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Evaluating the impact of deviating technical standards on business processes, trade and innovation

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Abstract: In context of the increasingly intense discussions about the emergence of new global standardization regimes, there has been much talk about countries purposefully using deviating national standards to erect trade barriers. The discussion of whether and to what extent technical standards deviate from international standards and how this affects the economy, business, trade, innovation and the standards system is of global relevance. As research on the impact of deviating technical standards is still severely underrepresented in the academic community, this research analyses the different "degrees" of deviation and the respective impact of minor or negligible deviation and major deviation on companies trading in a global context. By using a mixed method approach based on literature review, analysis of standards documents and semi-structured interviews, this study discusses peculiarities and challenges associated with deviating technical standards. This is relevant in the context of international trade and especially trade with countries that have become increasingly important players in the international standardization regime. Our research will therefore contribute to a better understanding of the close link between economic growth and standardization. This paper also shows how deviating technical standards affect companies around the world and how these companies could use a newly developed risk indicator to not only play the standards game but also better assess the consequences.

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1. Introduction

Technologies can be used to strengthen one's own economy at home and abroad, but they also have the power to influence political developments in individual countries and globally. Since the role in standardization is determined by technological leadership, the leading role in standardization is often automatically and even historically attributed to the US or the EU. According to the principle of "first come, first serve", the co-determination and interpretation of the structures through which standardization is promoted is often interpreted as a kind of prerogative of these states (Luedtke/Weithmann, 2022). However, several countries such as China, but also India and others have identified technology as a strategic resource and seek to challenge this prerogative.

While standards[3] are the "rules of the game by which economic actors play" (Pacheco et al., 2010), they are at the same time not necessarily set in stone. Each country and various stakeholders have a right not only to technology development, but also to design, interpret and potentially change existent standardization structures. However, developing new standards or changing existing ones creates winners and losers, not least because of the "tension between the employment of standards as an instrument of cooperation [...] and the use of standards in struggles for self-interested advantage" (Suttmeier et al., 2006). For example, China's strong commitment in electric vehicle standardization (Weithmann, 2018) has resulted in e.g., charging standards that deviate from other international automotive markets while charging standards are considered an important building block for the technical advancement of electric vehicles. Deviating technical standards have played a significant role in boosting China's engineering capacities and thus its market share in domestic and also international electric vehicles sales. In the first quarter of 2023, the electric vehicle manufacturer BYD overtook the previously dominant vehicle manufacturer Volkswagen in terms of domestic vehicle sales in China for the first time (Backovic/Hubik/Tyborski, 2023).

However, there are still many gaps in the existing literature on standardization and deviating technical standards in particular. Research on standardization was often focused on the impact of standards on the national economy in general (Blind/Jungmittag/Mangelsdorf, 2011), trade (Yang, 2023) or countries with specific trading relationships such as the Chinese economy (Wang, 2011 and 2014). The research topic was further discussed regarding compatibility with global standards (Katz/Shapiro, 1985; Farrell/Saloner, 1985) or for harmonization processes between countries. As an example of sector specific research approaches, German and Chinese electric vehicle standards have been researched by Weithmann (2018, 2017) or Ziegler and Gerst (2012) among others. There are also further studies on the same sector that go beyond China to explore India's experience with global automotive product standards (Chakraborty/Chaisse/Pahari, 2020).[4] Further research exists e.g., on how companies influence standards in case of China's Building Energy Efficiency industry to their advantage (Luedtke, 2020).

Studies on standardization often focus on rivalries between countries e.g., "standard wars" such as in the Information and Communication Technology sector (An, 2005; Zhang/Ma, 2005). Unfortunately, most studies also have limitations in their research approach with regard to their perspective on the benefits of standards for exporters (Schmidt/Steingress, 2022; Raballand/Aldaz-Caroll, 2007), which often leads to findings of an overall positive impact of the economics of standards. Recently, there has also been a lively discussion about China's deliberate use of deviating national standards as a part of its strategy to become a dominant standardization power (Luedtke/Weithmann, 2022). However, the issue of whether and to what

[3] There are various taxonomies of standards. According to Hesser and Inklaar (1998: 37), they can be split into functional, administrative, and structural types. Functional standards can be divided into basic, terminology, testing, product, safety, and service. An alternative grouping is variety reduction, interface, interchangeability, organization, and contract standards (cf. Weithmann 2018: 45). However, we studied explicitly technical standards, which are defined as "technical specifications designed to the quality, security and compatibility of various goods and services" (Seaman 2020: 3), and this terminology will be used throughout this paper.
[4] Chakraborty, Chaisse and Pahari (2020: 28) observed, for instance, that the "divergence in automotive product standards might crucially influence India's trade flows."

extent technical standards deviate from international standards and also impact business, trade and the standard system in general is of global relevance and not limited to China but also includes, for example, Africa, Armenia, Indonesia and many more (also see Czubala/Shepherd/Wilson, 2009; Jensen/Tarr, 2012; Mcdonald, 2020).[5] At the same time, companies have to deal with deviating technical standards no matter whether the deviation is intentional or not.[6]

This paper will focus on technical standard deviation as international challenge. Therefore, the aim of our study is to analyse the different "degrees" of deviation and the respective impact of minor or negligible deviation and strong deviation on global businesses trading. Our study is the first of its kind to measure risks caused by deviating technical standards on companies. Our results are based on a mixed method approach, including semi-structured interviews. They show that the accurate assessment of degrees of potential risks caused by deviating technical standards can be used properly to not only enhance corporate risk management but also forecast investment decisions related to standardization and technology intelligence on a general level.

1.1. Standard deviation as international challenge

Standards have not only a widespread effect on trade since "up to 80% of trade [… is] affected by standards" (Weithmann, 2018a; cf. OECD, 1999) and there is also a wide consensus about benefits of international harmonization of technical standards (cf. Mangelsdorf, 2011[7]; Schmidt/Steingress, 2022). Especially scholars of New Institutional Economics[8] point to the role of single actors in shaping their institutional framework (Richter/Bindseil, 1995), i.e., considering the standard-setting activities of companies, standard developing organizations and other stakeholders to build an efficient market infrastructure to reduce transaction costs (Maze, 2017).[9] Deviating standards can, for instance, impose trade barriers and restrict market entry for foreign technology imports. Standard deviations can also "hinder the export of Chinese technology to the global market" (Weithmann, 2018a). Technical standards can further create so-called lock-in effects (Hesser/Inklaar, 1998) but also path dependencies for future products

[5] Jensen and Tarr (2012: 32), for instance, argue that "the gains in standards are considerably less than from trade facilitation" but despite of adjustment costs of adapting new standards, production costs for Armenian exports to the EU will fall.

[6] For this study, the authors often reflect evidence from the Chinese economy as this is the previous area of expertise and where most of the research evidence is available. However, the authors try to integrate evidence from other countries wherever possible to illustrate the global relevance of the issue. Examples in the later analyses include e.g. India, Africa or Russia.

[7] In this regard, Mangelsdorf (2011: 726) points out that "any standard is trade creating because standards reduce information asymmetries, signal quality to consumers and create a common language for potential trading partners, thus reducing the overall transactions costs and creating a competitive advantage for firms" (see also Kindleberger 1983).

[8] The New Institutional Economics approach explains how institutions "arise, what purposes they serve, how they change and how they may be reformed" (Klein 1998: 456). Representatives of New Institutional Economics are, among others, North (1990), Coase (1937), and Olson (1965, 1982).

[9] The traditional Institutional Economics concept stresses the importance of institutions in determining economic behaviour. While various scholars contributed to this approach (e.g., Veblen 1898; Hamilton 1919), Hayek (1994, 1978) pointed out the issue of economics as a coordination problem based on information asymmetries and the role of institutions to make the competitive system work efficiently.

