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Industry consortia in mobile telecommunications standards setting: Purpose, organization and diversity

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A B S T R A C T

In mobile telecommunications, numerous formal and quasi-formal standard setting organizations (SSOs) exist that are dedicated to technology standardization. Yet, hundreds of more or less informal industry consortia have been established that also deal with technical standards. Some of these aim to develop standards themselves – and thus compete with existing, formal standard setting organizations – while others complement existing organizations or relate to them in other ways. Based on a novel dataset covering 100 consortia in the field of mobile telecommunications as well as interviews, we aim to explore and understand the role and diversity of standards-related consortia. We investigate their purpose, functioning, their members' motives, the position they occupy in the standardization landscape, and the way they interact with formal standard setting. On the basis of our analysis, we propose a taxonomy of standards-related consortia consisting of six groups: large industry and technology influencers, high-level concept developers, established standards developers, young technology specialists, small industry and technology influencers, and SSO-hosted industry drivers. We believe the resulting taxonomy to be relevant for researchers, practitioners and policymakers alike. It sheds light on the intricate landscape of industry consortia, and offers transparency on the peculiarities of these organizations. Hence, it can build the basis for an evaluation of potential memberships as well as policies and regulations.

1. Introduction

Since the 1980s, the mobile telecommunications industry has evolved rapidly, from various first generation analog standards, to second-generation GSM, third-generation UMTS/WCDMA, and fourth-generation LTE standards.[1] This evolution has not only changed the performance of telecommunication networks, such as data rates and latency, but in many respects also the underlying technologies. Standards impact potential uses as well as organizations and individuals, as we see with 3G, which was the result of a convergence between traditional telecommunications and the IT industry (Leiponen, 2008). For 5G standards in the making, this convergence is happening on an even larger scale, involving the Internet of Things (IoT), Industry 4.0, various vertical sectors, and more.

Technical standards are important for both technical and business reasons. Technically, it is crucial that various types of user equipment can communicate with each other, and that large numbers of components and (sub-)systems are interoperable (David &

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[1] GSM: Global System for Mobile Communications; UMTS: Universal Mobile Telecommunications System (often referred to by the name of its primary radio interface W-CDMA: Wideband Code Division Multiple Access); LTE: Long Term Evolution.

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Steinmueller, 1994; Belleflamme, 2002). Business aspects matter because standards can become very dominant due to prominent network externalities (Bekkers et al., 2002). This dominance results in standards significantly impacting the terms of competition, and industry players having strong commercial interests in a standard's design (Bar & Leiponen, 2014; Besen & Farrell, 1994; Chiao et al., 2007). For some firms, standards imply "the danger of being put at a disadvantage" because their specific design can affect a firm's success or failure (Genschel, 1997, p. 610). Thus, most firms in the industry tend to be heavily involved in standardization, and consequently with SSOs.

Formal Standards Setting Organizations (SSOs) play a crucial part in the creation of standards. The first digital mobile telecommunication standard, GSM, came with the new European Telecommunications Standards Institute (ETSI) in 1987/88 (Dalum et al., 1999; Funk & Methe, 2001), and the emerging Third Generation Partnership Project (3GPP) enabled the UMTS/WCDMA standard. 3GPP, which is a partnership of regional SSOs like ETSI, is currently the central global organization creating mobile telecommunication standards. The regional SSOs participating in 3GPP (currently seven) are called Organizational Partners.

Since the 1980s, firms have increasingly formed smaller and more informal standards-related organizations, so-called industry consortia, to co-exist with established SSOs (Hawkins, 1999; Genschel, 1997). Nowadays, most of the large industry players are involved in a multitude of consortia (Hawkins, 1999). The literature shows that industry consortia play an increasingly important role, in particular in fostering technological development (Baron et al., 2014; Baron & Pohlmann, 2013). Existing studies typically focus on the pre-standardization function of consortia, i.e., how consortia help firms coordinate prior to taking part in formal standard setting (Delcamp & Leiponen, 2014).

Existing categorizations of consortia (see Delcamp & Leiponen, 2014; Pohlmann, 2014; Biddle, 2018) usually involve few categories and a limited set of indicators (age, founding year, member composition, or contractual/legal form). This approach is adequate if categorization is just one step in a wider research process. However, a more detailed process of classification or taxonomy is needed to fully understand consortia's role in standardization. So far, we lack comprehensive insight in (1) why firms form or join consortia, and (2) the variety of consortia and their diverse objectives. These two aspects are tightly connected: Firms' motives for forming and joining consortia can be expected to be reified and reflected in the characteristics of consortia, more precisely in their organizational set-up. Also, building a thorough empirical basis capturing the different forms of existing consortia can help us shed more light on the motives for consortia formation. A taxonomy can help inform firms' choice of consortium membership, especially if standardization resources are limited. Moreover, it can strengthen policy evaluation: while many consortia clearly support the advancement of technology and the telecommunications industry as a whole, others might misuse their role to influence the market. These issues are difficult to assess, given the sometimes opaque nature of consortia. A taxonomy could also be helpful for the identification of relevant ICT standards developed by consortia, for instance by bodies such as the European Multi Stakeholder Platform on ICT Standardisation (known as the MSP[2]).

To build a taxonomy, we study the field of mobile communications as addressed by 3GPP. While there are many other areas of standardization, focusing on a single one allows us to derive meaningful results and avoid bias from unobserved variance. We selected this area for three reasons: Its size and general importance with respect to technology and markets; its considerable technical breadth, stemming from its multifaceted nature; and alignment with earlier studies, such as those by Leiponen (2008) and Delcamp and Leiponen (2014). While we cannot guarantee our results are fully generalizable to other areas of standardization, we expect that our choice of 3GPP will allow us to observe all important motives to engage in standardization.

We identified 100 consortia and collected data on them through interviews and desk research. These initial steps enabled us to devise an assessment scheme. Guided by a principal component analysis followed by a cluster analysis, we identified common themes and patterns, resulting in a taxonomy of six different types of consortia: Large industry and technology influencers, high-level concept developers, established standards developers, young technology specialists, small industry and technology influencers, and SSO-hosted industry drivers.

Our study contributes to the literature on the economics and management of standardization in telecommunications, especially the role and impact of industry consortia (Baron et al., 2014; Delcamp & Leiponen, 2014; Hawkins, 1999; Rosenkopf et al., 2001; Simcoe, 2012). We aim to shed light on the various forms of consortia as well as firms' rationales for setting up and joining these organizations.

We start by examining the literature on SSOs and consortia in Section 2, before describing our methodology in Section 3. We then discuss the insights from our in-depth interviews in Section 4. Section 5 introduces our dataset and sample of consortia. Section 6 presents the results of our analysis, and Section 7 concludes.

2. Background

2.1. Standards and SSOs

When talking about standards in the field of telecommunications, the literature usually refers to explicit standards agreements, or a "set of technical specifications" (David & Steinmueller, 1994, p. 218), crafted in dedicated SSOs. We interpret "SSOs" as organizations "that collaboratively develop standards, including 'traditional' standards development organizations [. . .] as well as the myriad consortia, alliances, and Special Interest Groups (SIGs)" (Bekkers & Updegrove, 2012, p. 5). They are associated with the development, definition, updating, and maintenance of formal standards (International Telecommunication Union, 2014). The term

[2] See https://ec.europa.eu/digital-single-market/en/identification-ict-specifications (retrieved on 28-07-2020).

"SSO" is often used interchangeably with Standards Development Organizations (SDOs) (International Telecommunication Union, 2014). Although these terms may mean the same, the actual range of organizations known as SSOs or SDOs varies considerably.

