The Effect of the COVID-19 Pandemic on Standardization

Philipp Heß and Knut Blind

***Abstract*—Standards played a central role in the quality infrastructure that supported the international reaction to the COVID-19 pandemic and were a cornerstone in managing new technology in times of crisis. They fostered the resilience of value chains, enabled the global production and distribution of medical equipment, and supported the reliable operation of laboratories. To provide new and updated standards, the standardization system needed to restructure highly complex processes that relied on contributions from stakeholders who, themselves, were affected by the crisis. In this article, we generate new and unique evidence on the impact of the pandemic on standardization by using the assessments of nearly 2400 standardizing organizations from a dedicated survey in combination with an 8-year-long panel. Our results show that firms' changes to their standard-setting activities are moderate, especially as digitalization effects compensate for shrinking budgets. An increase in the usage of standards was only noticeable for areas directly implicated by the pandemic, e.g., medical equipment. Standardizing firms appear to "sit out" the crisis while sinking costs for participation equip the system with resilience. However, the pandemic creates new challenges for standard-setting organizations due to disruptive effects on work in committees, where interpersonal exchange suffered, and introduced changes potentially cause creative destruction.**

***Index Terms*—COVID-19, innovation, quality infrastructure (QI), standards, standardization.**

I. Introduction

TECHNICAL standards are the output of collaborative efforts of actors from industry, science, government, and society to create specifications that ensure product interoperability and enhance quality, safety, and environmental protection. As part of the global quality infrastructure (QI), they have been essential for fostering the resilience of global value and supply chains and for supporting healthcare systems in the reaction to the spread of the virus [1]. The operation of laboratories, the application of testing procedures, and the production of medical equipment, such as masks and respirators profited heavily from existing QI. However, the QI itself has been impacted by the COVID-19 pandemic [2], [3]. Therefore, we are interested in revealing how the consensus-finding process, which involves a large number of participants and a high coordinative effort, has been challenged by the restrictions to physical meetings put in place due to COVID-19. Complementary, the negative demand shock in most markets diminished contributors' resources and created the need to reorganize processes quickly, which posed an additional threat to the system's reliable functioning.

Our investigation focuses on the resilience of the standardization system regarding stakeholder involvement, consensus-finding, and speed and efficiency of processes. We further evaluate changes to the usage of standards and if and how the pandemic affects their role in markets and as business success factors.

Intending to generate timely results, we used the 2020 survey of the German Standardization Panel to gather assessments of standardizing organizations regarding these issues. The survey generated a high response and showed that standard-setting activities could be maintained through the crisis that a substantial digitalization boost had set in, and that this was associated with positive and negative side effects.

Therefore, we make a first contribution to the analysis of the resilience of the standardization system in times of crises based on a large scale survey, which has been not considered in previous work on the dynamics of standardization [4] or on companies standardization strategies to address technological uncertainty [5].

In the following section, we elaborate on the contextual background of QI and standardization in the pandemic and analyze the available literature. We then develop a conceptual model of the influence of the crisis on the system, focusing on the effects of the demand shock on stakeholders and the digitalization of standard-setting processes. After describing the setup of our survey, the response, and the resulting sample, we evaluate the responses from both the 2020 survey and the 8-year-long panel. Finally, we discuss implications for standard-setting organizations, firms, and future research.

II. Background

Technical standards sit at the heart of the QI that enhances quality, safety, and interoperability for industry and consumers. They define the rules that form the basis for metrology, testing, quality management, certification, and accreditation. Such "formal" standards are developed at standard-setting organizations

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[6] on different regional levels, for example, internationally by the International Organization for Standardization (ISO), in the EU by Comité Européen de Normalisation (CEN) / Comité Européen de Normalisation Electrotechnique (CENELEC), and by national standards bodies, such as DIN in Germany or AFNOR in France. In contrast to other types of standards, such as de-facto market standards, consortia standards, or standards set by single companies [7], formal standards are developed under the voluntary participation of a variety of stakeholders from industry, science, government, and society [8], in a process that follows principles, such as openness, transparency, and consensus.[1] The development of standards is commonly organized in technical committees, in which participants agree on rules through the exchange of knowledge and the balance of interests.

The demand for new standards is tied to technological progress: new technologies require new standards that ensure the quality of innovative products and services, but also their interoperability with existing technologies. Firms participate in standardization to introduce their preferred technologies into standards in order to benefit from increased diffusion through mechanisms, such as variety reduction and economies of scale or positive network externalities [9]. Standardization, therefore, particularly mirrors the interorganizational activity of R&D-intensive and innovative firms that aim to use standardization to capture value from their innovations [8], [9]. As standardization processes involve intense knowledge exchange and codification [12], participating in this setting can create competitive advantages through early access to knowledge and extended access to relevant knowledge sources [7], [11].

Initiatives for standardization can also arise from the side of regulators that identify gaps in the existing ruleset and wish to employ the multistakeholder approach of formal standardization to harness state-of-the-art knowledge for potential solutions. In the EU, for example, under the New Approach and the New Legislative Framework, the European Commission can give concrete standardization mandates to the European standardization organizations to produce standards that concretize abstract rules set in regulations or directives [14]. Firms, in turn, use this channel intending to exert direct influence on regulation [13].

A UN report from 2020 [1] stressed that the QI system would be essential in managing the pandemic and that "QI services are an essential industry by itself and cannot stop operating even during crisis times." The contribution of standardization was seen in supplying relevant standards and harmonizing international standards to facilitate international trade. Highlighted areas were standards for medical and personal protective equipment (such as gloves or face masks), laboratory standards (to guarantee reliable COVID-19 testing), but also standards for business continuity and emergency management. The later stages of the pandemic saw a rising demand for the standardization of technologies related to vaccines. Other parts of the QI faced similar time-sensitive tasks, such as sped-up testing and certification of medical products or the accelerated accreditation of foreign testing laboratories to enable fast distribution of goods.

[1]Documented, e.g., by WTO: https://www.wto.org/english/tratop_e/tbt_e/principles_standards_tbt_e.htm

There is some evidence that parts of the QI struggled to uphold their normal activity levels during the pandemic. For example, a majority of conformity assessment bodies (CABs) were challenged with operational restrictions mainly pertaining to on-site audits and inspections. At the same time, many also faced lowered demand from customers in disrupted industries [2], [3]. Similar problems were faced by voluntary sustainability standards initiatives [15]. CABs met these challenges with increased levels of digitalization and, when possible, replaced on-site audits with remote audits [14], [15].

Some examples suggest that the standardization system also struggled with the pandemic. The case of standard-setting efforts for contact tracing apps [18], for example, showed that the standardization system failed to generate a timely, suitable, widely agreed-upon standard under the time pressure that was generated by the crisis. A time-consuming "format war" [19] took place, and instead of a standard developing through the usual modes of standardization [7], the outcome was determined by the platform-owners Google and Apple. In the later stages of the pandemic, following the development of the vaccines, rules for digital vaccination certificates were developed. The "EU Digital COVID Certificate" (EU DCC) was created by the European Commission and launched in July 2021. Instead of open standard-setting involving different stakeholders, e.g., achieved through a mandate to one of the European standard-setting organizations, the technical standard, which is based on a digitally signed document, was directly developed by the EU eHealth Network [20]. The EUDCC standard resulted in many implementing apps by EU member states and wide diffusion even outside the EU [21].