(Seaman, 2020). Therefore, developing new or creating deviating technical standards, which in the case of China are often fragmentary adoptions and extractions of existing international standards (Weithmann, 2018a), can provide substantial advantages, as the costs of change, e.g., in order to comply with these technical standards, can be high (Farrell/Saloner, 1985).

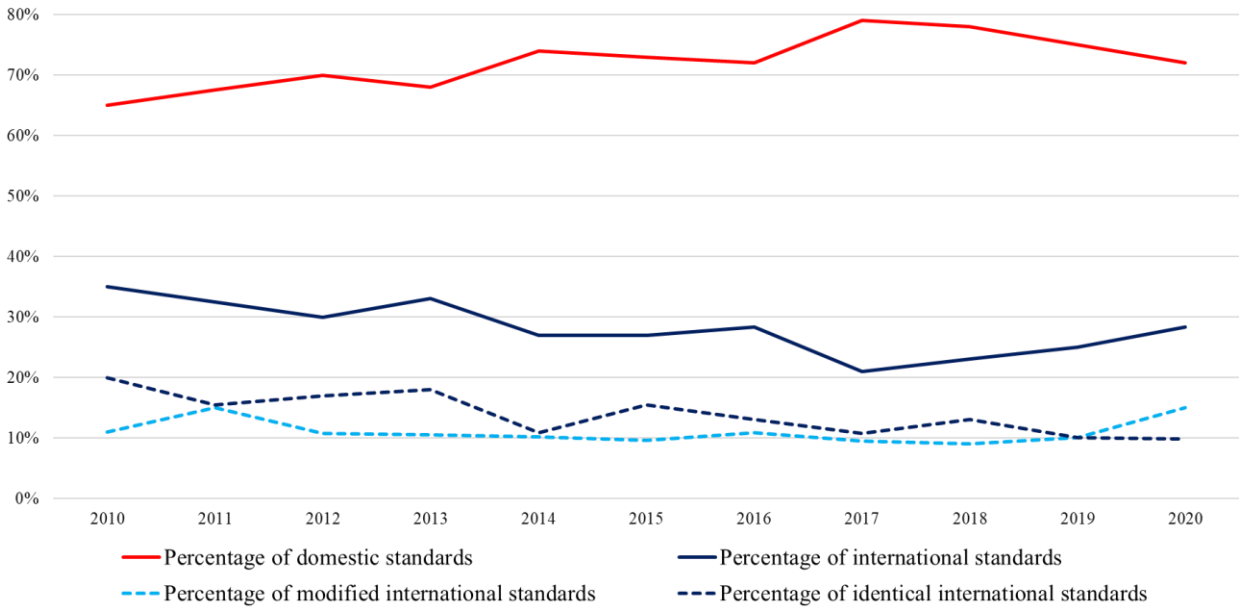
Against this background, it is often claimed that China deliberately creates such standard deviations because China is "exerting a strong influence over the direction that standards take" (EUCCC, 2021). We are sceptical about such a strategic decision or hidden political agendas influencing standardization. Recent research outlines that deviation usually occurs due to the complex processes, technological advances, national requirements through the involvement of various stakeholders (Weithmann, 2018a) and Wilson (2020) argues that the principle of cooperation hinders the development of deviating standards by intention. In the case of China, there are different claims regarding the adoption rate of international standards into Chinese national standards. For instance, Weithmann (2018a) reported that by the year 2010 "about 44% of national standards were adopted from international standard organizations". According to a study based on a survey by the European Chamber of Commerce in China the adoption rate was below 30% by the end of 2020 (EUCCC, 2021, see blue graph in figure 1) while another study mentions a conversion rate of new standards developed by ISO or IEC into national standards as below 20% for the year 2017, at the same time about 50% were new domestically developed standards (Rhodium Group, 2018).

There is an overall lack of statistics to what extent these standards deviate from the international application (Weithmann, 2018a). While the calculation itself might be not simple at all, it remains largely opaque how the few existing statistics on the number of deviating standards were generated.[10] For instance, the already mentioned figure 1 also illustrates both a slight downward trend of a number of standards that are not identical to their international counterparts and a rather stable number of modified international standards (see blue dotted line and turquoise dotted line graph in figure 1). The international counterpart is also often difficult to identify although first efforts are made by e.g., Han, Schmidt and Steingress (2019). Still, identical document numbers can be misleading as similar titles may still include a different scope of the standard application. As one interviewee of this study mentioned: "Finding identical standards is sometimes a bit like looking for a needle in a haystack. And of course, when I do this in product development for different countries, I have many of these haystacks to search in" (Interviewed Association Representative Electronics: 2022/05).[11] This is also insufficiently considered in most databases such as the Searle Center Database on Technology Standards (Baron/Spulber, 2018) or Perinorm, a bibliographic database, that relies on linguistic recognition of keywords. It further depends on who defines keywords and who defines whether a technical standard deviates from another given standard and therefore receives a marker in the dataset indicating that it is considered a "modification". According to an interviewee, this is often done by clerical administration and subsequently adjusted in the document numbers with e.g., the abbreviation MOD for modified (cf. Interviewed Association Executive:

[10] From earlier interviews with authors of comparable articles we know that only bibliographic data was analyzed in order to research larger data sets while the actual text body was neglected. For the above data, this approach could not be fully proven.
[11] Another interviewee pointed out that the similar issue also exists in context of HS-codes applied by different customs and import authorities (cf. Interviewed Consultant Product Compliance: 2022/04).

2022/04).[12] Some standardization bodies try to facilitate the search, such as the Frankfurt Agreement, where standards are marked as part of the document number (IEC/CENELEC, 1996).[13] Despite of the uncertainty about how the above-mentioned adoption rates are calculated, there is still no definition or classification of what constitutes a modification. Without further definition and classification, reliable corporate risk management or forecasting activities for technology investment decisions remain coffee-ground reading. In addition, it is important to keep in mind that the official adoption of standards does not necessarily mean that a country also applies the same standards in business practice (Timmermans/Epstein, 2010). Data on the use of standards such as download numbers or sales of copies by country of origin are not available. The same refers to data on product certification in accordance with specific standards (Harmes-Liedtke, 2022).

Figure 1: Percentage of international standards vs. domestic standards between 2010–2020



Source: Illustration modified based on EUCCC 2021: 38.

Deviating technical standards have a strong impact on international business. For the first time, the European Commission has mentioned the role of harmonized standards for competitiveness in its strategy paper, published in 2022 (COM, 2022). In some industries, there is enormous pressure to adapt products to local deviations and then comply with the standards applicable in each country. Against this background, there is more than anecdotal evidence that companies

[12] None of the additional interviewees knew how the classification or labelling of a standard happens in practice.
[13] According to the Frankfurt Agreement, a European common modification to an international standard is an alteration of, addition to or deletion from its content.

actively seek participation in standard-setting processes but face various hurdles in this regard.[14] Hurdles that can lead to unforeseen confrontation with deviating technical standards can push companies into hasty product adaption to remain in business. In the case of China, for instance, foreign companies face problems in participating in and shaping technical standard-setting due to "formal barriers to participate in domestic standards working groups; informal rules restricting [their] voting rights; exclusion from information coordination; restricted access to technical leadership positions; [and] lack of information and transparency (EUCCC 2021: 4, cf. also Suttmeier and Yao 2004). Previous research provides a concept that helps to limit the likelihood of possible technical deviation of standards within an economy and a specific industry sector.