In this paper, we use the term "SSOs". Based on the International Telecommunication Union (2014) classification, we differentiated formal and quasi-formal SSOs. Formal SSOs are formally recognized[3] by national or international authorities. For instance, in the European Union such recognition is reflected in the publication of formal SSOs (the European Standardisation Organisations - ESOs - and national standardization bodies) in Directive 98/34/EC of the European Parliament and the Council, annexed by Directive 98/48/EC. Formal SSOs are generally assumed to meet all the criteria for open standards as defined by the World Trade Organization (WTO) (World Trade Organization, 2000). They include national bodies (such as British Standards Institution BSI and German Institute for Standardization DIN), regional bodies (such as ETSI) and global bodies (such as ITU).

Quasi-formal SSOs are organizations that are in virtually every aspect similar to formal SSOs: they are large, have attained a status and position that is quite comparable to that of formal SSOs, and are also generally assumed to meet all the criteria for open standards as defined by the WTO. What distinguishes them from formal SSOs, however, is that they do not enjoy the formal recognition by a national or supra-national authority. In the field, the term quasi-formal SSOs is specifically used for the three following organizations: IEEE, IETF, and W3C (Contreras, 2017; ECSIP, 2014). The standards these bodies develop and promote are indeed well-established in the industry, such as the IEEE 802.11 series of standards (popularly known as "Wi-Fi") developed by the IEEE, the TCP/IP standard developed by the Internet Engineering Task Force (IETF), and the HTTP standard for rendering internet pages developed by W3C. According to Simcoe (2014), these organizations' standing is based on their past success. Even though quasi-formal SSOs "typically lack enforcement power", strong network effects in industries such as telecommunications can have a self-enforcing effect on standards written by these organizations (Simcoe, 2012, p. 307).

The importance of technical standards in the telecommunications industry has increased steadily since the 1980s, mainly thanks to international and data communications (Bekkers et al., 2002; Cargill, 2002). The technological progress in this field is closely linked to standardization. Since the third-generation UMTS/WCDMA standard, work on mobile[4] telecommunications standards has been centered around 3GPP. Initiated by ETSI and the Japanese Association of Radio Industries and Businesses (ARIB) (Bekkers & West, 2009), 3GPP was built as a "collaborative alliance" of regional telecommunication-focused SSOs in North America, Europe, and Asia, called Organizational Partners (Bar & Leiponen, 2014). They steer 3GPP's general direction via their representatives in the Project Coordination Group (PCG).

When it comes to developing standards, Technical Specification Groups (TSGs) coordinate the technical side by managing work items, and create Working Groups (WGs) to do the actual development work.[5] However, while 3GPP defines the technical specification of a standard, the 3GPP work results are transferred into actual, formal standards by the regional SSOs.[6]

2.2. The emergence of standards-related industry consortia

In addition to SSOs, new types of standards-related organizations have emerged since the 1990s (Cargill, 2002). Although diverse, these organizations are summarily referred to as standards-related "industry consortia" (from now on we will refer to them as "consortia"), described in the literature as alliances of like-minded companies (Cargill, 2002; Pohlmann, 2014) or "special-interest groups" with narrower interests than (quasi-)formal SSOs (Chiao et al., 2007). Consortia are perceived as alliances catering specifically to standardization (Pohlmann, 2014), or as fora where firms can coordinate "technological and market development activities", thus where members pursue goals "well beyond standards-setting as such" (Hawkins, 1999, p. 162). Leiponen (2008) finds that firms form and join consortia to learn from each other as well as generate and exchange new technological knowledge. Some consortia develop their own standards, such as the Bluetooth Special Interest Group (Bluetooth SIG) (Keil, 2002).

In line with our technology selection discussed above, this literature review specifically focuses on – but is not limited to – consortia in the field of mobile telecommunications.

In some ways, consortia are fundamentally different from SSOs. Pohlmann (2014, p. 1) notes that "participation in consortia is less bureaucratic, [and] more efficient in reacting to market needs". Despite the similarities to formal SSOs, consortia have more freedom to design their structures, rules, and processes. For instance, they can be more restrictive (Pohlmann, 2014) when it comes to admitting new members or assigning leadership positions. Most consortia are initiated and set up by a small group of founding members, who can then decide the exact terms of collaboration. Also, because of their smaller size, consortia may not have what is described as a "dominant position" in competition law, allowing them to engage in a wide range of activities. In contrast, formal SSOs (or their members jointly) often enjoy such a dominant position and are thus more limited in what they are allowed to do—especially regarding commercial matters.[7]

Studies comparing (quasi-)formal SSOs and consortia highlight that firms form and join consortia to influence the work on standards in (quasi-)formal SSOs (Bar & Leiponen, 2014; Delcamp & Leiponen, 2014; Leiponen, 2008; Pohlmann, 2014), thus

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[3] While the vast majorities of countries in the world has a system with formal recognition of SSOs by governments, the US is a notable exception. In the US, the American National Standards Institute (ANSI) has the role to accredit US organizations that develop standards, and ANSI itself serves as the official U.S. representative to ISO.

[4] We apply the common convention that "mobile communications standards" concern so-called "cellular" technologies, aiming to offer seamless services over a wide area (GSM, UMTS, and LTE). In contrast, "wireless communications standards" focus on shorter distances (Wi-Fi and Bluetooth, and cordless phone standards).

[5] For details, see http://www.3gpp.org/ftp/Information/Working_Procedures/3GPP_WP.pdf (retrieved August 2019).

[6] See http://www.3gpp.org/about-3gpp/partners (retrieved May 2019).

[7] See, e.g., the ETSI Guidelines for Antitrust Compliance (European Telecommunications Standards Institute, 2011).

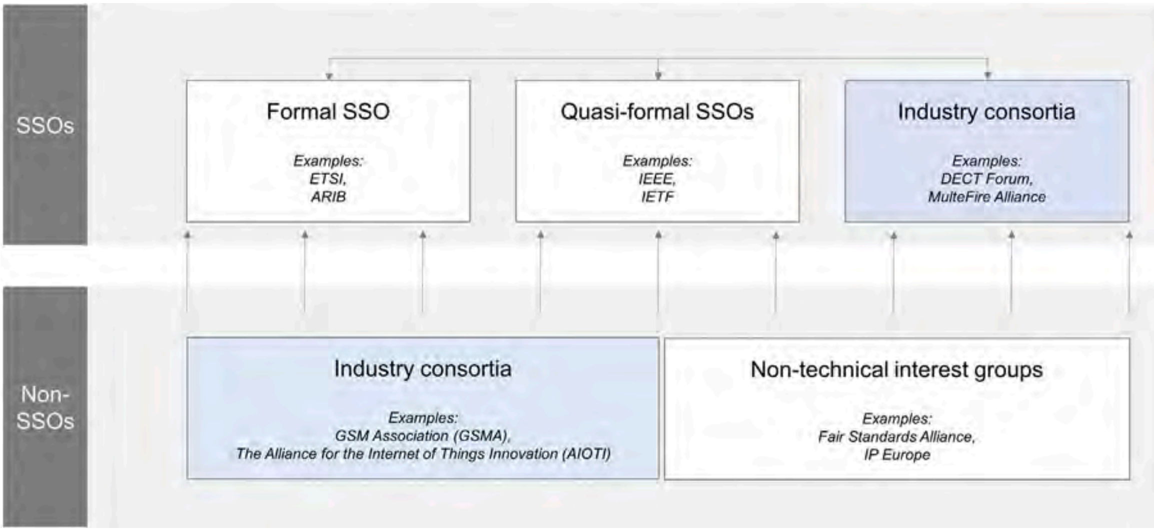

Fig. 1. Relationships between industry consortia, formal and quasi-formal SSOs.

serve a "pre-standardization" purpose (Delcamp & Leiponen, 2014). Standards-related technology discussions and development presumably take place in consortia outside formal organizations because consortia are perceived to be faster and more efficient (Keil, 2002; Pohlmann, 2014); also because firms can influence the standardization path prior to actual standardization work in formal organizations like 3GPP. This could mean that as many of their own technologies as possible are included in a standard, or that the standard is "compatible" with many of their existing solutions and products. Firms holding property rights that are essential for implementing a standard "can receive substantial royalty revenue", and "firms that influence the technical specifications early on can align system features with their own complementary assets" (Leiponen, 2008, p. 1906).