The contact tracing example might be a special case and potentially nonrepresentative of the system's reaction to the pandemic, as a specific determinant was Google and Apple's control over the underlying technology. The success of the dominating standard ultimately hinged on both actors' power over a critical feature in their mobile operating systems, namely, to allow apps to access Bluetooth even while inactive or in standby mode [18]. Arguably, the situation might have developed differently if this feature had been an option at the outset of the standardization efforts. Nevertheless, this case could be interpreted as evidence of a failure of the standardization system caused by a too-slow speed in responding to the challenges of the quickly developing crisis. Accordingly, the then following top-down standard-setting for digital vaccination certificates could be understood as the EU's pragmatic response to this failure.

The presented evidence highlights one aspect of formal standardization in times of crisis: its struggle to produce standards for time-critical scenarios. This is undoubtedly linked to the complexity of its otherwise most apparent strength of equipping rules with legitimacy through open processes, consensus, and the involvement of diverse stakeholders [14]. However, slow standardization processes are a known problem, not only in response to crises but generally in the face of accelerating technological progress [22]. It is unclear if the speed of standard development suffered further from the pandemic, e.g., due to the requirement of remote work, as in the case of CABs. It is further uncertain if there were other challenges that the system had to

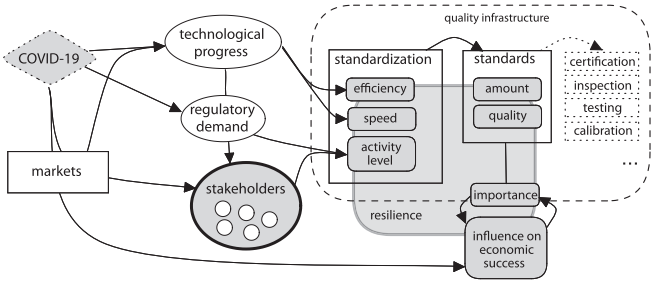

Fig. 1. Conceptual model of the effect of the COVID-19 pandemic on standardization.

cope with and how it tackled those challenges. Therefore, while these examples can be seen as indications, to assess the effect of the pandemic on standardization, a more extensive examination of potential effects and associated empirical evidence is needed.

Taking on the perspective of system resilience (fundamentally, a property that describes that a system can "incorporate change and perturbation without collapsing" [23]), the effect of the pandemic on the standardization system can be examined by setting the challenges that emerged from the pandemic into contrast with how well the system managed them [24]. The pandemic can be interpreted as an exogenous crisis for standardization that manifested itself primarily as two types of shocks. On the one hand, as a negative shock on the market, potentially through reduced demand, negative impacts on financial markets, and supply-side disruptions [25], which affected the system stakeholders and, subsequently, the system. On the other hand, as a direct "technology shock" on the processes within the system mainly related to the replacement of face-to-face meetings with digital remote meetings. An evaluation of the standardization system's resilience in this crisis is determined by how well the system absorbed the exerted stress, reacted to challenges by reorganizing, and persisted in delivering adequate output. This adequate output can be defined as 1) the quality and amount of developed standards in relationship to demand, while 2) maintaining a level of stakeholder participation that allows for the fulfilment of self-imposed "standardization principles," which equip resulting standards with legitimacy [26]. In the following paragraphs, and summarized in Fig. 1, we conceptualize the types of challenges that potentially resulted from the crisis, and discuss different hypothetical system reactions.

Evidence suggests that the impacts of the crisis on standardization stakeholders, particularly those from industry, were comprehensive [25], [26]. Many firms' financial situations changed abruptly; in some industries, firms had to reorganize in the face of disrupted value chains [29], unavailability of materials and staff, or even wholly obsolete business models [28], [29]. Particularly smaller firms faced insolvencies [32]. The effects on stakeholders of standardization and other actors of the QI imply that both the demand for standards, as well as the availability of standard-setters' resources, were affected.

Demand for standardization potentially had to adapt to a disrupted pace of technological progress. Evidence from prior crises shows that reduced firm resources, such as financial liquidity, imply reduced R&D expenditure [33], and changes in innovation strategies [34]. This, in turn, could lead to a lowered demand for the standardization of new technology or be accompanied by a shift to other appropriation mechanisms. An opposing effect, however, could be expected for technological areas in which the pandemic increased innovation and even led to radical innovations, for example, in the field of medical technology [33], [34]. Here, more standardization activity could be driven by the supply of new technology and the efficiency of standards as a coordination instrument in uncertain markets [5], [37]. The changing demand for new rules as a product of crisis-induced acceleration or slow-down of technological progress could have been accompanied by new demand for standardization that directly originated from the pandemic. New challenges, such as the need for standardized vaccination certificates, or testing procedures, were potentially reflected in additional standard-setting activity.

At the same time, the usage and diffusion of standards met new barriers. On the one hand, the number of certifications initially grew slower due to new constraints on on-site inspections [3]. On the other hand, the crisis could have spurred the diffusion of those standards that became more relevant. In specific categories, such as health management, the implementation of standards likely soared.

As standard-setters' resources were affected, they had to reconsider their expenditure for standardization. Some stakeholders were likely unable to contribute as much as before the crisis. Staff was affected by sickness and quarantine or potentially reassigned to other, more critical tasks. Even without effects on innovation and demand for standardization, the disruption of markets and the associated "creative destruction" [34] and the transformation of industries could have affected the standardization system. Resulting realignments of technological trajectories could have led to the creation or abandonment of standard-setting projects, and changes in power structures could have been reflected in the composition of committees, as in certain areas, the weakening of incumbents potentially made way for new actors.

The effects on demand and resources, mainly due to market-related shocks on stakeholders, were accompanied by a direct shock on the processes and governance of standardization as all face-to-face exchange at standard-setting organizations was switched to digitalized remote meetings following the restrictions in the spring of 2020. This likely hit standardization even harder than other parts of the QI. While the switch from on-site to remote audits affected a bilateral process at CABs and was associated with a loss of interpersonal relationships that affected the build-up of trust between CABs and their clients [17], the number of affected actors in standard-setting committees was far higher, and adverse effects likely more multifaceted. Collaborative development and consensus-finding in standardization require complex knowledge exchange, recombination, and negotiation [10], [11]. These activities are fostered by the availability of tacit knowledge transfer, the build-up of social capital [38] in communities of practice [39], and serendipitous, unplanned interactions [40]. Also, particularly the onboarding of new standardization experts might have proven difficult via online meetings and in the face of an established "pre-COVID" community. However, well-planned and -conducted online meetings could

have improved process efficiency and speed. Remote meetings were undoubtedly associated with reduced costs (no travel costs, less time spent on meeting due to lower "overhead"), which could lead to more exchange (meeting more often), and other, more diverse participants and knowledge sources as firms are able to send more staff or to participate at all. This could have led to even more, or higher quality, output [41].