1.2. Standardization Development Concept as Risk Indicator

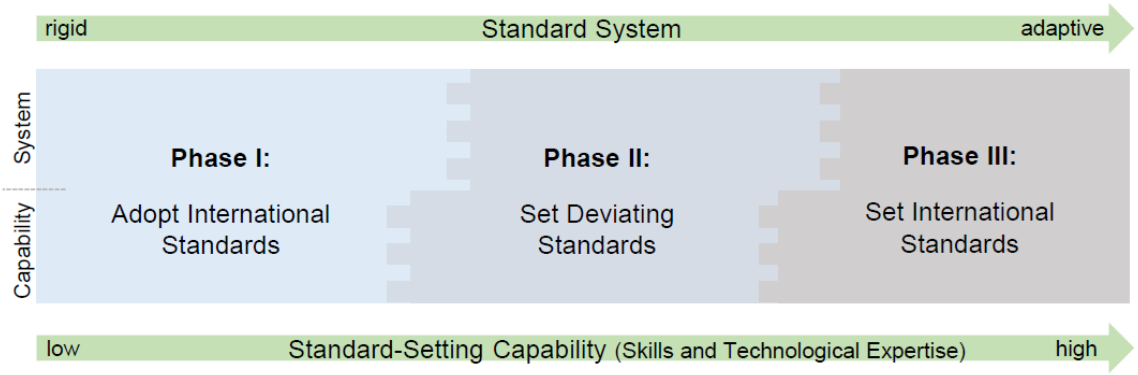
Developing countries trying to participate in the standard game, are often referred to as "catching-up" with other globally leading standardization powers: While in developed countries standardization systems have mostly grown organically in line with economic growth and related requirements of firms, this organic growth process has not taken place in most developing countries (Hesser/Inklaar, 1998). Instead, the catching-up process is common for countries that increasingly participate in technological competition (Weithmann, 2018a). However, this is varying between sectors: For instance, the example of China shows that in traditional sectors, such as automobile production, China's technological catch-up process was an essential prerequisite for participation in international standardization. However, this is not necessary for the development of new technologies, such as in the field of artificial intelligence (Luedtke/Weithmann, 2022). Emerging technology sectors offer countries the opportunity to establish themselves as global leaders without having to aim for the development level of other countries. In addition, sectoral distinction derives not only from different technological development level of industrial sectors, but also from the importance that a country attributes to a sector based on e.g., industrial development plans (Weithmann, 2018).

To further clarify the state of technology development and moreover the likelihood that deviating technology standards emerge as a result of a country's technology development process, the application of the 'Three-Phase Standardization Development Concept' (SDC) can serve as a first indicator (Weithmann, 2018a, see figure 2).[15]

[14] A recent survey by the European Chamber of Commerce in China confirms former research findings based on extensive field research conducted by Weithmann 2018 and Luedtke 2020 in China.

[15] Figure 2 depicts the 'standard-setting capability' that varies between low on the left and high on the right side. It illustrates the development of the standardization system that varies between 'rigid' and 'adaptive' as (the overall) development requires an adaptive framework to enable dynamic evolvement. The concept assumes that a country seeks economic development and therefore strives for an increasingly high capability in standard-setting (Weithmann 2018a).

Figure 2: The Three-Phase Standardization Development Concept



Source: Weithmann 2018 a

The SDC suggests that progress is based on experience, on which a country can build on during the technological development process. [16] In **phase I**, the technological level of the developing country is not yet sufficient to contribute to international standard-setting processes or adapt standards to domestic needs. Consequently, developing countries usually adopt international standards without adaptations. When a country follows international standards, manufacturers can certify production processes and products in accordance with these standards, which facilitates the attraction of FDI. Phase I is also subject to most studies on deviating technical standards and potential economic gain (Schmidt/Steingress, 2022; Czubala/Shepherd/Wilson, 2009; and others). In most cases, however, the benefits accrue to the exporting country rather than to the importing, developing country.[17] In **phase II**, the national standard-setting capability increases. This requires on the one hand technical understanding and on the other hand, an increased importance dedicated to the development of standards. Therefore, personnel skills also increase. Developing countries no longer adopt international standards without revision, but review and often adapt standards to domestic needs. The industry pushes domestic technologies to become industry standards. In case domestic standards serve as cornerstones for future technology development, non-reversible lock-in might occur. Phase II is where deviating standards setting usually increases as there is a growing confidence in the technological capabilities among members of an industry sector and a need to compete with importers rather than lag behind. In **phase III**, as companies grow, they want to compete with foreign firms in their domestic and foreign markets. Thus, the interest in product exports increases and compliance to international standards becomes again of key concern. Also, with increasing experience in international standardization, the contribution to international standard

[16] The description of all three phases is a direct citation of Weithmann 2018a.
[17] It is further stated – based on a study of African exports – that compliance costs can be substantial since "developing countries have largely not been involved in talks on Mutual Recognition Agreements and other agreements designed to mitigate compliance costs" (Czubala/Shepherd/Wilson, 2009: 712; cf. Baldwin, 2000).

discussions becomes easier. The behavior when pursuing standards internationally[18] moreover evolves during the transition process.

To sum up the SDC, there is no definition of how long either phase lasts. However, it is clear, that it is very important for the successful development of industry sectors to move from the phase of adopting standards to revising these and/or creating domestic standards. As a result, deviating technology standards emerge. As described earlier, individual technologies for which no clear path dependency has yet been established may be an exception to the rule as it is also possible to skip the second phase and set international standards directly. Depending on the development of a sector, progress does not always increase continuously, but can also stop and remain in one phase. This implies, for instance, that internationalization of standards (phase III) does not take place.[19]

The SDC can help companies to find out the level of standardization activity in their target country and should therefore be used as a first step in a company's risk assessment when analyzing risks arising from potential technical deviation in standards. If this first analysis indicates potential risks that the trading partner may develop a deviating technical standard, the second step is for companies to measure the risks caused by deviating technical standards in order to find out about the impact of non-compliance with deviating technical standards and therefore define the potential damage to their companies.

2. Research Methodology

The aim of this research is to analyse the different "degrees" of deviating technical standards and the respective impact of minor or negligible deviation and major deviation on business and trade. As an outcome, this research will develop a clustering method regarding the degree of deviation and incompatibility. To reach this aim, this research seeks to answer the following research questions: (1) How can deviating technical standards be defined? (2) Which different categories of deviating technical standards may occur? (3) How can deviation be measured in order to define whether a deviation can have harmful effects?

2.2. Data Sources and Collection

This research adopts a mixed methods approach using literature review, standard documents and semi-structured interviews. Based on the literature review, the authors provide insights into the existing approaches to defining the terms "deviation" and "technical deviation", "divergence", "non-conformity", "contradictory", "modified" and "incompatibility" or "not comply with a standard" and "non-compliance" to explore similarities and differences among these terms and provide a clear definition and classification that enables a proper assessment.

The next step was to develop a semi-structured interview guide. Online interviews were conducted with stakeholders from the corporate sector, industry associations and research

[18] The definition of what an international standard is (see ch. 3.3) remains open as there is no universal standardization organization. Pursuing a domestic standard in e.g., developing countries would still make this standard international although not compliant to an international standard of an 'official' standards developing organization.
[19] The illustration of the SDC indicates that the transition between the end of one phase and the beginning of the next phase intertwines (Weithmann, 2018a).

institutes in the first and second quarters of 2022. These interviews were conducted by one of the two authors as a four-eye conversation, including verbatim transcription.

In addition, this research applies parts of the Systematic and Reflexive Interviewing and Reporting (SRIR) method (Loubere, 2017). This is suitable for conducting reflexive dialogue with the second author after the interviews have taken place. The reflexive dialogue is used to interpret experts' views and cluster the degrees of deviation and incompatibility based on their implications for international business and trade. In this process, non-verbal data is added to the systematic interview reports.

2.3. Research Scope

Determining the ideal number of interviewee partners to target for the interview selection is based on the approach that ideally, given the initial research objectives and availability of data and resources, information gathering continues until the incremental gains become small, (Miles/Huberman/Saldana, 2018). It was not the intention of this research to explore all possible cases of deviating technical standards, nor was it to explain how and why deviation occurs (cf. Weithmann, 2018a) or how standard setting can be influenced by the industry. For instance, previous studies already provide extensive explanation of **how** companies can successfully influence the development of standards in China's building energy efficiency industry and passive house sector in particular (Luedtke, 2020, 2022; Luedtke/Weithmann, 2022).