In most cases, "pre-standardization" implies that only parts of standards are developed within a consortium, not entire standards or specifications. But consortia can also fully develop a standard or specification before handing it over to another, usually larger and more established organization. For instance, the first version of the Bluetooth technology was published in 1998 by the Bluetooth Special Interest Group (SIG). In 2002, a newer version was ratified by IEEE as 802.15 (Personal Area Networks), while the Bluetooth SIG still maintains and updates the specifications.[8] A slightly different scenario took place in the field of Wireless Local Area Networks (WLAN). Here, IEEE developed and standardized the original (and later) standards under 802.11,[9] while the Wi-Fi Alliance certifies whether specific products conform to IEEE 802.11 and manages the trade name "Wi-Fi" for these certified products.

A topic of debate in the literature is whether industry consortia supplement or partly replace (quasi-)formal SSOs (Blind & Gauch, 2005; Hawkins, 1999). In line with the idea of pre-standardization taking place in industry consortia, the main theory is that consortia rather "supplement the formal standard setting process" (Baron et al., 2014, p. 22). However, categories are not exactly clear-cut, and the term consortium is sometimes used interchangeably with quasi-formal SSO (see Simcoe, 2014). For the purpose of this paper, our definition of industry consortia is: *"Collaborative alliances of organizations which offer a forum for the discussion, development, coordination of development, testing, certification, and/or promotion of technologies or technology systems, but not recognized as formal SSOs or quasi-formal SSOs".*

Note that, within this definition, consortia can develop technologies; they can contribute these to standardization by (quasi-)formal SSOs, or publish standards themselves, in which case they perform similar roles as (quasi-)formal SSOs. They can contribute to standards or not work on standards at all, yet still be very relevant for technical evolution in the industry. Our definition of consortia only includes organizations that are at least to some extent involved with technical aspects, so we exclude organizations solely occupied with non-technical issues. This is illustrated in Fig. 1, which shows our understanding of industry consortia in relation to (quasi-)formal SSOs and non-technical industry groups. Non-technical interest groups focus only on non-technical rules of the industry (for instance relating to intellectual property). Thus our definition of consortia does not include them.

2.3. Reasons for joining and committing to industry consortia

Hagedoorn (1993, p. 372) examines, on a general level, the reasons why firms engage in technology partnering, which he understands as "interfirm cooperation for which a combined innovative activity or an exchange of technology is at least part of their agreement". He identifies three categories:

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[8] See http://www.bluetooth.com/specifications/bluetooth-core-specification/ (retrieved May 2019).

[9] See http://standards.ieee.org/standard/802_11-2016.html (retrieved May 2019).

1. Motives related to basic and applied research and some general characteristics of technological development, including for instance the reduction and sharing of uncertainty in R&D.
2. Motives related to concrete innovation processes, including for instance technology transfer and technological leapfrogging.
3. Motives related to market access and search for opportunities, including for instance offering new products and entering new markets.

The relative importance of these motives is one of the main determinants of the mode of cooperation that the partners choose. There is a wide array of diverse organizational modes for technology partnering (Hagedoorn, 1990), including strategic technology alliances (Hagedoorn, 1993; Hagedoorn & Duysters, 2002), joint research pacts and research joint ventures and research corporations (Hagedoorn, 1990), inter-firm R&D partnerships (Hagedoorn, 2002), and mergers and acquisitions (Hagedoorn & Duysters, 2002).

A specific form of technology partnering, and in particular of forming strategic technology alliances, is cooperation in the realm of standardization. According to Wiegmann, de Vries, and Blind (2017, p. 1371), standardization "aims to resolve situations where involved actors prefer a common solution to a problem, but have not yet agreed which option to choose". Firms in the telecommunication industry are eager to take part in standardization for a variety of reasons. The overarching motive of participating in standardization is of commercial nature, since "commercial stakes attached to standards and patents" are high for firms in the industry (Chiao et al., 2007, p. 905). More specifically, Keil (2002, p. 206) summarizes that "firms that are able to control winning standards experience high returns while firms supporting losing technologies might be effectively locked out of the market".

Industry consortia are an even more specific case of inter-firm cooperation. In general, similarly to technology partnering and strategic technology alliances, they often involve what Hagedoorn and Duysters (2002, p. 168) call "combined innovative activity or an exchange of technology". Yet, in a broader sense, they could rather be seen as alignment mechanisms, since they are usually not confined to these two activities in a narrow sense, but also enable discussion and coordination between firms in the industry (Axelrod, Mitchell, Thomas, Bennett, & Bruderer, 1995; Baron & Pohlmann, 2013; Delcamp & Leiponen, 2014).

While there is a rich literature on the modes and motives of technology-related inter-firm collaboration, as reviewed above, firms' reasons for getting (and remaining) involved in industry consortia have not yet been systematically studied. This question is particularly interesting in the context of standardization in telecommunications, since there are already numerous (quasi-)formal SSOs allowing firms to get together, coordinate, and collaborate. Why is it that consortia are formed even though all these organizations already exist—and why does it make sense for firms to initiate, establish, and commit to industry consortia?

As already mentioned above, there are two competing views on the role of industry consortia: Consortia can either supplement or compete with (quasi-)formal SSOs (Blind & Gauch, 2005). The prevailing view in the literature seems to be that industry consortia play a supplementary role with regards to (quasi-)formal SSOs. Blind and Gauch (2005, p. 38) find that there are "intensive contacts" between consortia and (quasi-)formal SSOs, and that several formal standards "have a predecessor in the consortia world", and note that both observations point toward a complementary relationship. Even though Baron et al. (2014, p. 22) find that "some consortia substitute for more formal SSOs and issue their own standards", along with Weiss and Cargill (1992), they emphasize the complementary role of consortia. This complementary role is also salient in the previously mentioned pre-standardization function of industry consortia (Delcamp & Leiponen, 2014; Leiponen, 2008). This means that consortia can create technical specifications to be handed over to more formal SSOs, but they can also "offer opportunities to discuss, test, or promote certain technologies" (Delcamp & Leiponen, 2014, p. 36). In contrast with this view are the contributions that regard industry consortia as competitors of (quasi-)formal SSO. They understand consortia as standardization venues, which implies that standards or parts thereof are actually made within consortia. For instance, Wiegmann et al. (2017) differentiate between committee-based, market-based, and government-based standardization, and note that standardization through cooperation can also happen within consortia. When consortia perform functions substitutive to those of (quasi-)formal SSOs, firms will consider various criteria when choosing one or the other. On the plus side, as discussed in Section 2.2, consortia are perceived as faster and more efficient (Keil, 2002; Pohlmann, 2014), and allow more freedom regarding the design of structures and rules (Pohlmann, 2014). On the other hand, they may lack the enforcement strength of (quasi-)formal SSOs (Simcoe, 2012).