Fig. 1 gives an overview of the pandemic effects and their potential impact on the standardization system, as discussed in the paragraphs above. Accordingly, the main concepts that are under investigation as characteristics of the system resilience during the pandemic are as follows:

1) changes to its *activity level* (e.g., the number of new projects and participants) due to impacts on stakeholders and demand for standards;
2) changed process *speed and efficiency* in light of sudden organizational challenges and a quick technological response (digitalized remote meetings);
3) changes to the system's output, measured in *amount* and *quality of produced standards* (due to changes in activity, efficiency, or changed demand for standards). Furthermore, we investigate the impacts that the pandemic might have had on the role of standards by analyzing;
4) changes to the *importance* of standards and their *impact on company success factors*.

III. Methodology

In light of the timeliness of our investigation and the unavailability of existing data sources, we turned to a direct survey of standardization stakeholders. We collected data on firm perceptions of the pandemic using the questionnaire of an annual panel on firms' standardization activities. The questionnaire consisted of two sections[2]: a core section with a set of questions fixed across survey waves and a special section designed explicitly around the potential effects of the pandemic on standardization, as described in the previous section. The survey is conducted in the fall of each year and commonly addresses the past fiscal year, in this case, 2019. To be able to generate the first data on the effect of the pandemic, some questions were duplicated and targeted at 2020. There are two datasets that we use in our analysis. First, answers to the special section from the 2020 survey. Second, an 8-year panel dataset of general firm perceptions of standards and standardization (2013–2020).[3]

The special section consisted of the following four parts. The first part aimed to estimate how strongly standardizing firms were affected by the pandemic and if/how they use standards to respond to these new challenges. We first asked which negative effects the pandemic had in general on the organization up until the time of the survey. Answer categories for this question were based on a survey that was conducted for the former German Federal Ministry for Economic Affairs and Energy in June 2020.[4] This was followed by a part on how organizations used and evaluated standards as tools to react to the pandemic. The third part aimed at the extent of digitalization in the course of the crisis. Finally, we asked organizations to assess the changes and evaluate the implications for the future of standardization. To be able to differentiate assessments according to organizations' varying degrees of digital capabilities, we included a self-assessment with four categories (digital novice, horizontal collaborator, vertical integrator, and digital champion).[5]

In previous waves, significant differences in ratings between firms were most commonly related to industry association and firm size (small and medium-sized enterprises (SMEs) versus large firms). To reduce self-selection bias, we weighted the yearly responses such that each weighted sample was distributed according to the base population of organizations active at DIN in regard to their industry and size (number of employees). We gathered the target distribution of industry and size from the DIN customer database and used the iterative rim weighting (or "raking," [42]) algorithm to generate weights per response and year. We further validated between-wave comparisons by regressing on ratings while controlling for industry, size, and year. As the 2020 survey was set in a highly volatile context, we assumed that the firms' situations and perceptions had potentially changed during the answer period. We grouped the responses by their time (week/month) of submission and weighted them according to the same target distribution as for between-sample comparisons. We further controlled for week/month in additional regression analyzes.

Several questions were subdivided by type of standards according to our taxonomy of standards, allowing us to distinguish effects by mode of standardization [7]. Next to formal standards (our main focus) and their prestage rules and specifications, the taxonomy included informal standards developed by industry consortia, single companies, or established as de-facto market standards. We further investigated three different regional levels, which, in the case of formal standardization, referred to standards set by either the national standards body (e.g., DIN in Germany), by CEN, CENELEC or the European Telecommunications Standards Institute (ETSI) on European level, or ISO, the International Electrotechnical Commission (IEC), or the International Telecommunication Union (ITU) on international level. This taxonomy was explained in detail to participants and found robust in prior panel waves.

IV. Results

A. Response and Sample

Based on participation in previous waves and a database provided by DIN, we invited 34 000 individuals associated with standardization to fill in our web-based questionnaire. Overall, we received 3900 answers, of which 2395 (=7% response

[2]The questionnaire can be accessed at https://www.normungspanel.de/publications/dnp-questionnaire-2021/

[3]See yearly indicator reports, https://www.normungspanel.de/en/#results

[4]https://www.bmwi.de/Redaktion/DE/Downloads/B/betroffenheit-deutscher-unternehmen-durch-die-corona-pandemie-zweite-erhebungswelle.pdf?__blob=publicationFile&v=10

[5]Based on a PwC study on digitalization in Industry 4.0. We first used this classification in 2015, see https://www.normungspanel.de/publications/indicator-report-2016-digitization/

TABLE I
SAMPLE (2020 SURVEY)

Industry	%	n	size (number of employees)			
			small (1–49)	medium (50–249)	large (250–999)	very large (1000+)
Mechanical eng., plant constr.	12%	291	14%	27%	29%	30%
Research orgs., assoc., federations	8%	183	47%	30%	12%	12%
Electrical engineering	8%	181	24%	23%	22%	32%
Public administration	7%	175	14%	19%	25%	42%
Certification and testing	7%	160	38%	32%	13%	18%
Construction	6%	153	41%	25%	13%	22%
Chemical and pharma. industry	6%	152	18%	29%	22%	31%
Automotive engineering	6%	140	17%	22%	20%	41%
Metal production	5%	122	15%	30%	34%	21%
Medical engineering, optics	5%	121	27%	34%	12%	27%
Other service activities	4%	98	47%	34%	6%	13%
Professional and scientific activities	4%	97	79%	9%	9%	3%
Consumer goods production	4%	92	20%	26%	26%	28%
Energy, water, and oil	4%	86	17%	19%	17%	47%
Information and communication	2%	54	47%	32%	5%	16%
Other	12%	290	26%	21%	19%	34%
		2395				

rate) remained in the sample after excluding incomplete and invalid responses and selecting one respondent per organization according to a predefined set of rules. We did not find any significant association between item nonresponse or drop-out behavior and the main demographics (industry, size, etc.). The overall response was the highest in any of the panel's waves, surpassing that of the first year by about 300 answers and that from 2019 by more than 1000. Most answers were received in the days following the invitation e-mails (October 14/15) and the first and second reminders (middle of November/December). This means that the first round of respondents answered before the second lockdown in Germany (end of October). The second round answered during the second lockdown but before the extension of the second lockdown. The third round answered before Christmas, with a looming third lockdown.

The 2020 sample represented 2395 organizations, of which 86% were located in Germany, 8% in Europe, 3% in the U.S., and the remaining 3% in various other regions. Most respondents answered from the perspective of a firm that was either active in mechanical engineering or plant construction (12%), electrical engineering (8%), construction (6%), or chemicals/pharmaceuticals (6%), see Table I. A further large part of respondents represented research organizations or associations (8%) or public entities (7%). The sample contained a similar number of large corporations (250+ employees, 52%) and SMEs (48%). Most respondents providing this information ($n = 658$) worked in R&D departments (22%), on the executive level (22%, mostly in smaller firms), in dedicated standardization departments (9%), or in quality management departments (9%). The self-classification of digital maturity levels resulted in 25% digital novices, 29% horizontal collaborators, 36% vertical integrators, and 11% digital champions. The classification differed significantly between size classes: large corporations more often classified themselves as digital champions (52% of digital champions had 1000+ employees), and SMEs more often as digital novices (68% of digital novices were SMEs).