Rather, the researchers want to understand how to determine the degree of deviation and how to measure the impact on businesses in order to identify potential risks. As countries such as China will continue to develop deviating standards for various reasons, it is even more important to gain a better understanding of the impact on companies deriving from deviation of technical standards and how to manage potential risks to their businesses. In addition to providing unprecedent insights about that, this research will also provide pioneering insights into the nexus of standards and innovation i.e., securing specific countries and firms a forerunner position in technological development and international standardization.

3. Discussion

3.1. Clarification of terms: Deviating technical standards

When reviewing previous literature to find appropriate search terms for our research question, the key issue was to tailor to match search results to the purpose of this study. When searching for so-called standard deviation, most of the literature speaks of measuring dispersion as the value of a "standard deviation" which tells how closely the values of a data set are clustered around the mean. To ensure our research is not mixed up with the standard deviation of data sets, we first tried to explore the different wordings all referring to deviation. We found the terms "deviation" and "technical deviation", "divergence", "adoption", "non-conformity", "contradictory", "modification", "double standards" and "incompatibility" or "non-compliance". We therefore explored similarities and differences among these terms to provide a clear definition and classification that enables a proper assessment according to the impact of a 'standard deviation' on business and trade.

*For this study, we define as **deviating technical standards** anything that differs from one technical standard to another (the original) standard for the same or comparable goods or services, processes and production methods in quality, security, and compatibility no matter how large the intensity or impact of the respective deviation is.*

In the context of our study, we always consider deviating technical standards from the perspective of the party concerned and the respective applied standard. Apart from establishing the term of reference being **"deviating technical standard"** for this study, we also suggest doing so for future research related to the same frame of reference.

To remain stringent on our definition, the term "original standard" also requires further clarification. According to the ISO/IEC (GUIDE 21-1:2005), a *"technical deviation (from an International Standard in a regional or national standard) [is] any difference between the technical content of the International Standard and that of the regional or national standard."* When referring to ISO sources, it is nowhere defined what the "original standard" is, but it remains obvious that ISO refers to its own standards as the original. [20] At the international level, there is an unresolved discourse related to definitions of international standardization organizations that seek to define whether a technical standard is deviating from the international standard or not. Such a discourse fails because there is no common definition of what the international standardization body is across the diverse fields of standardization practice. The reference body therefore rather must be accepted as the international body by the parties involved, which is not always the case (Wijkström/McDaniels, 2013). The German standardization Institute (DIN) for instance states that *"International Standards are developed by one of the three international standards organizations, ISO, IEC or ITU"* (DIN, 2022) and therefore only officially recognizes these three bodies. In contrast the US standardization body ANSI is less restrictive as *"ANSI promotes the use of U.S. standards internationally, advocates on behalf of U.S. policy and technical positions in international and regional standards organizations, and encourages the adoption of international standards as national standards **where needed**"* (ANSI, 2022, for a similar approach by China cf. Weithmann, 2022).

For policymakers, this disagreement over definition can be problematic as it does not provide sufficient basis for e.g., resolving trade disputes. For incumbent firms, adjusting to market requirements appears to be everyday business practice that they are used to. According to one interviewee, „[e]specially between America and Europe you can never say what is original because mostly it is developed on both sides, and both have their history. This is especially true when it comes to highly complex standards, such as the standards for pressure vessels, which is a classic safety standard. That the thing doesn't blow up in your face. And there are two sets of standards. One is a CEN standard. […] And then there's the ASTM standard […]. And those exist in parallel. And depending on the market, people use one or the other although the standards are really different. Of course, the basic safety thinking behind it is the same, but Europe says, the people are very well trained, the welds are good. You can make it thinner there. And the Americans say, the people are poorly trained, so we must build everything with much greater safety reserves, so it must be thicker. Both standards have their justification" (Interviewed Business Executive: 2022/03). The example of pressure vessels shows how deviating standards are handled in the day-to-day business of established industries as

[20] For this study, we reject this as a definition, as the world of standards is far more diverse.

companies often have no choice but to adopt or comply with deviating technical standards. However, this example also illustrates that deviations are not always linked to downside risks. Drawing on the frameworks of institutional economics (see section 1.1), deviation can be seen as beneficial in terms of adaptation to local circumstances. Against this background, the choice of standard-setting actors to urge for deviation from technical standards as a reason for local adaptations can be understood in terms of the theory of "innovation commons".[21]

Within established industries the aspect of the 'power of habit' also plays a large part in defining the original standard through the role of the standards developing organization involved. One interviewee said that the original standard is defined where "[…] I am familiar with the processes, and we have also had good experiences with them. That is something that corresponds to our philosophy and our interpretation. Then I think one would tend to say: The standards that have emerged with a process that I know that I think is transparent – That is the original standard. But a question of fairness such as whether everybody is involved there should also be asked. And why does a German standard, which is a European standard, must become an international standard and thus be fair for everybody? Well, it simply corresponds to my cultural understanding" (Interviewed Association Representative Electronics: 2022/05). It can further be added that within traditional industries the roles between standardization bodies and experts, mostly from incumbent firms, seems clearly defined and dealing with deviating technical standards has often become an established process. The same can be said of new market entrants in traditional sectors. In this case, language is also often a decisive factor for firms as the languages of the standard texts need to be easily accessible and therefore the barriers to the application of a standards should be low e.g., English as common language, colonial heritage, etc. (cf. Interviewed Standardization Expert: 2022/04).

3.2. Clarification of terms: Original standards

However, the definition of the original standard becomes relevant again in the context of new industries and the development of new technology, and is also important in the context of international trade fora as it serves as a key reference for e.g., dispute resolution. In addition to determining the usage of the term deviating technical standards, we have decided to use the term original standard for this study and beyond as follows:

*An **original standard** is a defining variable that emphasizes the ranking order of the establishment OR the forum where most industry-leading firms find common representation of one or more version of a standard that vary(ies) for the same or comparable goods or services, processes and production methods in quality, security, and compatibility (no matter how large the intensity or impact of the respective deviation is).*

In practice, as new industries and new technologies develop, it is often increasingly difficult for standardization experts to keep track of 'where', implying in which forum or group of experts, they should participate in the development of technical standards. An interviewed expert on biotechnology explained, that only a few years ago, a standard expert in his field of expertise would have tried to cover standardization debates in e.g., life science and chemistry.

[21] Studies on the origin of innovation often refer to institutional economic theory. Therefore, the innovation commons theory draws upon Hayek, Williamson and Ostrom and considers the innovation problem as a "combined knowledge problem [Hayek 1945], implicit contracting problem [Williamson 1979, 1985] and collective action governance problem [Ostrom 1990]" (Potts, 2018: 1025).

However, multiple fields of expertise have added sub-fields especially from the IT such as bio informatics, bio safety, bio security, bio cybersecurity (cf. Interviewed Association Representative Biotech: 2022/05).

In addition, there is often a backlog of standards development in areas that are particularly innovative in terms of research and market development, such as artificial intelligence. “In the development of AI, the norm is not necessarily already there, but it develops mostly, in the best case in parallel with the product […] or in the worst case happens when the product is already finished. Then you have an issue. You […] can't sell it then in the market where the deviating standard is” (Interviewed Business Executive MNC: 2022/05). Another interviewee mentioned that the speed of standard development is also an issue as it does not reflect the product development time, which is faster than the standard (24 months at most). For instance, the ambitions from Chinese standard-setters are to develop standards in 18 months, which the interviewee said, would be possible for his firm if it accelerated its internal development. Yet, this would most likely result in different product versions for national and international markets due to longer standard development durations outside of China (cf. Interviewed Business Executive MNC: 2022/06).