When examining more specific examples of industry consortia, one comes across a large variety of organizations, and also understandings of consortia. Keil (2002) takes a closer look at the case of the Bluetooth standard, as created and maintained by the Bluetooth Special Interest Group (SIG). He stresses the importance of alliance design that he thinks "plays a critical role", balancing "speed of standards development" and "standard penetration in the market place" (Keil, 2002, p. 206). He identifies a few critical design parameters, encompassing the balance between openness and closedness, partner selection, and the filling of critical roles. In the context of the Bluetooth SIG, he further argues that standards development can happen faster than in (quasi-)formal SSOs. In comparison to market-based mechanisms, the cooperation and collaboration within the alliance allows for "drawing upon the knowledge and capability of firms from several industries thus allowing for solutions that are better geared toward these industries" (Keil, 2002, p. 211). van de Kaa, den Hartog, and de Vries (2009) and van de Kaa and de Bruijn (2015) make clear that it is not always one consortium or one SSO involved in the making of standards, but that there is often an entire ecosystem or network, sometimes including different industries and product markets. van de Kaa and de Bruijn (2015) shed light on the development process of the IEEE 802.11 (Wireless LAN) standard. They argue that "the network around IEEE 802.11 may be seen as an example of an organization where technical experts spontaneously come together in committees and consortia and together develop and promote a common platform" (van de Kaa & de Bruijn, 2015, p. 586). They further emphasize the importance of the rules, especially decision making process, in order to make sure that participants are sufficiently encouraged to take part in the process, and also continue to stay involved. In the case of small and medium-sized enterprises (SMEs), Blind and Mangelsdorf (2013) find that their participation in standard setting is to some extent motivated by opportunities to gain access to other firms' knowledge.

2.4. Types of consortia

Existing studies differentiate between standardization-related and R&D consortia, and between technical and marketing-oriented consortia (Delcamp & Leiponen, 2014). Pohlmann (2014) characterizes consortia by member quantity, membership levels, business spectrum, and industry sector. Focusing on consortia's technological objectives, Simcoe (2014) distinguishes "single platform" and "single standard" consortia.[10] He states that single platform consortia are similar in size to national SSOs, while single standard consortia are much smaller.

Biddle (2018) adopts a different approach of grouping consortia that is structural or functional in nature. The taxonomy he develops comprises three types: (1) incorporated consortia, (2) contractual consortia, and (3) umbrella consortia. The difference between these types lies mainly in their legal status: While incorporated consortia are "distinct legal entities, typically formed by a collection of interested companies and founded by such companies", contractual consortia, as the name suggests, are based on contractual relationships between participants. Umbrella consortia, in turn, are non-profit incorporated organizations that host other consortia under a defined framework.

Attempts to classify consortia are impeded by the fact that consortia are often opaque (Delcamp & Leiponen, 2014). As a result, existing classifications are typically limited to few general characteristics such as founding year and number of members. We aim to extend the literature by including qualitative data available through websites and documents provided by consortia. Despite realizing that consortia are flexible in devising their structures, processes, and rules, existing studies do not include an in-depth analysis of whether consortia utilize this flexibility. This is also due to the nature of the information: It is qualitative and not easy to find, often "hidden" in bylaws or other documents. That said, we believe this information is relevant for assessing consortia's role in the telecommunications industry. If, as the majority of the literature suggests, consortia wield a great deal of influence in standardization and hence the steering of industry development, a more detailed look at consortia is called for.

3. Methodology

3.1. Approach

We aim to build a taxonomy of industry consortia and thereby aid our understanding of this phenomenon. Taxonomies can help organize data and objects, and hence provide an overview (Archibugi, 2001; Pavitt, 1984). They can be useful for simplification (Milligan & Cooper, 2016) and can reduce "the complexity of empirical phenomena to few and easy to remember categories" (de Jong & Marsili, 2006, p. 214). We used an inductive approach, meaning that our taxonomy was based on patterns observed in data on consortia. The inductive approach is appropriate because there is no well-established and comprehensive theory of consortia that could serve as a basis for a deductive approach.

To gain an overall understanding of consortia, we conducted semi-structured interviews with 14 industry and standardization experts, lasting in total twelve hours. Interviewees included individuals active in consortia as well as in (quasi-)formal SSOs, while we also interviewed representatives of major telecommunications equipment vendors and a network operator. When formulating the interview guidelines, we took into account the literature exploring concrete phenomena in standardization, or providing precise descriptions of standardization processes, such as Bekkers et al. (2002), Besen (1990), Delcamp and Leiponen (2014), Hawkins (1999), Keil (2002), and Leiponen (2008). The guidelines were continuously refined in an iterative process based on experience from previous interviews. The interviews were recorded, transcribed, and coded in NVivo. To facilitate open conversations, we informed interviewees that their identity would remain confidential.

For the quantitative analysis, in line with our chosen focus, we selected consortia in the field of 3GPP/ETSI using the Gesmer Updegrove classification,[11] both those in the core area and those fulfilling an "add-on" function. To ensure data availability, we included only consortia that were active at the time of data collection.[12] We collected the data from online lists created by Gesmer Updegrove[13] and Raising Standards,[14] as well as a free text online search. We also asked interviewees to name any relevant consortia missing from our list, and we added organizations accordingly. In total, we identified 100 consortia active in mobile telecommunications. Thanks to the combination of search methods we are confident our list is as good as complete.

For systematic data collection, we inductively built a classification scheme with 44 items, comprising qualitative and quantitative indicators. We manually collected these indicators from the consortia websites, relying in particular on the "About Us" sections (see Section 3.2 for details). To mitigate the (inevitable) issue of missing values, we imputed these in three different ways (see Annex B for details). We then conducted a principal component analysis (PCA) to reduce the number of variables. The resulting data we fed into a cluster analysis (CA) to group similar consortia together, using different approaches for robustness (see Section 6.2 for further

[10] According to Simcoe, these types of consortia co-exist with Standards Developing Organizations (SDOs) which he characterizes as "multiplatform/multi-industry". He defines both SDOs and consortia as SSOs.

[11] See https://www.consortiuminfo.org/links/#.X3OfAGgzZPY.

[12] We considered including discontinued consortia, and tried collecting data and information via Internet archives. However, we found data to be highly incomplete, since many websites had been taken down and we were not able to find archives of them. We thus decided to exclude discontinued consortia from our analysis, to avoid concerns around methodology and data availability biases.

[13] See http://www.consortiuminfo.org/ (data retrieved until September 2017). See also Updegrove (2016).

[14] See http://www.raisingstandards.eu/ (data retrieved until September 2017).

details on the PCA and CA analyses). Finally, we describe the clusters based on the arithmetic means in the underlying classification items.

We note that our findings from interviews and those from the analysis of consortia websites show some discrepancies. However, this is natural and due to the differing nature of the data sources: Information provided on websites is carefully presented and formulated, and is supposed to let a consortium appear in a certain way. In contrast, interviewees did not receive the questions beforehand, implying that they formulated their responses spontaneously. As a result, they sometimes emphasized different aspects than the respective website did. The discrepancies we observe (which do not include contradictory findings) are thus not a cause of concern, but rather an indication that the data triangulation achieved by our multi-method approach increases robustness of the findings and provides us with a richer picture.

3.2. Classification scheme and data collection

Our classification scheme to collect data started with an analysis of the consortia's websites, to give us a general idea of their characteristics, and to spot any special or unique aspects. Comparing the consortia's structures, rules, and processes with those of formal and quasi-formal SSOs (specifically ETSI respectively IEEE), further helped us to narrow down key characteristics, complemented with a literature review (also see Section 2) and information from interviewees. The resulting classification scheme (see Annex B) contains 38 items based on qualitative information and six quantitative variables, amounting to 44 items.

The qualitative items relate to the consortia's objectives, technological focus, rules, and processes. We specifically aim to shed light on organizational characteristics often hidden within bylaws or documents, and which have not been considered in earlier studies. They include membership admission and voting rules, plus ease of access to membership tiers and leadership positions. Raters converted the 38 qualitative items into quantitative items (see Annex B). In preparation, each qualitative item was described in a summary document, together with the exact definitions of the scale for that item. Most items were rated on a Likert scale, some using binary variables. The definitions of the items and scales were adapted and refined after a test run of 13 consortia, performed independently by two raters.