B. Impact on Standardizing Organizations

Standardizing organizations were affected by the pandemic. Fig. 2 shows the effect sizes for different causes and, as a reference, results from a survey from June on a representative sample of German companies. The most substantial negative effect was caused by a decline in demand or the cancellation of existing orders, which applied to 72% of all organizations. The negative effect of staff shortages due to illness, quarantine, or child care was even more common. In total, 81% stated to have been affected by this factor; however, on average, less strongly than by declines in demand. This was followed by effects that hindered production and sales, either by making access to raw material or intermediate products more difficult (71%) or by affecting logistics, e.g., in distributing products to customers (60%). Around half of the organizations were affected by (temporary) closures of subunits, such as factories or stores (48%) or liquidity shortages (49%). Only a small fraction of respondents (13%) stated that their organization had shut down completely.

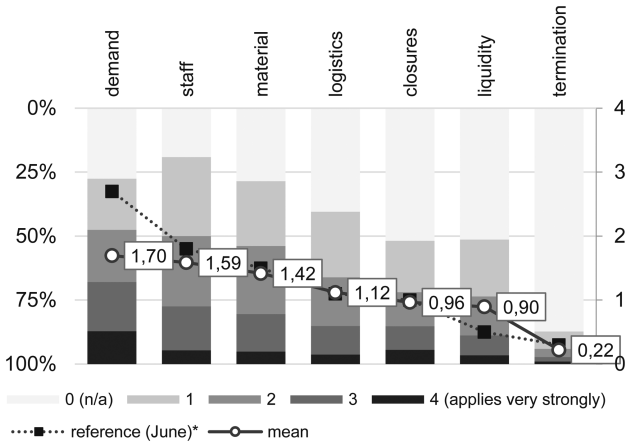

Fig. 2. Negative impact of pandemic on standardizing organizations: Which of the following adverse effects does the COVID-19 pandemic have on your organization up until now? $n = 2122$ to 2158.

An industry-level comparison of average impact (see Table II) showed that automotive and mechanical engineering/plant construction were significantly stronger affected in most effect categories. In contrast, organizations in the service industry faced fewer problems with material flow and logistics, while the construction industry suffered less from a drop

TABLE II
AVERAGE NEGATIVE IMPACT OF THE PANDEMIC BY INDUSTRY (0—NO IMPACT TO 4 VERY STRONG IMPACT)

	n=	demand	staff	materials	logistics	closure	liquidity	termination
Public administration	148	**0.78**	1.70	**0.97**	**0.47**	0.77	**0.35**	0.14
Construction	133	**1.25**	1.60	1.49	1.10	0.84	0.80	0.33
Research orgs., assoc., federations	159	**1.26**	**1.87**	**1.10**	**0.81**	**1.38**	**0.69**	0.27
Energy. Water. and Oil	72	1.36	1.43	1.45	1.16	0.91	0.79	0.20
Consumer Goods Production	84	1.55	1.65	**1.74**	**1.49**	1.12	0.93	0.30
Other	222	1.55	1.44	1.30	1.00	0.85	0.79	0.17
Professional / scientific act.	87	1.56	1.38	1.15	**0.75**	0.82	0.91	0.29
Certification and testing	140	1.72	1.63	**1.08**	0.99	1.05	0.90	0.32
Information and Communication	48	1.78	1.27	1.02	1.10	0.96	1.08	0.24
Chemicals and Pharmaceuticals	123	1.82	1.75	1.50	1.30	0.75	0.85	0.19
Medical Engineering and Optics	103	1.85	1.71	**1.85**	1.35	1.02	1.10	0.15
Other service activities	87	1.88	1.39	**0.88**	0.85	**0.65**	0.89	0.29
Electrical Engineering	161	1.90	1.51	**1.75**	**1.34**	0.80	0.90	0.16
Mechanical Engineering, Plant construction	252	**2.12**	**1.43**	**1.74**	**1.41**	0.92	**1.11**	0.19
Metal Production	109	**2.15**	1.59	1.35	1.25	0.85	0.90	0.14
Automotive Engineering	103	**2.60**	**1.94**	**2.01**	**1.60**	**1.87**	**1.63**	0.26

Bold values: sig. different to the overall average (*t*-tests, p < 0.05 with FDR correction), underlined: sig. higher negative impact.

in demand. We conducted additional logistic regressions for each factor on whether organizations were affected (response > 0) or not (response $= 0$). Independent variables were sector, level of digital maturity, and company size. We controlled for the month the response was given in (October–December) to account for the developing pandemic situation. The estimates showed significant associations for each model variable (all following results sig. with $p < 0.05$). Overall, the secondary sector was more strongly affected by material shortages and logistical difficulties. Larger organizations (250+ employees) were more affected by staff and material shortages or logistical difficulties than smaller organizations. The crisis appeared to concern digital champions less, as horizontal collaborators and vertical integrators stated more often to have had problems with staff availability, and digital novices were more likely to be affected by liquidity shortages. The fraction of organizations affected by partial/temporary closures increased significantly between the survey start in October and later responses in November/December.

Standards were mainly not considered tools that helped organizations to mitigate these negative impacts. In answer to the corresponding question with a 5-item scale from 0 (not at all) to 4 (very much), 59% stated that formal standards did not help at all (0). Support was perceived to be even lower from company standards (65% no help at all), technical rules or specifications (65%), de-facto standards (69%), and consortia standards (74%). There were significant differences between secondary and tertiary sectors, where the secondary sector valued company standards higher, while the opposite was true for formal standards, technical rules/specifications, and consortia standards.

During the pandemic, standard-setting organizations, such as DIN or CEN made relevant standards (e.g., for medical equipment) available for free. In total, 9% of all respondents stated having downloaded or applied these standards in response to the crisis. This share was significantly higher among medical engineering firms and certification and testing organizations (13%). Two open-ended questions on the application ($n = 95$ responses) and certification ($n = 53$) of standards showed that standards for medical products, such as masks, safety glasses, or gloves (EN 149, EN 14683, EN 13795, EN 455, etc.) were the most applied. Respondents also stated the relevance of company standards, risk/crisis management standards (ISO 31000, ISO 22301), and IT standards (ISO/IEC 27001, etc.). Certifications in response to the pandemic were mostly carried out for health and safety standards like ISO 45001/OHSAS 18001, general management standards (ISO 9001, ISO 14001), or specific standards for medical products (EN 14683, ISO 13485, EN 166).