All interviewed representatives active within ISO and IEC, whether in an incumbent or new industry, confirmed that they can no longer rely solely on ISO and IEC standard publications but also consider publications from other fora and consortia as internationally valid standards. From the perspective of most standard developers, the discussion about ‘original’ or not is less important. However, the discussion is more important for policy makers when trying to resolve disputes or promote fair trade and is also important for lawyers as part of contract law. For firms, the decision on which standard to use is mostly based on financial considerations and subsequent opportunistic behavior.

Throughout the interviews conducted, the theoretical assumptions about the rather confusing pertaining definition of deviating technical standards were confirmed: It remains difficult to find a ‘starting point’ how to define “deviation” in terms of (depth and breadth of deviation). Developing a definition and deriving follow-up steps from a firm’s perspective requires a benchmark for measuring the scope of a deviation. This can be in relation to international standards (ISO/IEC, ITU, IEEE, etc.), forums and consortia or also the own company standard.

Finding out whether a deviating technical standard is in place therefore remains complex and the industry has to take a number of approaches: The first step is to search for the respective standard reference number for the product and the country of destination where you want to access the market. Second, check the ‘not equal’ or ‘modified’ category (‘degree of correspondence’), then review the affected standard scope. If the scope of the standard does not reflect the searched standard reference number, go back to the search for the correct corresponding standard. If this is the case, as a third step, get information from associations, technical committees (TCs), testing laboratories etc. Following these steps will help to establish a clear overview of the possibly affected areas and therefore provides the baseline against which the impact can be assessed. It is important to consider the impact of a deviating technical standard as deviation may come in different guises.

3.3. Categories of deviating technical standards

To begin with a definition of the intensity and impact of a deviation, it seems necessary to distinguish between *"[…] standards, which have been somehow adapted by […] standard-setters and now differ from the original, and second, so-called 'unique' standards, […] that support […] 'home-grown' technologies"* [22] (Weithmann, 2018). This previous scientific research by Weithmann (2018) particularly focused on investigating **why** national standards deviate from international standards[23] and further, **how deviation of standards emerges**. As a result, Weithmann developed a concept that depicts to evolutionary trajectory that often leads to deviating technology standards.[24] However, this concept does not yet distinguish between (1) how affected businesses are when confronted with deviating technical standards and (2) the impact that deviating technical standards may have. The above-mentioned citation also lacks a clear distinction as to where the definition of "adapted" and differing from the "original" and "unique" begins as it does not refer to the associated effects.

Under the WTO TBT Agreement, countries have various options for applying deviating technical standards, but these different locally adopted international or national standards should be notified to other members. In order to facilitate the identification of technical deviation owing to the differences in the structure and wording of the original standard, ISO/IEC has published a guideline according to which the three named categories of correspondence are: Identical Standards, Modified Standards and Not Equivalent Standards (ISO/IEC, 2005). The latter two are relevant for this study. A standard is considered modified if a regional or national standard contains less, contains more, alters a part of the international standard, or provides an alternative choice (ISO/IEC, 2005). Furthermore, a standard is not equivalent to the "[…] International Standard in technical content and structure and the changes have not been clearly identified. This may include the case where only a minority in number or significance of the international provisions remain in the regional or national standard (ISO/IEC, 2005)." Thus, ISO/IEC only differentiates between a standard that has been adapted without providing information on gradation of adaptation (and therefore counts as deviating technical standard) or simply as a not equivalent standard (which counts as a deviating standard in this study). Any judgement on the intensity and impact is neglected.[25]

[22] The reference to Chinese practices has been erased from this citation as practical experience shows that this is not a specifically Chinese practice.
[23] For reference: The WTO TBT Agreement lists as legitimate reasons: "national security requirements; the prevention of deceptive practices; protection of human health or safety, animal or plant life or health, or the environment; fundamental climatic or other geographical factors; fundamental technological or infrastructural problems" (WTO TBT Agreement: Article 5.4).
[24] As a key finding, this research has found that it "[…] requires differentiation between the standard-setting process that creates deviating standards and the regulatory intervention that applies such deviating standards to promote the diffusion of standards." (Weithmann, 2008: 116).
[25] According to ISO/IEC the identification through the three degrees of correspondence states: "[…] is sufficient and an over-detailed indication is not reasonable because of the variety of possible cases. Any comparison will have to be made point by point and will need to cover both the scope and the content to discover deviating items" (ISO/IEC 2005: 3). Yet, this often causes intense additional work on behalf of businesses.

3.4. Classification of deviating technical standard categories

In order to determine the intensity and impact of deviating technical standards mi, this research has designed a Risk Assessment Index System for further classification (see Table 1). Based on the effect of a deviating technical standard, it can have an impact on different stages within business processes, e.g., operational activities due to required product redesigns or simply result in organizational burdens such as additional paperwork. To complement our interviews, we used the European Commission's "Access2Markets" database, which lists various deviations that create trade barriers in some way and have been reported to DG TRADE as these affect EU exports to non-EU countries[26] (EC, 2022a). However, our study focuses primarily on the extraction of expert interviews.

Based on the sources analyzed, **technical** components, **operational** processes, **corporate** strategy and planning, **administrative** processes, **organizational** engagement, and **market access** barriers were found to be the main categories (1-6) for assessing potential risks that occur in context of deviating technical standards. As part of these main categories, the authors have indexed subcategories that highlight where risks manifest in practice. The Risk Assessment Index System, shown in table 1, serves as an intermediate step to draw attention to or exclude certain potential risks and thus engage the affected business unit in advance.

Table 1: Risk Assessment Index System for deviating technical standards

Risk Categories		**Indexed Risk Subcategories**	
1	Technical	1A	Technical requirements are more stringent
		1B	Technical requirements are less stringent
		1C	Technical requirements are completely different
		1D	Variation of product or service quality
		1E	Variation of product or service safety
		1F	Variation of product or service design
		1G	Additional R&D activities
		1H	Tender requirements cannot be met technically
		1I	Technical requirements go beyond the intention of a standard
2	Operational	2A	Adaptation of production process
		2B	Adaptation of service structures
		2C	Adjustment of supplier network
3	Corporate / Business unit	3A	Changes in cost structures
		3B	Economic loss / gain[27]
		3C	Loss / gain in patents (SEPs)
		3D	Additional R&D budget requirements
		3E	Changes of business models

[26] The barriers listed in Access2Markets are classified by the type of measures, and by the sectors affected by the measures. For this study the authors chose to limit the search results by choosing the so-called measures „standards and other technical requirements" and "non-compliance with internationals standards" as the type of measure (cf. EC, 2022a).

[27] Depending on the perspective of the firm and the originally applied standard, deviating technical standards might not necessarily cause loss but potentially result in economic gain.

Risk Categories		Indexed Risk Subcategories	
		3F	Consumer risk and reputational loss[28] / gain
		3G	Corporate communication
4	Administrative	4A	Adaptation of labels on products
		4B	Additional product and service registrations
		4C	Additional paperwork
5	Organizational	5A	Access to national standardization bodies
		5B	Participation opportunities in national standardization bodies
		5C	Cooperation opportunities with partners nationally
		5D	Cooperation opportunities with partners internationally
		5E	Dominance of standard-setting parties
6	Market access	6A	Market entrance hindrance
		6B	Deferral / postponement of market entry
		6C	Audits, Testing and Certification requirements
		6C.1	Additional audits based on national standards
		6C.2	Double testing needed despite mutual recognition
		6C.3	Only local methods carried on certain local institutions are accepted
		6C.4	Acceptance of 3rd party certification by ILAC[29] accredited laboratories
		6C.5	Multiple requirements to sustain the efficacy claims
		6D	Mutual recognition
		6E	Homologation agreements
		6F	Standard cannot be implemented in accordance with local jurisdiction

Source: Authors' own compilation based on data evaluation and interviews.

