	0.07	0.10	0.14	0.59	0.25	0.05	0.21	0.03	13
14. Complexity	0.47	0.09	0.05	0.17	0.39	0.13	0.08	0.12	0.13	0.24	0.19	0.03	15
15. Observability	0.19	0.17	0.13	0.22	0.15	0.16	0.29	0.06	0.58	0.14	0.21	0.03	12

Table 4
Input-based consistency ratios and the associated thresholds.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10
Categories	0.05 (0.13)	0.02 (0.13)	0.13 (0.14)	0.17 (0.17)	0.30 (0.13)	0.13 (0.14)	0.17 (0.17)	0.13 (0.14)	0.50 (0.14)	0.05 (0.14)
Pressure from (external) stakeholders	0.21 (0.35)	0.05 (0.27)	0.00 (0.35)	0.26 (0.35)	0.38 (0.35)	0.13 (0.34)	0.21 (0.35)	0.37 (0.35)	0.17 (0.35)	0.02 (0.34)
Organizational characteristics	0.13 (0.27)	0.19 (0.25)	0.26 (0.27)	0.08 (0.27)	0.20 (0.20)	0.05 (0.20)	0.17 (0.15)	0.15 (0.27)	0.32 (0.27)	0.15 (0.27)
Perceived characteristics of quality standard	0.19 (0.25)	0.05 (0.20)	0.15 (0.27)	0.33 (0.20)	0.20 (0.20)	0.07 (0.20)	0.35 (0.20)	0.29 (0.25)	0.46 (0.27)	0.21 (0.27)

When using this method, it is inevitable that a certain degree of inconsistency will occur in the experts' answers. However, this is not problematic if the inconsistency is not excessively high (below the associated threshold), which is the case for most results. Furthermore, the most inconsistent results were slightly above the associated thresholds. The low consistency of some answers could indicate that the experts found it difficult to compare the criteria. We tried to avoid this by defining the factors for standard adoption as clearly as possible and conducting face-to-face interviews so that the interviewer could explain the factors to the interviewees if necessary. We also asked interviewees to reevaluate inconsistent comparisons, which increased the consistency of the data.

Implications

Theoretical implications

This study contributes to the standardization literature in several ways, which are discussed in this subsection. The main contribution of this study is that it is one of the first to determine the factors affecting the adoption of quality standards and to assign weights to these factors. An exception is the study by Hoogerbrugge et al. (2023). The other contributions of this study include the following. First, although many researchers have focused on standards development (Backhouse et al., 2006) and selection (Hill, 1997), few have focused on standards adoption (Van de Kaa 2023). Second, few scholars who focused on the factors in standard adoption focus on compatibility standards (Hovav et al., 2004). We focused on quality standards. Third, this is one of the first studies to apply BWM to assign weights to factors for standard adoption. Finally, researchers who focus on standardization have mostly conducted research in consumer electronics, information technology, telecommunications, and the energy sector (Hovav & Schuff, 2005; Liu et al., 2018; van der Burg et al., 2022). Few scholars have focused on the semiconductor industry (some exceptions are Funk and Luo (2015) and Garud and Kumaraswamy (1993)), which is the focus of this study.

Practical implications

This subsection focuses on practical implications. Managers often face uncertainty regarding the standards that should be chosen when multiple standards coexist. This uncertainty can be reduced by understanding the factors that influence the adoption of standards, which is the focus of this study. This study focuses specifically on standards that indirectly promote sustainability and cleaner production within the semiconductor industry; thus, managers who perform this task and are

responsible for it can benefit from the results of this study. Our findings suggest that practitioners should focus on determining the standards that customers adopt. In addition, they should investigate the big players in the industry and the standards they adopt. Given the importance of the pressure from customers and big players, we recommend that managers choose the standards adopted by these stakeholders.

Policy-related implications

Implications for policymakers are discussed in this subsection. They sometimes prefer certain standards. Policymakers can use our results to investigate the factors that will influence the adoption of certain standards. Given that companies partly base their choice of a standard on the choice of their customers and large players, policymakers are advised to persuade these parties to choose their preferred standard. This can be achieved, for example, by providing subsidies to reduce the price of implementing the standards. In addition, policymakers can perform similar studies for other standards using the presented approach and thus define policies that ensure that certain standards are adopted.

Future research directions

This study examined the factors that affect the adoption of quality standards in the semiconductor industry in The Netherlands, according to experts. We identified fifteen relevant factors for the adoption of quality standards by analyzing the literature and conducting expert interviews. Four factors appeared to be especially important for the adoption of quality standards: pressure from customers, management support, pressure from big players (s), and formalization. The remainder of this section provides recommendations for future research.

This study focused on quality standards. However, more types of standards exist, including compatibility, information, and variety reduction standards (De Vries, 1998). Although factors for the adoption of compatibility standards have already been investigated (Hovav et al., 2004), those for the adoption of information standards and variety reduction standards have not been investigated before and could provide a fruitful avenue for future research. Scholars interested in this topic are recommended to investigate relevant factors for the adoption of the type of standard by following the same steps: reviewing the literature, conducting expert interviews, and applying a similar MCDM method, such as BWM. However, given that the literature on adoption for these types of standards is scarce, we recommend applying general factors for compatibility and quality standard adoption.

In this study, the experts had the greatest difficulty comparing the categories of perceived characteristics of quality standards and organizational characteristics. If scholars choose to adopt our list of factors for future research, it is recommended that the factors be categorized differently, or that the categories (pressure from (external) stakeholders, organizational characteristics, and perceived characteristics of quality standards) be distinguished more clearly from one another. This could be achieved by conducting additional interviews with experts.

The relevance and importance of these factors may be context-specific. For example, the importance of pressure from the government in the form of regulations on standards adoption might depend on the power of the government in certain regions regarding standardization. The government in The Netherlands may intervene less quickly than in other countries. Previous research has shown that, in China, the government has a much more powerful role in standardization (Van de Kaa et al., 2013). Future research could study the extent to which the relevance and importance of factors in the adoption of standards depend on the specificities of the region. Scholars can focus on countries other than The Netherlands. Furthermore, future research could study the extent to which a list of factors may be used to explain (or even predict) the adoption of quality standards by other companies in the semiconductor sector and other sectors such as consumer electronics.

In this study, coercive pressure was found to be particularly important. However, the question is whether these pressures can be influenced by an individual company, and if so, how. According to one of the interviewed experts, pressure from big players cannot be influenced by a company, as major companies in the market can only be customers if they comply with their demand characteristics. In other words, companies at the corporate level (e.g., ASML and ZEISS) are protected in the market. Therefore, another interesting area for future research is the extent to which and way in which individual companies can influence the adoption of standards. Scholars could perform a literature study and investigate whether this topic has been addressed explicitly or implicitly in case studies of standards adoption, and they could conduct case studies that have such an explicit focus.

CRediT authorship contribution statement

Maarten F.M. Jurg: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Linda M. Kamp:** Writing – review & editing, Writing – original draft. **Geerten van de Kaa:** Writing – review & editing, Writing – original draft.

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