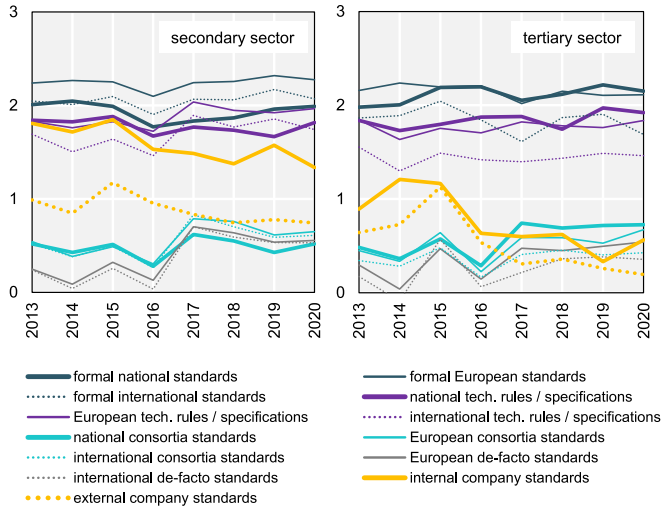

Fig. 3. Mean importance of standards on a 7-item scale (−3, not important to +3 very important). Unbalanced panel, yearly weighted samples. Left: secondary sector (7869 ratings), right: tertiary sector (2808 ratings).

C. Change in Perceptions

The perceptions of the importance of standards and their impact on different success factors point in two directions. On the one hand, the perceived importance of standards remained relatively constant compared to the previous survey waves. Fig. 3 shows the mean importance by year based on weighted samples. While the secondary sector puts more emphasis on formal standards on the European level and (internal) company standards, the tertiary sector is more nationally oriented and perceives the importance of company standards on the same (low) level as consortia standards. This picture did not change in 2020: *t*-tests of the differences between means (2020 versus

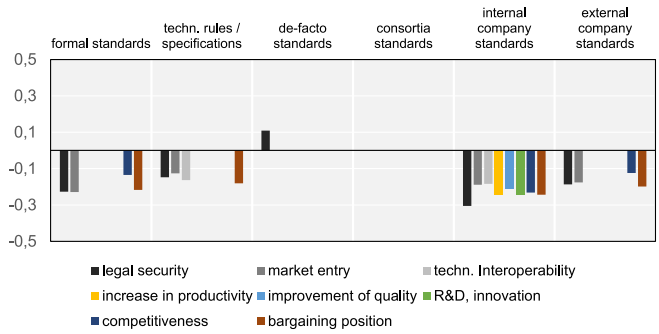

Fig. 4. Change in perceived impact on success factors 2013–2019 versus 2020. Differences in mean impact on success factors, 7-item scale −3 (very negative) to +3 (very positive), 2013–2019 versus 2020. Only stat. sig. differences are shown (t-tests with $p < 0.05$ and FDR correction, weighted samples).

2019/2020 versus rest) are not significant on a 95% confidence level.

The perceived impact of standards on success factors, on the other hand, appears to have decreased since the pandemic. As Figs. 4 and 5 show, average ratings for the impact of most types of standards dropped in 2020. The only exception was the impact of de-facto standards on legal security, which increased on average. Especially standards developed at standard-setting organizations (formal standards, technical rules, specifications) had lower average impact ratings than in previous years. The differences were mainly significant for market-related functions: ensuring legal security, facilitating market entry, and improving the bargaining position vis-à-vis suppliers and customers. Ratings for external company standards showed a very similar pattern. In contrast, ratings for internal company standards dropped significantly for all factors. Here, differences were noticeably more negative than for all other types of standards. However, concerning company standards, the development might be part of a general trend. Impact ratings for internal company standards have already shown a negative development over the last eight years (see Fig. 5). Similarly, their importance in the secondary sector has dropped consistently since 2013 (see Fig. 3).

D. *Effect on Standard-Setting Activity*

The extent of standard-setting activity was perceived to be relatively little affected by the pandemic. Most organizations (55%) stated that their corresponding workload did not change in formal standardization (see Fig. 6). The rest was almost equally split between de- (23%) and increase (22%). An even higher share of participants noticed no changes in consortia (67%). Here, those that noticed changes (33%) were also equally split between de- and increased workload. Going into more detail, we asked about the development of the level of participation, the change in the output of new standards, and the change in the emergence of new standard-setting topics. Each of these aspects revealed results similar to the overall workload. No change was perceived in the level of participation in formal standardization by 61% of organizations (73% for consortia). Equivalent values lay at 71% (formal standardization) and 81% (consortia) for the

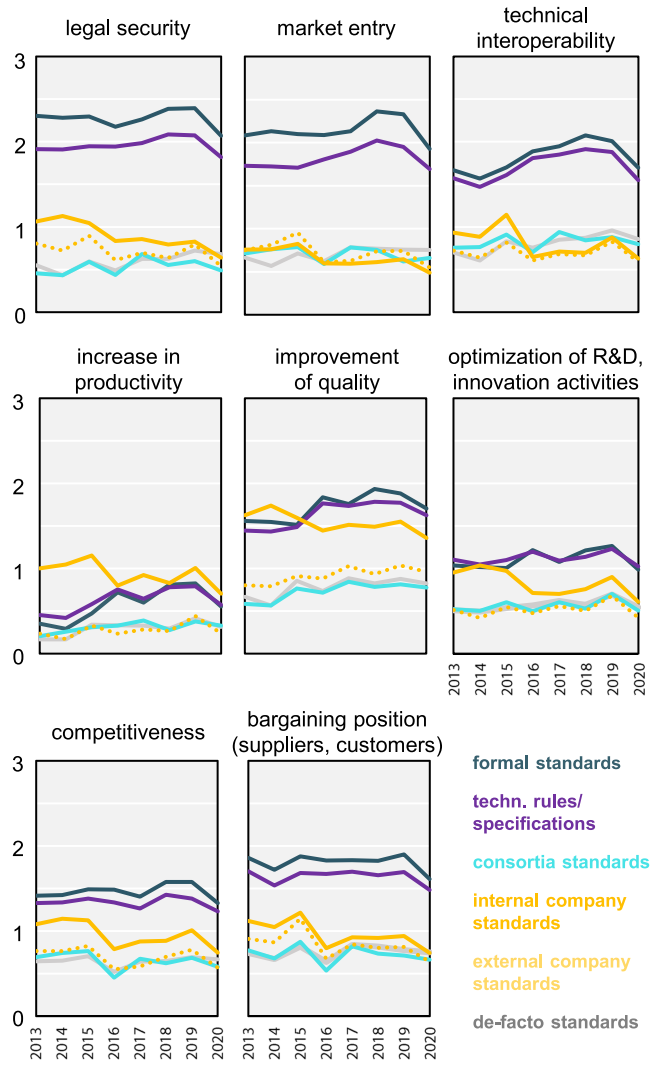

Fig. 5. Mean impact on success factors, 7-item scale −3 (very negative) to +3 (very positive). Yearly weighted samples (4429 to 6322 ratings).

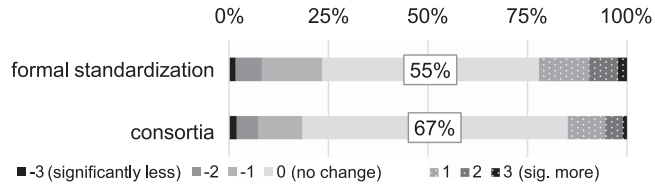

Fig. 6. Change in workload ($n = 1940$ to 2007).

development of new standards and at 70% (formal standardization) and 79% (consortia) for the emergence of new topics. The rest was almost perfectly split between perceived in- or decreases so that the average absolute change was ≤ 0.07 on the −3 to +3 scale for each question and addressing both institutional contexts.