We also acknowledge that most of the aspects mentioned in the context of organizational commitment and market risks may not relate to deviating standards that occur throughout the technology development process but are rather "[…] seen as a prerequisite to make certain regulatory mechanisms work, such as government procurement or the exclusive issuance of licenses to domestic companies. The government therefore support[s] the domestic industry based on deviating standards. This enable[s] domestic firms to move on independently from foreign patents and related royalties" (Weithmann, 2018a). "[T]he line between setting deviating standard requirements to support [national] firms and deliberately harming foreign companies can turn out fairly thin" (Weithmann, 2018a). This can be illustrated by the example of India: As international travel was suspended due to Covid-19 e.g., the Bureau of Indian Standards (BIS) did not conduct any audits of foreign manufacturing plants in relation to additional Quality Control Orders (QCOs) for auto components that already comply with international standards and are now urged to comply with Indian standards as well (EC, 2022b). Having a deviating technical standard can be one part of the game, but linking these standards to regulatory requirements, makes it a political trade burden and was therefore listed as trade concern to DG Trade in the illustrated case of India.

When speaking about the different categories with our interview partners, the first category 'technical' and the sixth category 'market access' were the most frequently mentioned and are therefore described in more detail. Overall, most of the cases mentioned by interviewees did

[28] In case of less stringent safety requirements and potential consequences.
[29] ILAC refers to International Laboratory Accreditation Cooperation.

not mention decoupling, deliberate market barriers or burdens designed to harm foreign trading partners. Most impacts related to deviating standards are rather linked to technological path dependencies, relations among insider circles and the dynamics or the slowness of other standardization processes, or to chance.

As the sixth category 'market access' was most often mentioned, it is discussed first in this study. All interviewees confirmed that particularly testing and certification requirements have increased in recent years. This may have different reasons such as in case of India: "India is struggling very hard with the influx of Chinese products, which are of inferior quality or counterfeits. And that is why the Indian government and the Indian industry representatives are tightening the access restrictions" (Interviewed Business Executives Explosive-Products[30]: 2022/06). In such cases none of the interviewees blamed India for such measures but rather pointed out that the economic rise of various Asian countries also has an impact on the standardization ecosystem. Rather, it was acknowledged that similar approaches have been established in Europe or the US e.g., in the EU market access mostly requires aspects like CE-certification[31], conformity declarations or also type examinations. Direct costs of diverging market access and homologation requirements were generally not mentioned as an issue. One interviewee even spoke of "simple overhead costs" (cf. Interviewed Business Executive MNC: 2022/05) that each firm includes in its product development cost or project planning anyway. However, "[…] the secondary and tertiary costs downstream are significantly higher, as is the development time […]. We may have to audit production sites, pay annual fees, tie up resources" (Interviewed Business Executives Ex-Products: 2022/06). This underlines the importance of harmonization efforts between trading partners.

Secondly, the first risk category 'technical' refers to the aspect of product design related types of labelling and was also mentioned a lot as these aspects are increasing in size. Different interview partners said that they do not know how to deal with the amount of labelling requirements anymore. "Every country now wants to have its own labeling and four letters instead of two, so that it is particularly large […]. And we […] no longer know where to put all the stuff on a sensor" (Interviewed Business Executive Sensors: 2022/06). In this case, it is not just about the administrative process of placing a label on a product, it also has sincere effects on design and production processes. On the same level as such changes of labelling types are "[…] minor changes which do not fundamentally change anything in the core design or the engineering, but also […] the product remains 90 plus percent the same. But these are unproblematic, less function and performance determining minor changes […]" (Interviewed Business Executive MNC: 2022/05). However, there are other examples that strongly influence technology development and require new technological solutions: "In the area of fire protection, there were indeed requirements that made life massively more difficult for us, such as things like testing cables. There were levels of forces required that were actually no longer feasible for a sensor the size of a matchstick and with minimal cable cross-sections. Because the copper tensile strength constant alone could no longer withstand these forces" (Interviewed Business Executive Sensors: 2022/06).

As the examples show, it is mostly a combination of two or more categories as e.g., labelling differences are associated with redesign of the product, administrative extra-work, and

[30] From here on abbreviated as Ex-Products.
[31] Conformity with European health, safety and environmental protection.

additional certification requirements. The introduced risk assessment index therefore supports companies in establishing a complete overview of the related aspects when confronted with deviating technical standards.

3.5. Evaluating the impact of deviating technical standards

The previous categorization now enables the identification of areas where deviating technical standards manifest themselves in practice. This already allows a more detailed picture of standard adoption rates and can no longer be seen as merely black and white, or as ISO/IEC puts it: modified or non-equivalent. Nevertheless, modified can still provide many shades of grey, which this research aims to clarify. The next step is to assess whether a deviation could be detrimental to a company's business. The **Risk Assessment Index System** already introduced (see Table 1) is regarded as a first-class index and is used as the basis for constructing the risk impact scale of deviating technical standards, as shown in Table 2. The impact scale in Table 2 ranges from 1, which equals insignificant up to 5, which would be catastrophic for companies trading internationally. Based on the previous categorization, the transfer to the impact scale can be achieved. While companies should try to scale each subcategory in detail, the Table 2 provides a compilation of our conducted interviews and therefore illustrates a generic table.

Table 2: Impact Scale of Deviating Technical Standards on Trading Companies

	Impact Scale				
	Insignificant 1	**Minor 2**	**Medium 3**	**Major 4**	**Catastrophic 5**
Technical	No product/service adaption needed	Small product/service adaptation needed	Medium product/service adaptation	Significant product/service redesign	Entirely new product/service; exceeds possibilities
Operational	No adaptation of product processes / service structures needed	Small adaptation of product processes / service structures needed	Medium adaptation of product processes / service structures needed	Significant redesign of product processes / service structures needed	No match of existing product processes / service structures
Corporate	No impact on corporate governance	Small impact on corporate governance	Medium impact on corporate governance	Major impact on corporate governance	Catastrophic Small impact on corporate governance
Administrative	No administrative burden	Small administrative burden	Medium administrative burden	Major administrative burden	Catastrophic administrative burden
Organiza-tional	No limitation to standardization engagement	Minor limitations to standardization engagement	Minor limitations to standardization engagement	Minor limitations to standardization engagement	Very high limitations to standardization engagement
Market	No market entry barriers	Minor market entry barriers	Medium market entry barriers	Major market entry barriers	No market access

Source: Authors' own compilation.

Within the impact scale 1, which reflects 'insignificant impact', it would be likely that products follow e.g., a homologated standard. There are neither product compatibility requirements, nor network effects, nor any certification requirements. The importing country has published a deviating standard but has no impact on a firm's business. An example is the prioritization of intra-regional trade of wood products within the African Community. Regionally concentrated standard-setting activities, between two business partners or within the African Regional Standards Association (ARSO) forum may result in a local standard. In this context, deviating technical standards are not yet critical when trying to enter the African market as there are no established testing laboratories (cf. Interviewed Standardization Expert: 2022/04). Therefore, despite deviating standards, the impact on business is negligible.

Placed on 2-3 of the impact scales are the more common but less damaging deviating technical standards with 'minor' or 'medium' impact on companies' business. The example of Covid-19, where the Bureau of Indian Standards (BIS) did not conduct audits of foreign manufacturing plants of auto components was mentioned in chapter 3.4. However, there are also minor first and secondary requirements that need to be fulfilled in the context of additional certification needs. However, depending also on the tertiary costs associated with market access, the impact of a deviating technical standard can already be rated as rank 4 on the impact scale and needs to be analysed on a case-by-case basis.