The refined scheme was then used for the rest of the sample. Data collection took place between August 2017 and June 2018. Two raters independently assessed each consortium and we discussed deviations to obtain a final assessment for each item. We also collected data on the founding year, which allows us to calculate the age of the consortia with respect to the data collection endpoint in June 2018. Furthermore, we added the number of members and their identity, as well as the degree to which consortia members were attending 3GPP meetings between 2010 and 2016. From the records of meetings on the 3GPP website, we extracted information on participants and their firm affiliation. We had to match firm names manually to identify overlaps with consortia member rosters. We captured meeting representation using four variables: the number and percentage of consortium members that were highly active in 3GPP Technical Specification Groups (TSGs) and in Working Groups (WGs). We operationalize 'highly active' as being in the top quartile of all participants in TSG/WG meetings with respect to the number of meetings with at least one representative of the member organization. We used the absolute number as well as the percentage of consortium members to ensure large consortia were not automatically assumed to have stronger 3GPP linkages due to their high number of members.

4. Insights from interviews

The main aim of our interviews was to gain insight on firms' rationales for forming or joining consortia. We first discussed the role and purpose of consortia, especially regarding formal standard setting within 3GPP and its Operational Partners like ETSI. We summarize the insights from our interviews below.

An overarching theme raised by interviewees is that market players are free to shape consortia in line with their needs and goals. While the structures, rules, and processes of large and established SSOs are usually already defined and rather rigid (and significantly constrained by competition law), the aims and workings of newly formed consortia are up for discussion among (founding) members. As one interviewee put it: "The motive is always that the creators have the control. They set the rules of engagement [...] how who can have what and who can do what." This aspect affects all the topics described below, and partly explains why we observed such a wide variety of consortia.

Thanks to the large number of existing and continuously emerging consortia, firms have ample choice. But active participation in consortia (and in SSOs, for that matter) requires manpower, for attending meetings or drafting specifications, making involvement in a larger number of consortia costly. Firms keep a watchful eye on the industry landscape, and emerging relevant consortia. A manager of a large network vendor asserted that it is important to "keep track of what the industry landscape looks like—whether maybe organizations are forming that you are not invited for or part of." Then firms decide, usually based on their business strategy, which consortia to join. However, some interviewees suggested that many firms do not yet have a coherent strategy for observing and detecting interesting consortia. Many interviewees stressed it was vital for firms not to miss out on important developments, which are sometimes proposed by consortia.

Our interviews enabled us to identify rationales for firms forming or joining consortia, based on the five objectives discussed in the following sections.

4.1. Objective 1: Add-on technology development

Consortia may not just contribute to or impact standardization, but also develop "add-on" technologies. These include technologies that often (but not always) complement 3GPP technologies—basically "on top of the 3GPP access network architecture" (comment by a manager at a large vendor). Examples are Open Source Software (OSS) applications. Whenever a consortium's technologies are very close to 3GPP technologies, a large overlap between firms in 3GPP and the relevant consortium is deemed useful.

Concerning the current evolution toward 5G and the Internet of Things (IoT), some cellular technology uses affect firms outside the ICT industry. One interviewee emphasized that "the scope of application within 5G will be much broader than only mobile broadband", and he sees the need to "interact [...] with lots of other industries not represented in 3GPP." Most interviewees do not think it is necessary or even possible to include firms from these industries in 3GPP itself, which they already view as large and ponderous. They believe the best way to interact with other industries is through external consortia.

4.2. Objective 2: Early technology development and circumventing political interest

Consortia can act as "upstream" organizations to 3GPP, where technical ideas and approaches are "prepared" for formal SSOs. This especially happens when very novel ideas are proposed. Then, proofs of concept and trials can take place within industry consortia, external to 3GPP. Once proofs of concept and trials are successfully completed, ideas can be brought into formal standardization. Otherwise, as one SSO secretariat staff member remarked, novel technologies could be rejected or ignored in formal standardization. Standardization participants may perceive the use of these technologies as too risky and be reluctant to rely on immature technology.

Work may also be done outside 3GPP amid political resistance to a certain technology. Political resistance can arise when firms have a stake in another technology contested by the new one, or rely on different technology. Two interviewees mentioned the example of MulteFire, an LTE-based technology operating in an unlicensed and shared spectrum, and in some respects competing with Wi-Fi. As many firms within 3GPP, especially network operators, have a stake in using licensed spectrum (and may have a stake in Wi-Fi insofar unlicensed spectrum is used), it makes sense for firms involved in MulteFire to do the first stage of development within a consortium. Interviewees said that it is generally easier and less costly for them to remain within 3GPP. However, one interviewee commented that if they "foresee it will be cumbersome to drive the work in 3GPP due to political resistance", they are likely to drive it elsewhere, for instance within consortia. Most interviewees agreed, and recognize the risk of promising technologies being blocked or lacking support within 3GPP.

4.3. Objective 3: Promote group interests

Consortia can also promote the interests of a certain group of firms or industry not directly related to a specific technology or group of technologies, such as commercial interests linked in a wider sense to technology. For instance, a consortium could promote cost-efficient technologies in general, and not concentrate on promoting specific technological solutions. Establishing a new consortium allows founding members to purposefully lock out specific (competing) interests, by restricting (new) membership access, voting rights, or access to leadership positions.

4.4. Objective 4: Speed up the standards development process

Consortia can help accelerate standards development, both full standards or parts of them. Our interviewees thought this may be because of participants' heightened interest and commitment, or the (mostly) smaller size and like-minded groups, which make it easier to reach consensus, or the use of novel tools and processes. Furthermore, parts of 3GPP standards can be driven outside 3GPP, then later brought back into the 3GPP standardization process. Firms tend to do this if something is "very important to them" and they know 3GPP will be too slow for their needs (ETSI Board member and standardization manager at large vendor). Another interviewee, however, claimed that working in a consortium is "rarely faster" because before starting the actual development work, founder members need to determine the organization's processes and rules, which takes a substantial amount of time.

4.5. Objective 5: Anticipate key technological developments

Industry players want to be embedded in a large network of firms so that they can closely monitor the industry landscape and thus anticipate and respond to major technological developments. Anticipation is key for firms aiming to maintain or achieve an advantageous position in the market. A manager of a large vendor stressed that it is crucial to "make sure that you are at the forefront of research". An SSO secretariat staff member added that "the industry will sometimes enter their bets in two or three different directions, and then see which one wins." Hence, some firms are part of consortia that support competing solutions. By diversifying in this way, firms are more likely to spot key developments early and act accordingly. One industry expert even claimed "if you don't spot where the next technology is going and what you need to develop for it, then you're dead."

Anticipation is also highly relevant for development cycles. Once a standard is frozen, the infrastructure is probably more or less ready to be deployed, and compatible products are on their way. Firms higher up the value chain, such as infrastructure vendors or manufacturers of cellular modules, must provide (almost) market-ready solutions very soon after the standard is fixed. As one interviewee pointed out, "you have to sort of [...] know what is happening in five years." This especially applies to hardware, with its long development cycles.