For multivariate analysis, we performed linear regressions on each of the four ratings (change in workload, number of participants, new standards, new topics) for standard-setting activities in either formal standardization or consortia. The models included the independent variables of company size,

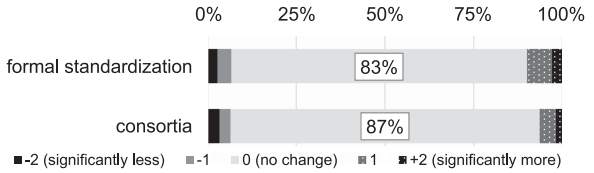

Fig. 7. Planned change in standardization activity due to pandemic ($n = 2136$ to 2151).

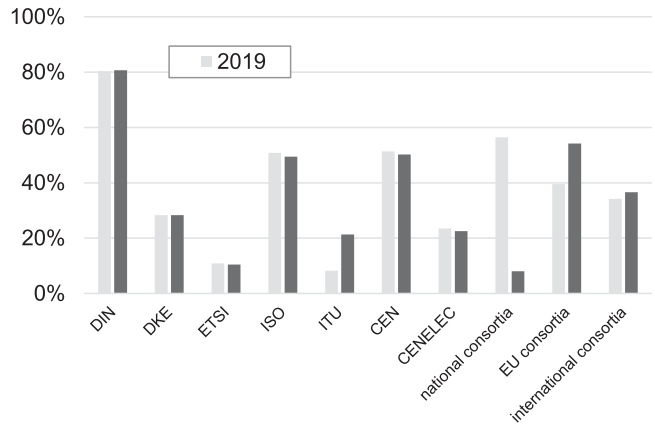

Fig. 8. Share of organizations active in at least one SSO committee/consortium. $n > 1600$.

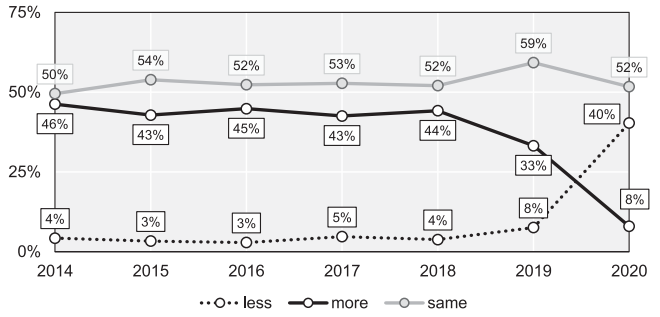

Fig. 9. Change in expenditure for standardization departments (weighted samples, eff. $n = 2128$).

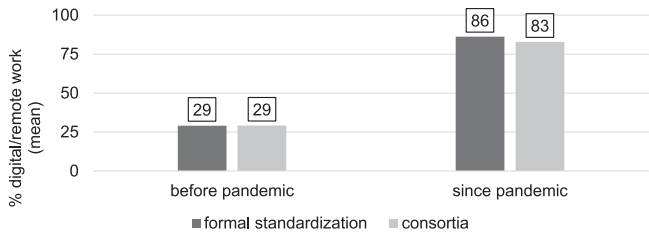

Fig. 10. Level of digitalization. Average extent of digital/remote work in formal standardization and consortia before and since the pandemic. Free numerical entry in 5% steps, $n = 996$.

digital maturity, industry, and response month. Coefficient estimates with robust standard errors revealed three significant associations ($p < 0.05$). Vertical integrators were overall more likely to report decreased workloads in formal standardization. Respondents were more likely to report increased levels of participation in December compared to October or November. This temporal association also existed for the overall workload in consortia.

In an additional question, we asked whether organizations had, or planned to, change their participation in standardization due to the pandemic. This was aimed at capturing the effect on standard-setting activity that stemmed from internal motivation within participating organizations (such as a reduction of activity due to own financial constraints) rather than external changes coming from SSOs, as in the previous questions. Here, the fraction of organizations that reported no change (or no plan to change) was even higher: 83% selected no change in formal standardization and 87% in consortia (see Fig. 7). (Significantly) more activity was reported by 10% (formal standardization) and 6% (consortia). Multivariate analyses revealed no significant differences in regard to organization properties.

The overall stability of participation was also reflected in activity in different SSOs (see Fig. 8). Numbers from 2019 on whether organizations participated in at least one committee remained almost constant, with most participants at the national standards body (81%) and about half at CEN (50%) and ISO (49%). Participation at ITU was even more prevalent in 2020, with the fraction of active organizations rising from 8% to 21%.[6]

[6]A potential reason for this could have been the planned date of the ITU's World Telecommunication Standardization Assembly (WTSA) in November 2020, which might have raised additional interest by participants.

More changes in standard-setting activity could be noted for industry committees. Participation at national consortia dropped from more than half of the sample in 2019 (56%) to only 8% in 2020. In contrast, the fraction of organizations active in international consortia rose. Most prominently on the EU level, where 54% stated to participate in at least one consortium, compared to 40% in 2019.

Changes in expenditure for standardization contrasted with the stability in participation. Direct questions about exact standardization expenses with numerical entry yielded few and unreliable responses. So instead, we refer to categorical answers from organizations with standardization departments (who likely have a better overview of these expenses). Answers were given on a 3-item scale, indicating whether expenses had risen, dropped, or stayed the same. As Fig. 9 shows, around 92% to 97% of organizations had increased or kept their standardization expenses constant from 2014 to 2019. In 2020, this share dropped to 60%, while the share of organizations reducing their expenses rose to 40%.

E. Digitalization

During the pandemic, physical meetings were replaced by digital remote meetings. The fraction of digital work increased from an average of 29% (mode = 10%) to 86% (mode = 100%) in formal standardization and 83% (mode = 100%) in consortia (numerical entry in 5% steps, Fig. 10). The change was consistent when grouping by industry, size, or digital maturity, where differences to the overall average were not significant (t-tests, all $p > 0.05$, FDR correction). Participants stated that the pandemic had somewhat promoted the digitalization of work, both in their general business activities and in standard-setting.

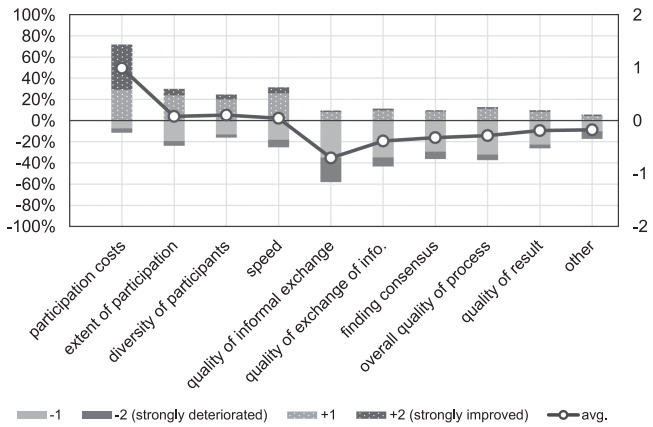

Fig. 11. Positive and negative effects on the standardization process. Effect of digitalization of work in formal standardization on different aspects. 5-item scale from −2 (strongly deteriorated) to +2 (strongly improved), $n = 1187$ to 1947.