Rank 4 on the impact scale is mainly concerned with 'major' product adaptions within the 'technical' category. The case of safety standards for pressure vessels was mentioned in chapter 3.1. In addition, one interviewee recalls the case of "[…] connection technology for electric motors where you have deviating requirements in the USA, so-called NEMA motors. The [National American Manufacturers Association (NEMA)] standard has completely different requirements. It applies not only to the connection, but also to the energy efficiency measurement method. So, you […] end up with a different product for the US than for the rest of the world. Another example is circuit breakers, which are basically fuses like the ones you have in your box at home, behind the front door. There are different requirements for tripping sensitivity in China. And because of this, the switches must also be designed differently than in our country" (Interviewed Business Executive MNC: 2022/05).

However, within ranks 2-4 of the impact scale, the interviewees reflected a shift in their perception of the intensity of the impact of a deviating technical standard on their business. This is also partly due to the regular transformation processes that takes place once intense business impacts are discovered. After the initial discovery, companies would therefore rate the impact as major or even close to catastrophic, which would typically lead to a shift in personnel and financial capacity to address the identified issues. At the same time, management boards would pay far more attention to the issue and e.g., seek to influence standard-setting to avoid adverse business impact. As the first successes are achieved in standard discussions or internal product replanning progresses, the ranking of the business impact might shift towards 3 or even lower as it is no longer perceived as a major risk for further business processes. Finally, firms might potentially become accustomed to developing different products for two or more different markets. For a more detailed example of rank 4 on the impact scale, see also the example of electric vehicle charging as researched by Weithmann (2018a).

The worst-case scenario, ranked 5, is certainly denial of market access due to certification based on deviating technical standards in the target country. For instance, a deviating certification is

required to enter the Chinese bank card market. Certification there is based on a national standard, the so-called OSCCA-standardization[32] that deviates from other international standards (cf. IEEE Explore, 2020). The technical deviation is based on a part of the standard, for which a sub-working group has defined the related algorithms and the implementation on the hardware e.g., on the chip (cf. Interviewed Business Executive MNC: 2022/06). The result of this sub-working group was not made public, which means that any other company (none-Chinese) is denied market access as they cannot even learn about the aspects that would be necessary to meet certification requirements. Another example mentioned was related to the radio and telecommunication sector. In this industry, countries often develop their own standards, which may cause significant need for product adaption or market access barriers (cf. Interviewed Business Executive Sensors: 2022/06) due to e.g., declaration of the sector and national security relevance. This again highlights the importance of evaluating the development phase according to the SDC (introduced in chapter 1.2) as this is useful for defining the level of development of the targeted export country and thus to guide expectation and risk management. Finally, high rankings on the impact scale can also lead to entire export markets being written off, as cost of product adaptation is no longer proportionate to the associated sales to be generated.

In addition, some aspects have been observed where the impact can be ranked 5 but does not directly lead to denial of market access. The combination of the categories '1J Technical requirements' where the requirements go beyond the intention of a standard and '5E Dominance of standard-setting parties' appears to be a rather grey area in standardization, but appears to be growing in its importance.[33] For instance, the discussion around standards for umbilical cord stem cells was used by firms "[…] trying to set an international standard that would provide a quasi-legal situation for minority interests so that they could do their business in China. There is a very large market for stem cells in China. These are creams, for example, or even vaccinations. They once told me that such an injection costs $10-15,000. [They say] this is the fountain of youth and then you will be completely rejuvenated and [you will be] at least 300 years old" (Interviewed Association Representative Biotech: 2022/05). In this case, standard-setters tried to misuse the standardization framework to legalize the consumer end-products and also defined additional quality criteria for the further use of the extracted stem cells. The interviewee further explained that it was very difficult to focus on shaping a standard for extraction processes of umbilical stem cells because Chinese representatives were heavily involved in the discussion but had a different objective. Above all, the direction of this discussion did not deny market access to companies, but rather shaped societal debate and misused standards to confront legislation with an already existing standard. Similar cases where debates about technical requirements are misled can also be found e.g., in marine communication or cash registers where the issue is about data collection and divergent data protection interests (cf. Interviewed Business Executive Ocean Engineering: 2022/05).

For companies, the application of the '*Impact Scale of Deviating Technical Standards on Trading Companies'* (see Table 2) can overall help to assess the potential risks arising from deviating technical standards. It can also help to define how many human or financial resources

[32] OSCCA is the abbreviation of the Chinese Office of State Commercial Cryptography Administration.
[33] This was an impression shared by older generation standard experts with lots of experience in the field but cannot be proven through data.

to devote to standard development. However, our interviews also revealed that foresight in standards development remains particularly difficult for companies as this requires top-level support from management board members, established standardization structures within the organization and continuous training and attention from a wide range of experts involved in research, development, and product management processes.

3.6. Managing deviating technical standards: Business practice

In our interviews we found that management response to deviating technical standards is rarely institutionalized and varies widely between firms. From those who **do not have** established any monitoring and intervention tools to those having established more sophisticated systems in recent years. Of the former, one interviewee said: "Testing is certainly the point where it simply falls on the feet of many. Companies are obliged to carry out certain certifications because there are compulsory certifications or other processes that force them to do so. And then the test laboratory, the test institute is certainly always the one that says okay, but here we need a different limit or value. And then, of course, the astonishment is enormous" (cf. Interviewed Association Representative Electronics: 2022/05). A similar outcome can occur if a company does not plan to enter a specific country at the product development stage but decided to do so at a later stage of the product life cycle: "Not every company has a strategy that they want to sell their product globally right away. Most customers who come to us ask what requirements they must meet" (cf. Interviewed Consultant Product Compliance: 2022/04).

Although some companies are unaware that they can participate in the development of standards, this is usually due to lack of personnel resources: "If I am involved in standardization, I have personnel XYZ at my disposal, and I only have that once. This means that I cannot contribute internationally to Germany, Europe, India, China, USA […] because I only have 'this' budget, which I can spend on standardization, in one place" (Interviewed Association Representative Electronics: 2022/05). In addition, many interviewees complained about the difficulty of finding the right human resources: "We have the big problem that you cannot buy standardization experts off the shelf. There is no apprenticeship for it. And there are very different and sometimes even contradictory requirements for people. On the one hand, they should be very technically versed, know our portfolio [and] our markets. [They should] also understand and be able to analyze the standards in depth. [They should further understand] the consequences of certain activities. On the other hand, you have to be integrative to the highest degree. That means you have to look into and understand the moods within a standards committee. Are there companies that want to go in one direction, where do we want to go? And, of course, they have to go hand in hand with the corporate strategy […]" (cf. Interviewed Business Executive MNC: 2022/06).

Although many firms show strong intentions to establish foresight structures to manage the ever faster changing standardization development and adaptation needs, the focus is more on managing day-to-day business needs. One interviewee further highlighted that "[…] we try to identify such [standard requirements] changes as early as possible. To be honest, that's not possible on a global scale, and the focus is on the top 20 countries because that's where we generate 95% of global sales […]" (Interviewed Business Executives Ex-Products: 2022/06). Keeping an eye on this usually implies that companies try to engage in standard development.

In this research, participation in the standardization development has therefore become apparent as the key foresight tool in standardization.