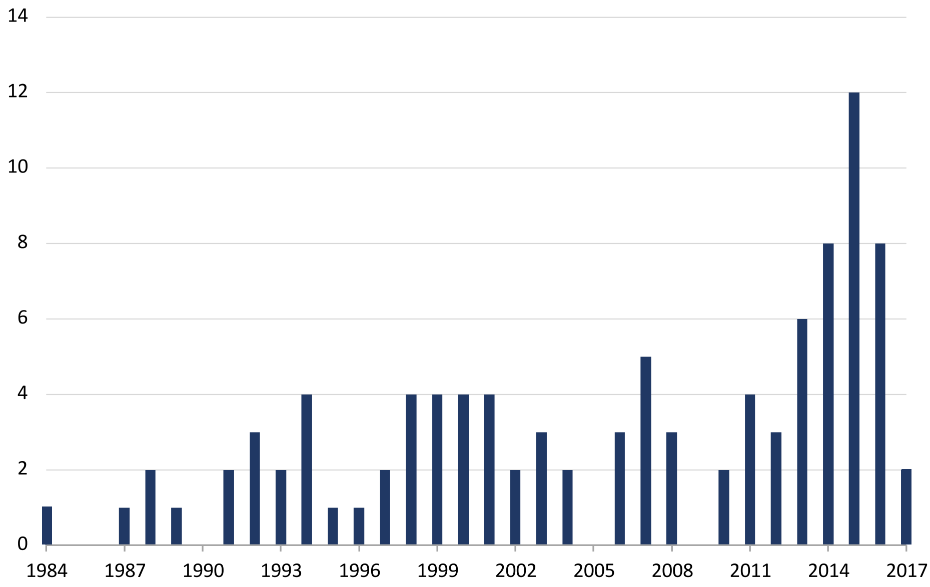

Fig. 2. Number of consortia by founding year.

5. Investigation of 100 consortia

This chapter describes several characteristics of our consortia sample, and provides some descriptive statistics. The average founding year of the consortia in our sample is 2005 (median 2007), which amounts to a mean age[15] of approximately 13 years (median 11 years). The average number of member firms is 186 (median 97), excluding pure adopter members not taking part in development activities.

As shown in Fig. 2, the founding years of the consortia in our sample are distributed between 1984 (plus one observation from 1958, omitted in the graph), with an overall upward trend and some variation. The overall trend is at least partly due to survivor bias, since we only consider active consortia. The pronounced peak around 2015 coincides with heightened public interest in 5G, and the first attempts[16] to understand and define use cases and requirements for the new standard. The 5G Infrastructure Public Private Partnership (5G PPP), a joint initiative between the European Commission and the European ICT industry, was launched in 2014. That is when the first publicly known small 5G trials took place; trials on a larger scale were started in 2016 (see Gold 2016). After 2016, we observe a drop, which is partly due to data cut-off (we froze the list of consortia in September 2017).

Focusing next on objectives (or purpose), Fig. 3 shows how many consortia state a certain aspect as their primary or secondary objective on their website. We take the most emphasized objective as primary, and the other ones as secondary. The two leftmost objectives in the figure are directly related to technology development, while the next two indirectly relate to it (existing technologies can be certified and marketed). The next three pertain to standardization, and the final two to market and societal issues.

In total, 62 consortia indicate they are involved in developing mature technologies, and 48 in early-phase technologies (an individual consortium might be involved in both mature and novel technologies, hence the total of 110). Quite a few consortia (51) are involved in certification (a well-known example is the Wi-Fi Alliance, which certifies products based on the IEEE 802.11 series of wireless LAN standards). Certification activities often go hand in hand with marketing activities. This makes sense, because if a consortium arranges the certification of products according to a certain standard, it will also want to promote this standard—hence, certification and marketing activities may indicate that consortia promote a certain standard or group of standards, even if they do not formally list this as a goal. Many consortia (58) aim to develop standards; examples of such standards are ZigBee and LoRa. Even if a consortium does not officially publish a standard (any more), the maintenance and further development may still be done within that consortium (we already mentioned Bluetooth as an example of this). Furthermore, 52 consortia explicitly mention their aim to formally contribute to a standard, mostly via official liaisons and partnerships. Twenty-nine consortia indicate that they contribute informally through their members, but how they do this is difficult to gauge.

A frequently (n = 70) mentioned objective, not directly linked to technology or standards, is industry development—which we perceive as furthering overall industry evolution and technological progress. A similar goal (n = 27) is to address economic and societal aspects, such as supporting society with technological developments.

15 This is the age as of June 2018, which is the endpoint of data collection.

16 In 2014, the European Commission published an article "5G: a new philosophy in connectivity" (European Commission, 2014), and there are numerous reports on understanding 5G (such as GSMA Intelligence, 2014).

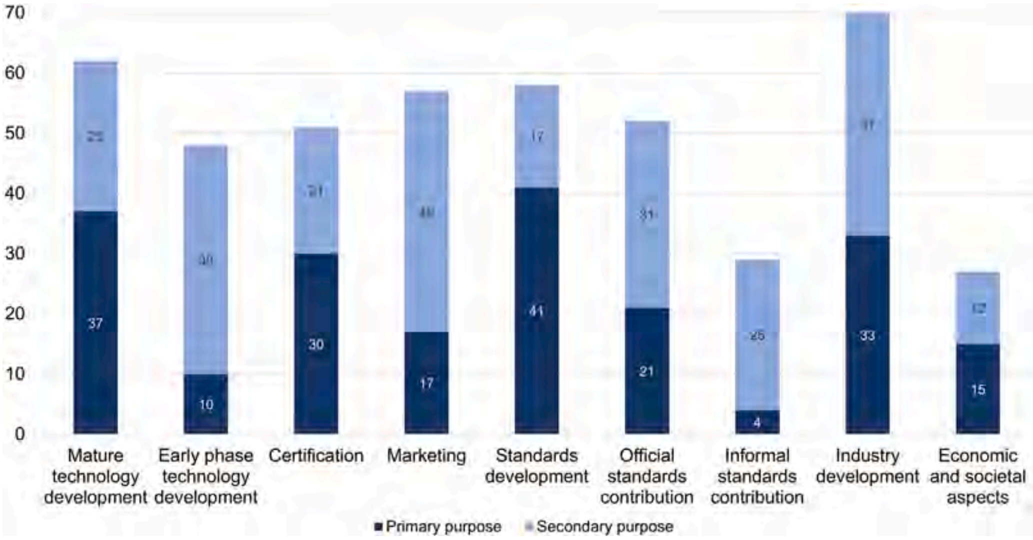

Fig. 3. Number of consortia listing a specific primary or secondary objective.

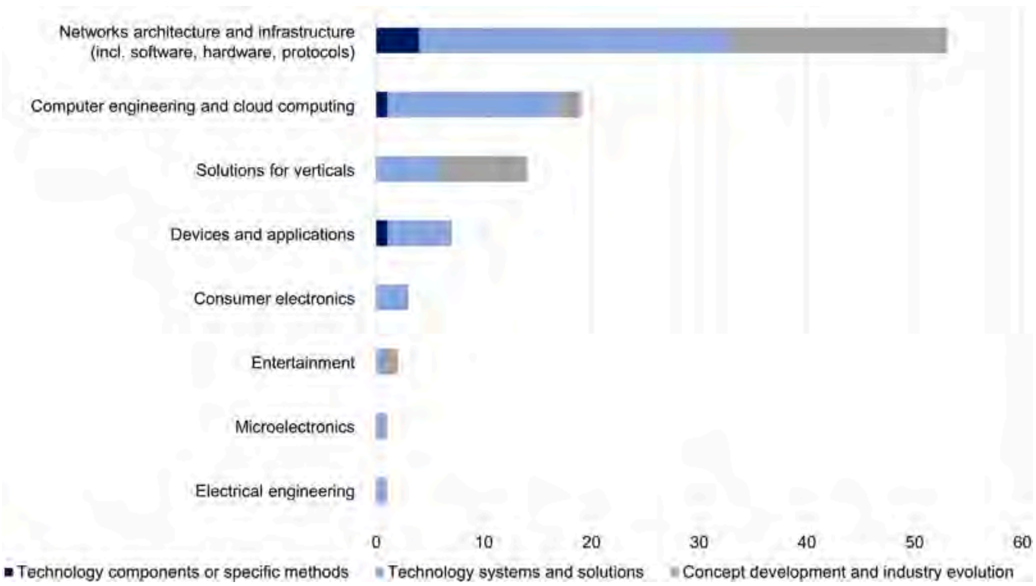

Fig. 4. Consortia's technological breadth.