The effect was, however, significantly more pronounced for general business ($M = 1.47$, SD $= 1.1$) than for standardization activities ($M = 0.78$, SD $= 1.1$), 7-item scale from −3 "strongly inhibited" to +3 "strongly promoted" ($t(2001) = 28.1$, $p < 0.01$). The ratings were slightly but significantly higher in December ($M = 1.6$, SD $= 1.1$) than in the two previous months ($M = 1.4$, SD $= 1.1$), weighted samples, $t(468) = 2.5$, $p < 0.05$. The digitalization effect on general business activities was, on average, significantly higher for universities, federations, and associations ($M = 1.8$, SD $= 1.1$), $t(194) = 4.0$, $p < 0.01$. The effect on standardization activities was significantly higher for certification and testing organizations ($M = 1.1$, SD $= 1.2$), $t(155) = 3.0$, $p < 0.01$, possibly because, for them, participation in standard-setting was part of their core business activities.

We investigated the effect of the digitalization of processes on different aspects related to participation costs, the extent of participation, quality, and speed (see Fig. 11). On a 5-item scale, respondents could state whether the aspects had strongly deteriorated (−2) to strongly improved (+2) during the pandemic. The question was asked about formal standardization and standardization in industry consortia, but responses did not show considerable differences. For both contexts, two aspects could be clearly assigned to either side of the scale. On the positive side, a majority of 72% stated that participation costs had improved in formal standardization. This included travel costs, which were the most important cost factor judging from the responses to open follow-up questions (see below). On the negative side, the most prominent effect of digitized formal standardization processes was the deterioration of the quality of informal exchange, which was reported by 58% of respondents, particularly by large organizations (1000+). Opinions were almost equally split between positive and negative effects on the extent of participation, the diversity of participants, and the speed of processes. Aspects that were more often seen as having worsened were related to process and output quality: 37% of respondents perceived lower overall quality of the standardization process, 43% lower quality of information exchange, 36% reported worse consensus-finding, and 26% lower quality of results.

Many respondents ($n = 397$) used the text field of the additional item "other" to give more detailed accounts of the effect of the digitalization of standardization processes. The most discussed topic was the negative impact on the quality or extent of informal exchange (stated by 51%) or the exchange in general (11%). Some complained about a total absence of informal exchange, while others described a lack of depth, clarity, or understandability in digital exchange. Many stated that the lack of informal exchange made communication more difficult, especially by reducing the social aspects of collaboration. The most positive effects were the suspension of travel (5%) (not only regarding saved costs, but also as a reduction of effort on a personal level), shorter and more frequent meetings (17%), and more participation (4%), especially internationally.

In addition to restating and giving their opinion on some of the aspects already available as items in the original question, some respondents raised new aspects. These were often related to personal and social effects, such as decreasing motivation or commitment to contribute in meetings ("zoom fatigue"), loss of "team spirit," or concentration difficulties (7%). Another adverse effect was the more complicated integration of new participants due to lower acceptance without personal contact and more challenging onboarding processes (3%). Further remarks that were collected in an additional open-ended question painted a similar picture ($n = 278$). Here, 19% stated that digital meetings made coordination easier, 14% stressed that more informal exchange was needed, and 12% commented that in-person meetings were irreplaceable and that the current exchange form was cumbersome (10%). In addition, some participants (8%) requested more modern communication tools, while others (7%) proposed hybrid meetings (some participants meet in person, others join digitally) as a better solution for the future.

Answers to the question "how will these aspects change in the future?" ($n = 860$) matched the same pattern. Most respondents envisioned future standardization processes to be more often based on digital or hybrid meetings (51%). Many commented on the generally positive effects of the pandemic on the digitalization of standardization processes (30%), sometimes referring to higher speed and productivity (5%). The share of comments stating negative effects was lower (15%) and most often related to a deterioration of output quality (5%). Accordingly, the majority of respondents wanted to keep all or some changes to the processes in standardization (66% formal standardization, 57% consortia, Fig. 12), and only 7% wanted to revert the processes to the format from before the pandemic.

V. Discussion

The results (see see Table III for a qualitative summary) show that standardizing firms were affected by the pandemic, mainly by a decline in demand, staff shortages, and logistical difficulties. However, the system showed growth in participation and workload during the survey weeks (October–December). This likely followed an initial shock at the beginning of the pandemic, which resulted in the reorganization of structures and processes. Participation in formal standardization had not

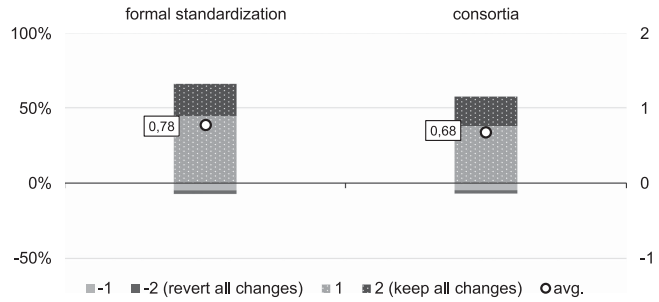

Fig. 12. Keep or revert changes? $n = 1753$ to 1928.

TABLE III
QUALITATIVE SUMMARY OF MAIN RESULTS, SOURCES: SURVEY (2020) AND PANEL (SURVEYS 2013–2020)

Aspect	Change	Details
stakeholder resources	-	most affected: demand, staff, material
cost of standardization	-	especially due to reduced travel costs
fraction of digital/remote work	++	
extent of participation in standardization	o	slightly growing after an initial shock
workload in standardization	o	
expenditure for standardization (departments)	-	
quality of standardization & standards	-/o	primary negative effect: lack of informal exchange
importance of standards	o	exception: longer-term decreasing importance of company standards
impact of standards on company success	-	most affected: market-related success factors such as legal security, market-entry, bargaining position

changed significantly compared to 2019, except for more participants at ITU and a shift from national to international consortia. The latter could be related to reduced differences in participation costs between national and international consortia, e.g., due to saving travel costs.

Standards were only perceived by a few to be tools that help to mitigate the crisis—accordingly, the number of organizations that introduced or certified against new standards as a reaction was low. The offer of free access to relevant standards (especially for medical equipment) was also only used by a few organizations, mainly by the testing and certification industry and medical engineering firms. While the overall perception of the importance of standards remained essentially unchanged, the (perceived) impact on success factors decreased slightly. We interpret this as a change in relative impact. Other factors, such as reduced demand and staff availability, might have dominated over standards-related factors during the crisis.

The workload created by developing standards remained constant or even increased for most firms. A very high share of organizations (93%) reported not having lowered or planned to lower their standard-setting activities due to the pandemic. These numbers were a bit lower when asked explicitly about perceived changes in the level of participation, the output of new/adapted standards, and the newly approached topics. Apparently, there was a difference in organizations' intentions to be active in standard-setting and to which extent they were able to realize their activities. An interpretation of this difference could be that limitations to standard-setting activities were rather evoked by restrictions and new rules raised by the system than being rooted in the reduction of efforts by the participating organizations due to new financial constraints. This suggests that it is likely that after the restrictions that were imposed due to the crisis are lifted, the extent of standard-setting activities will return to the previous levels (from which they apparently had not deviated very much).