For most of the interviewees, standardization is still part of general business processes "[…] The reality is that as part of the very normal business consideration process, there are already supply chain and project management methods with certain milestones and checklists […] in the process, and there we have a mandatory item called '[we] have double-checked regulatory requirements and potentially deviating standards.' And so that's quite a pointed stumbling block in the process" (Interviewed Business Executive MNC: 2022/05). In some cases, this can lead to withdrawal from certain markets: "At the end of the day, you look at whether the business case is profitable enough to adjust a product to local requirements. [For long, delivery] to North Africa with the same requirement as for Europe [was possible]. And now the North Africans want [additional] documents [that require] paperwork, [efforts] that simply do not add to the sales revenue because the [North African] markets are too small. This is where you deliberately think [… If] our colleagues do that, they won't do anything else" (Interviewed Business Executive MNC: 2022/06). Other companies also document the processes in a product lifecycle management system, knowledge management systems or collaboration platforms. In the end, however, most interviewees admitted that there is still a need for standardization experts to review new standards or standard updates individually. In addition to technical experts, this includes e.g., lawyers for regulative aspects, administrative certification experts, product compliance managers and others. Most interviewed experts consider their standardization work as a product of organization internal and external swarm intelligence which is further enriched by personal networks within associations and individual long-term relationships with other standardization experts.

As part of this swarm intelligence, companies also use externally purchased software to receive information about newly changed or adapted requirements. In terms of software tools, all interviewees seemed to have one or the other tool in place to monitor or screen markets, but none of the tools appeared satisfactory and fully reliable or comprehensive (cf. Interviewed Business Executive Ex-Products: 2022/06). Thus, a lot of additional research is necessary e.g., via government or legal websites (cf. Interviewed Consultant Product Compliance: 2022/04). In this context, standardization is not seen a single aspect but always comes in guises of regulatory demands, compliance, conformity and certification under the umbrella of overall market access requirements. However, all interviewees emphasized that the 'human' standardization expert itself is always the best tool.

4. Conclusion, Limitations and Outlook

4.1. Conclusion

Findings from this study provide a better understanding of deviating technical standards and also stimulate academic discourse in a largely untapped area of research to further address the challenge of technical standardization in a globally interconnected world.

First, the authors propose a clearer wording when talking about deviating technical standards. This will help to avoid finger pointing between international partners and to better understand how deviating technical standards affect companies around the world. In the study, the authors therefore define **deviating technical standards** as anything that differs from one technical

standard to another (the original) standard for the same or comparable goods or services, processes and production methods in quality, security, and compatibility, regardless of the intensity or impact of the respective deviation (see our definition in ch. 3.1). To analyze deviating technical standards, it is always necessary to adopt the perspective of the party concerned. Apart from establishing the term of reference being "deviating technical standard" for this study, the authors also suggest doing so for future research related to the same frame of reference.

This study further shows that deviation in technical standards can have multiple shades depending on their impact on companies. We therefore recommend to (1) clarify the character of a deviation with more precision and (2) evaluate the impact of the deviating technical standard to find out whether it may cause harmful effects or not. This grading seems essential for clear communication and fair discussion among international trading partners and particularly when dealing with developing countries trying to join the standard game. At the same time, we emphasize that the distinction between setting deviating standard requirements to support national firms, which could be seen as only way out of the vicious circle of technology development dominated by developed countries (cf. SDC in ch. 1), and deliberately harming foreign companies remains a narrow one.

Second, we propose a proprietary and newly developed risk indicator to not only engage in the standard game but also to better assess the consequences. In this context, we have proposed six main categories to ease business planning for affected companies by assessing potential risks that occur in context of deviating technical standards. Within these main categories, we indexed subcategories that highlight where risks manifest themselves in business practice. This risk assessment index system (see Table 1) serves as an intermediate step to engage potentially affected business units upfront. The next step was to assess whether a deviation may be harmful for businesses practice. The Risk Assessment Index System (Table 1) is regarded as a first-class index and is used as a basis for the construction of the risk impact scale of deviating technical standards (Table 2). As a third step it would be necessary to establish a risk management approach to define the consequences of dealing with deviating technical standards.

The key findings of this study emphasize the need for fully integrated and easy-to-use standardization management systems that enable companies to deal with standardization and also with potential risks deriving from deviating technical standards. As risk management was not yet part of our research focus, we suggest this for further studies.

4.2. Recommendations

For the time being, and based on the here presented results of the study, companies are encouraged to follow a four-step approach to deal with deviating technical standards occurring in everyday business practice:

- First, start with a macroanalysis of the respective industry setting using the SDC (see ch. 1.2). If a company finds itself in phase 2 or on the rim of phase 1 and 2, the likelihood for deviating technical standards increases. Depending on your resources: e.g., start with key countries, industries, products, etc.
- Second, apply the Risk Assessment Index System and adapt it to the respective business model and industry approach of the company.

- Third, based on the adapted Risk Assessment Index, prepare and evaluate the Impact Analysis to find out what impact a deviating or potentially deviating standard could have on the company. This will then guide your subsequent management approach within the target market.
- Fourth, manage the risks according to the low-middle-high ranking and invest in further research.

On a more general management level, this research also suggests that companies should start to think beyond established structures, workarounds and approaches and accept new standard setters, consortia, or different collaborative constellations as clinging to old structures and routine processes in standardization may no longer work for new industries and fast changing technologies. In addition, this research provides insights on how to rethink the efficiency of standardization work e.g., regarding your participation in certain TCs or standardization groups. And while the results may not yet be overwhelming, try to adopt a proactive – foresight driven – standardization strategy and try to add big data driven decisions to successfully manage different use cases. The use of such a reliable database can help companies make decisions not only about compliance and interoperability, but also about future product innovation and investment.

On a more industrial and geopolitical level, the here presented research findings provide evidential support that the call for more standardization competence should be heard not only by the industry but also by academia and policy makers. State actors should develop a coherent strategy for key industries and countries that are important for their national economy and trade approach. Furthermore, state actors should strategically invest in education of standard-setting practices to provide the strongly needed expert capacity. For Germany, programmes such as WIPANO (BMWK, 2022) are in place. But these programmes and other initiatives require a rethink on what kind of prioritization is needed before receiving additional funding. At present, the German industry is not supported sufficiently because participation in standardization activities is too costly and standard-setting processes are too slow. In the end, it is not only a more digitized and systematic approach that will bring this important topic out of its niche. People in positions of responsibility also need to rethink how they deal with and talk about standardization. Closely associated with this is investment in academia on university level, in terms of research into standardization management and education and training of young professionals.

4.3. Limitation and Outlook

The researchers of this study have used largely mixed but mostly qualitative research methods for this study. More detailed analyses based on quantitative standards data would be highly appreciated if available, in particular more fine-grained analyses at the level of industry, country, and technical standards. For example, a more distinct focus on such kind of standards data can yield insights into cross-border interdependencies and the diffusion of international technical standards between early adopters and laggards. It may also be interesting to combine our standards research with corporate and financial data, or actual decision-making schemes of corporate representatives, to identify internal reasonings related to corporate standards strategies. In addition, data analysis could benefit from the increasing availability of data on relevant ITU standards, which are often better analysed than in other industries. This study did

not consider standards that are part of their own eco-system (e.g., Apple's proprietary lightning interface), despite their considerable market power and influence on suppliers. The power of such eco-systems might also deliver interesting insights into monopoly constellations in certain industry branches and their respective impact on industrial innovation.

This study will be a first step towards a better understanding of the role of different "degrees" of deviation and the respective impact of minor or negligible deviation and major deviation on businesses trading in a global context. The findings close an important research gap by showing how companies could use a newly developed risk indicator not only to play the standards game but also to better assess the consequences. However, there are challenges ahead in creating a functioning international standardization system that go beyond the discussion of deviating technical standards. Additional studies are further needed to shed light on the business responses i.e., risk management to such deviating technical standards. A recent initiative of the IEC called the Global Relevance Toolbox involves specifications of regionally deviating standards in the annex of the international standard to facilitate the comparison of deviating aspects in standards. However, this is still under consideration and most of our interview partners have not even heard about it. In the future, it would be important to take a holistic approach to deviating technical standards – one that considers the entire life cycle of standardization. With this in mind, it is important to keep an eye on software tools that have **not** yet been developed to reliably track and analyze the massive stack of documents generated by an increasing number of standards.

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