A closer look at technologies (see Fig. 4) shows that around half of the consortia (53) work on network architecture and infrastructure (software, hardware, and protocols), 19 are involved in computer engineering or cloud computing, and 14 create solutions for non-ICT industries (so-called verticals). In terms of technological breadth, most consortia (63) are "in the middle", that is to say they focus on technology systems and solutions (such as small cells or device-to-device communication). Very few consortia (6) focus on specific technology components or methods (like SIP[17] or CDMA). A total of 31 consortia concentrate on wider and higher-level topics such as the Internet of Things, or mobile networks.

In terms of participating in 3GPP meetings, on average 20 members (i.e. member firms) per consortium are in the upper quartile of 3GPP TSG meeting representation, and 22 in the upper quartile of WG meeting representation. This amounts to approximately 20% respectively 22% of the members of an average consortium. The most active firms have taken part in 26–28 meetings in each

[17] SIP: Session Initiation Protocol.

TSG. However, these numbers can differ considerably depending on the size[18] of a consortium—large consortia tend to have higher absolute overlaps with 3GPP meetings, while percentage overlaps are often higher for smaller consortia. We found that 66 consortia have formalized ties with 3GPP, in the form of Market Representation Partnerships or other formalized collaborations, and 49 have formalized ties with 3GPP Operational Partners. Because most Organizational Partners (and many consortia) do not keep a public database of their partnerships and collaborations, we could not capture all the ties between these organizations. Twelve consortia in our sample are ETSI Industry Specification Groups (ISGs),[19] and are thus hosted and supported by ETSI. Even though ISGs work under the ETSI umbrella, they are accessible to both ETSI members and non-members, and can adopt their own voting rules and work programs (though all ISGs must apply the ETSI IPR policy).

When it comes to transparency and accessibility,[20] most consortia impose some restrictions. Comprehensive information on structures and processes is often not presented directly on the website, at least not to the same extent that (quasi-)formal SSOs provide them. Obtaining this information requires reading the bylaws or policy documents. Although these documents are usually easy to find via web pages, one often has to comb through (usually lengthy) texts meticulously. The same applies to membership information and processes or participation options. Thus, firms interested in joining a consortium can find it cumbersome to obtain extensive information. Also, most consortia have a tiered membership structure, and restrict access to upper membership tiers (usually those with the most far-reaching rights). Such privileges also have repercussions on assigning leadership positions, since only a few firms can influence these decisions. As we will later see, these exclusiveness issues can be associated with prerogatives and advantages of founding members. However, it is not always the case that founding members secure these privileges for themselves. The large majority of consortia are initiated by a set of interested corporate or non-corporate actors, also called promoters. Hence, we believe the sheer presence of promoters in a consortium is not a distinguishing factor—rather, it is the footprint that some of these promoters leave in the rules and structures of consortia. Moreover, the information on promoters is often not public[21] or incomplete, which is why we do not include this information in order to avoid a potential bias.

6. A taxonomy of industry consortia

Ultimately, we aim to group consortia in a systematic and objective way, and do that by creating a taxonomy. To achieve this, we used clustering algorithms to group consortia according to their similarities and differences. We used principal component analysis (PCA), followed by cluster analysis (CA). The first step reduced a large number of variables to a smaller set of components. The second step grouped all the consortia into clusters. These clusters, each described and analyzed in terms of their characteristics, form the basis of our taxonomy.

6.1. Principal component analysis

Principal component analysis allows us to group variables into factors according to their correlations, and hence to reduce the dimensionality of the dataset. To ensure our results are robust, we build on three datasets (see Annex B) obtained using three different methods of dealing with missing values. For all three datasets the Barlett test of sphericity indicated that the data is suitable for factor and principal component analysis ($p < 2.22e^{-16}$). To determine the number of components, we used the nFactors algorithm[22] to compute and inspect the eigenvalues, optimal coordinates, and acceleration factor, as well as a parallel analysis. Based on these indicators, in all three cases, we built seven components. We conducted PCA with varimax rotation, then examined the factor loadings in order to interpret the resulting factors. To analyze these factors, we checked for the highest loading of each variable, concentrating on loadings above 0.5. Based on the loadings, we computed factor scores for both solutions, and each consortium.

Although the solutions differed somewhat between our three datasets, we identified seven common "themes" (see Table 1). As is often the case with PCA, variables load on more than one component, and so the themes overlap.

6.2. Cluster analysis: Approach

To identify types of consortia, we ran a cluster analysis that groups consortia according to their proximity in the seven-dimensional space defined by the results of the principal component analysis. We applied two clustering algorithms with various parameter combinations to refine and check our results.

First, we used the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm.[23] The advantage of DBSCAN is that one does not have to specify the number of clusters beforehand.[24] Consequently, DBSCAN was the first step in obtaining

[18] Also, in very rare cases (e.g. GSMA), more than one of a firm's subsidiaries are represented in a consortium. These subsidiaries are counted separately because they may pursue different business interests. Given that such cases are rare, the outcome would largely remain unchanged if they were merged instead.

[19] For information on ETSI ISGs, see http://www.etsi.org/about/how-we-work/how-we-organize-our-work/industry-specification-groups-isgs (retrieved on 28-07-2020).

[20] Here, "accessibility" refers to how easily an interested firm can become an influential member of a consortium.

[21] It is plausible that such promoters have no interest in disclosing this information.

[22] See http://cran.r-project.org/web/packages/nFactors/nFactors.pdf.

[23] For details on the DBSCAN algorithm, see http://cran.r-project.org/web/packages/dbscan/dbscan.pdf.

[24] To use DBSCAN, one must first define two main parameters: the size of an *epsilon* neighborhood as well as its minimum number of points. The algorithm starts at a random point, then checks its pre-defined neighborhood for points at most *epsilon* distance from the starting point. If that number is at least as large as the pre-defined minimum, a cluster is built. If not, the point is defined as noise. However, if there is another cluster with a core point at most *epsilon* from our starting point, the two clusters become one. This process continues until all clusters and noise points are defined. Then, the algorithm assigns border points to the clusters.

Table 1
Common themes of principal component solutions.

Theme	Component	Description
1	Technology and standards focus	Extent to which a consortium is concerned with technology and standards development (in contrast to societal goals relating to overall industry development, and economic or social aspects). Technology and standards development may go along with marketing or certification activities.
2	Non-commercial orientation	Extent to which a consortium is supported and populated by non-corporate entities (governmental or multilateral entities/authorities).
3	Size	Number of members; also extent of (absolute) presence of consortia members at meetings of 3GPP.
4	Novelty	Consortium's young age and whether it leans toward early technology development.
5	3GPP ties and involvement	Whether a consortium has official co-operations with 3GPP, and what share of its members is highly involved in 3GPP meetings.
6	Structural transparency	Whether information on structures, processes, and work status is easily available and comprehensive, including ties with other organizations, and work documentation.
7	Information provision and accessibility	Ease of access to a consortium, i.e. whether an interested firm would be able to find all relevant documents regarding membership (bylaws, IP rules, conditions) and how easily a firm can gain influence in the organization (voting rights, access to leadership positions). Also: lack of advantages and privileges for founding members.