In contrast to relatively stable levels of activity, there appeared to be a significant drop in expenditures for standardization activities. In 2020, 40% of organizations had reduced their budgets for dedicated standardization departments. At first glance, the lower expenditures appear inconsistent with stable activity levels and the expressed intentions to keep up standard-setting efforts. However, a simple explanation is the drastically increased level of digitalization, which reduced costs (e.g., for traveling and accommodation, mirroring the experience in remote auditing [17]). From this perspective, lowered expenditures can be understood as a sign of increased efficiency.

The average fraction of digital/remote work rose from 29% before the pandemic to 86% since, which is consistent with the increased investments in digital infrastructure by CABs [3]. It is not entirely clear how the remaining fractions of nondigital/nonremote work were performed. However, it could reference activities within organizations, such as internal in-person meetings in preparation for digital exchanges in technical committees. The increases were consistent among all surveyed industries and all digital maturity levels, indicating that the switch to digital processes had happened in all areas of standardization and had included the whole spectrum of participants. We further noticed that the digitalization process was still ongoing during the survey period of three months. While digitalized processes decreased costs and simplified participation by new actors, the quality of the standardization process and resulting standards deteriorated. A major reason for that was the lack of informal exchange. This mirrors the finding from remote auditing, where a lack of personal interaction negatively affected process efficiency due to lacking build-up of trust [17]. Also, judging from the participants' focus in the answers to the open questions, it appears that this aspect suffered the most due to the "digitalization shock." The discussion and consensus-finding processes are based on informal, face-to-face exchanges. The often complex knowledge involved in standards and standard-setting is most effectively exchanged directly. Digital channels reduce information transmission capacity and, therefore, impede consensus-finding. Digitized meetings could also lower information asymmetries within standard-setting committees and between committees and nonparticipating external stakeholders.

Coming in the last step back to our conceptual model (see Fig. 1), we can observe that the available resources of the stakeholders available for standardization have been reduced by the economic implications of the COVID-19 pandemic. However, the digitalization of the standardization process, e.g., via remote sessions, as the most relevant technological progress triggered by COVID-19, has significantly reduced stakeholders' participation costs. Combined, both impacts did not influence

their participation or activity level because stakeholders could reduce their participation costs. Consequently, the output of the standardization process, the number of standards, has not changed. However, their quality has suffered by the significantly changed standardization process. Whereas the overall relevance of standards for the stakeholders has not changed, their impact on companies' specific success factors has suffered. Whether this has been triggered by the higher relevance of other challenges to be addressed or by the complained reduction in the quality of the recently produced standards within a much more digitalized standardization process has not been (and cannot be) answered yet. Overall, the conceptual model helps to structure and interpret our numerous interacting results.

This study extends research on standardization, on the one hand, and gives evidence of the reaction of industry and the role of information technology during the COVID pandemic, on the other. It generates new insights on the impact of reduced participation costs via digitalized remote standardization processes on the involvement of stakeholders. As [43] show, firm size is a significant factor for entry into standardization, which, as we show, can be moderated by digitalization and associated lowered costs. Our investigation of the effects of the pandemic on standardization also supplements the perspective of standard dynamics [4] with that of "standardization dynamics," highlighting that not only standards evolve, but the standard-producing system itself is subject to changes.

A. Limitations

There are some limitations to our findings. First of all, our sample is only representative of organizations already active in standardization, with a clear regional focus (86% of respondents from Germany). While activity in our sample remains relatively stable, there might be a different effect on nonstandardizing organizations and their propensity to engage in standard-setting in the future. The Germany-focused sample also means that our results might not be generalizable internationally. We could, however, not find systematic differences in the central findings between responding German and non-German organizations. Second, the participation statistics must be interpreted cautiously with potential survey response biases in mind. Organizations that have reduced or ceded standardization activity altogether might have been less motivated to participate in the survey. The comparison with a representative survey from June (see Fig. 2), however, suggests that our sample captures the whole spectrum of variously affected organizations, including a sufficiently large share of organizations that had terminated business. Comparing the 2020 sample composition to the panel's previous waves further shows that no particular group had "dropped out" (such as very small companies or specific industries). Third, the robustness of between-wave comparisons suffers from unbalanced samples. While we could have set up a balanced panel, we decided to trade a conceptually better identification strategy for larger and more diverse sample sizes. We argue that very similar yearly sample compositions combined with the weighting approach offer sufficient consistency to identify fundamental trends and changes. More in-depth analyzes in the future can add robustness by using balanced samples and multivariate panel regression models.

VI. Conclusion

Our results point to three main interpretations. First, the reaction of standardizing organizations was moderate: levels of participation did not change significantly. This can be interpreted as "sitting a crisis out" that was not expected to cause sustained negative effects in the long run. For most participants, standard-setting is likely a mid- to long-term strategic activity. The analyzed period of restrictions (less than a year) seems too short to overcome "system inertia," potentially also because of the role of planned, incremental, versus radical innovation in standardization [44]. Second, surveyed organizations mostly welcome the changes introduced in the crisis and expect them to be the "new normal." A return to business-as-usual appears unlikely, as participants have recognized the benefits of the newly introduced formats.

Third, negative shocks created by the COVID-19 pandemic, like the COVID-19 pandemic, appear to be mitigated by a "technology shock." The sharp rise in digitalization increased speed and efficiency and allowed organizations to reduce costs without reducing their standard-setting efforts. Digital meetings, however, lead to the deterioration of informal exchange. Frequent close, personal interactions are essential for exchanging complex and tacit knowledge and the collaborative, recombinatory search that is part of standards development [10], [37]. Therefore, a lack of interaction decreases consensus-finding performance and the quality of processes and outputs. On the one hand, this can also lead to weaker innovative effects from participation in standardization due to reduced social capital and a decreased capacity as a knowledge transfer channel [38], [39]. On the other hand, access to new, more diverse actors and the "creative destruction" of established structures could result in the opposite [47].

Therefore, rather than endangering investments in standardization, the crisis appears to disrupt the system by changing routines and potentially diversifying involved actors. For firms, reduced participation costs can be an opportunity to explore new technological areas in standardization, thereby using it to react to the crisis by diversifying and expanding their networks. Standard-setting organizations can use the current willingness to accept changes as a window of opportunity to reorganize and introduce further updates to their processes. However, to keep up quality levels, they need to find formats that enable informal exchange among standardizers (e.g., hybrid meetings). Simplified access to meetings and reduced costs can be a chance to increase participation, especially from SMEs and start-ups, which are according to [48] still underrepresented and less likely to enter standardization [43]. It can also be a way to connect better new groups of actors, such as participants from developing countries [49] as well as from the open source community [50], and help to usher in a new generation of standardization experts. As our findings are based on data from the first phase of the pandemic, further research needs to investigate and validate these results in the mid- and long term.

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