a rough overview of groupings. However, the clustering results were indeed rough (in the sense of yielding a small number of clusters), and in the absence of a second algorithm, difficult to interpret. K-means helped us refine the results, providing a more granular clustering with well-defined characteristics for each cluster. We applied both DBSCAN as well as the k-means algorithm with various parameter inputs for each dataset. To find suitable *epsilon* parameters for DBSCAN, we inspected the distances to the nearest neighbor, checking three, four, and five neighbors for each consortium. These numbers also corresponded with the minimum points parameter to be defined for the DBSCAN algorithm. We used the average distances to the nearest neighbor as guiding value for trying various parameter combinations. Finally, we kept one DBSCAN solution per dataset, based on parameter combinations providing more than one cluster and a reasonably low number of noise points. For k-means clustering,[25] the number of clusters k to be formed has to be defined in advance. To determine a suitable number, we used three approaches, namely the Elbow and Silhouette, as well as the Gap Statistic.[26] Based on the above considerations, we decided to build six cluster solutions, and compare overlaps and characteristics to achieve a more robust result.[27] We inspected cluster overlaps by first comparing all the clusters obtained by k-means, and computed the percentage overlap between two clusters. Specifically, we wanted to see what share of consortia showed up in two clusters if they were from different cluster solutions. We selected the cluster combinations with the highest overlapping consortia, then built and described six final clusters comprising combinations of two to three initial clusters. We then compared the characteristics of the newly constructed clusters with the two DBSCAN clusters.

6.3. Cluster analysis: Results

We obtained a taxonomy consisting of six clusters of consortia, which we named as follows (in order of decreasing average size of consortia in the cluster):

- **Cluster 1**: Large industry and technology influencers
- **Cluster 2**: High-level concept developers
- **Cluster 3**: Established standards developers
- **Cluster 4**: Young technology specialists
- **Cluster 5**: Small industry and technology influencers
- **Cluster 6**: SSO-hosted industry drivers

[25] We used the Hartigan and Wong algorithm: it forms k clusters by dividing all the consortia into groups. It does this by first adding each data point to the cluster with the centroid closest to it.

[26] As the Gap Statistic indicated only forming one cluster, which is not in line with the two other indicators, we dismissed the Gap Statistic results.

[27] The advantages of DBSCAN are that the number of clusters does not have to be defined beforehand, and it can build clusters in various forms and sizes. In our case, it formed one large, and one or two small clusters. Increasing *epsilon* can reduce the number of noise points, but the largest cluster usually becomes even larger. The extent of similarity within the single clusters can vary; DBSCAN tends not to recognize these differences, and constructs very few clusters. On the other hand, k-means forced us to pre-define the number of clusters, and build clusters of more similar size and form.

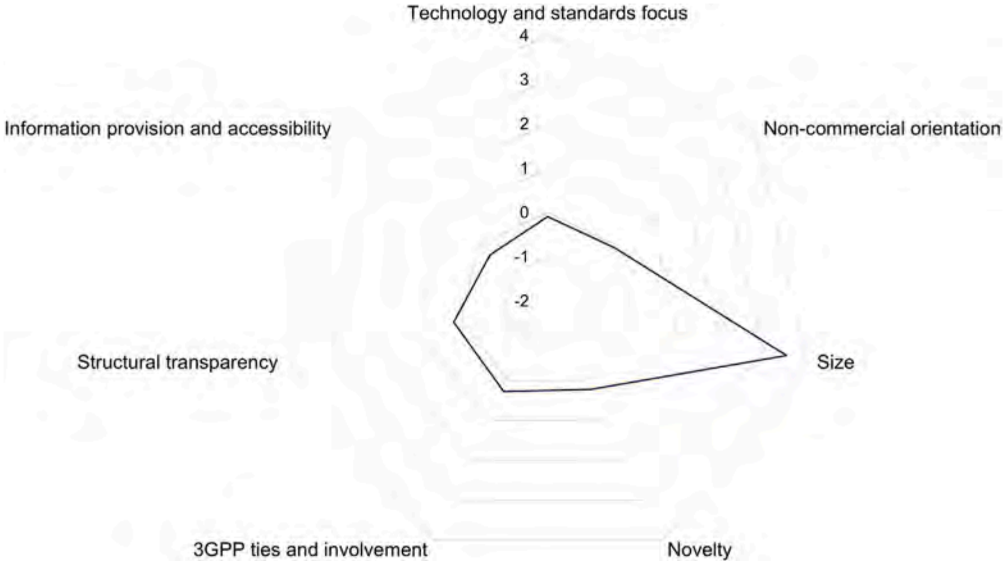

Fig. 5. Average factor scores for Cluster 1 - *Large industry and technology influencers*.

Since the outcomes from the three datasets were similar, we just present one set of results (the set in which variables were imputed using assumptions). Our detailed descriptions of each cluster include a radar graph presenting scores for the dimensions described in Table 1.[28] The numbers in the radar graph show the arithmetic mean of factor scores for all consortia in the respective cluster. Factor scores relating to one component/dimension have a mean of zero, such that a positive value indicates an above-average score.

Cluster 1 (Fig. 5) comprises "large industry and technology influencers." They often emphasize broad technological concepts combined with goals relating to furthering industry development and economic or societal issues. Although some are involved with the development of novel technology, their main focus is then the maintenance or enhancement of mature technologies. Most consortia in this cluster are very large (639 members on average) and their average founding year is 1999, which means that their average age was 19 years when we collected our data. This age is significantly higher than the average of consortia in other clusters. We noted slightly above-average levels of transparency: Information on structures and processes, as well as most policy documents, are usually publicly available and easy to find. However, comprehensive information on membership options and work documentation is missing in some cases. In many cases, We also observe restricted access to membership tiers, meaning that new consortia entrants cannot enter upper tiers. Consequently, certain (groups of) firms enjoy privileges regarding the assignment of leadership positions. We found quite a few formalized 3GPP co-operations, and average levels of 3GPP meeting representation. This was also reflected in the consortia's goals—many organizations plan to contribute formally to standards. This cluster has five consortia, including the GSM Association (GSMA), oneM2M, and the Wi-Fi Alliance.

Cluster 2 (Fig. 6) are the "high-level concept developers" because this group focuses on industry development as well as economic and societal goals, rather than technology development. For that reason, these consortia are frequently supported or joined by government or multilateral entities. They tend to work on very broad technological concepts rather than specific and well-defined technologies. They have 329 members on average, and are of a higher age than the average consortium in the dataset (mean founding year 2002, corresponding to an average age of 16 years). Even though some information on structures is missing or incomplete, consortia in this group tend to exhibit above-average levels of transparency. Membership tiers and leadership positions are mostly easily accessible to all firms. 3GPP ties do not seem to be particularly strong, there are mostly no formalized 3GPP co-operations, and meeting representation is relatively low. Consortia in this cluster include the Alliance of the Internet of Things Innovation (AIOTI), 5G PPP, and DigitalEurope.

Cluster 3 (Fig. 7), is what we call the "established standards developers" and comprises consortia that focus on the maintenance and enhancement of mature technologies. They often engage in standards development, sometimes promoting them with certification and marketing tools. This means they can compete with 3GPP in some respects. The consortia have an average of 224 members, and are of mature age (mean founding year 2000, corresponding to an average age of 18 years). Their transparency ratings are average as they provide a moderate amount of information on their structures, processes, and rules, while some details are not clear. Most of their membership tiers are accessible, although certain (groups of) firms enjoy privileges when it comes to assigning leadership positions. There are very few formalized co-operations with 3GPP, and 3GPP meeting representation is below average. This cluster has 32 consortia, including Bluetooth SIG, Broadband Forum, and DECT Forum.

[28] Due to the slight differences between the PCA solutions summarized in Table 1, a "theme" in Table 1 is somewhat less clearly defined than a "dimension" in the cluster analysis that follows.

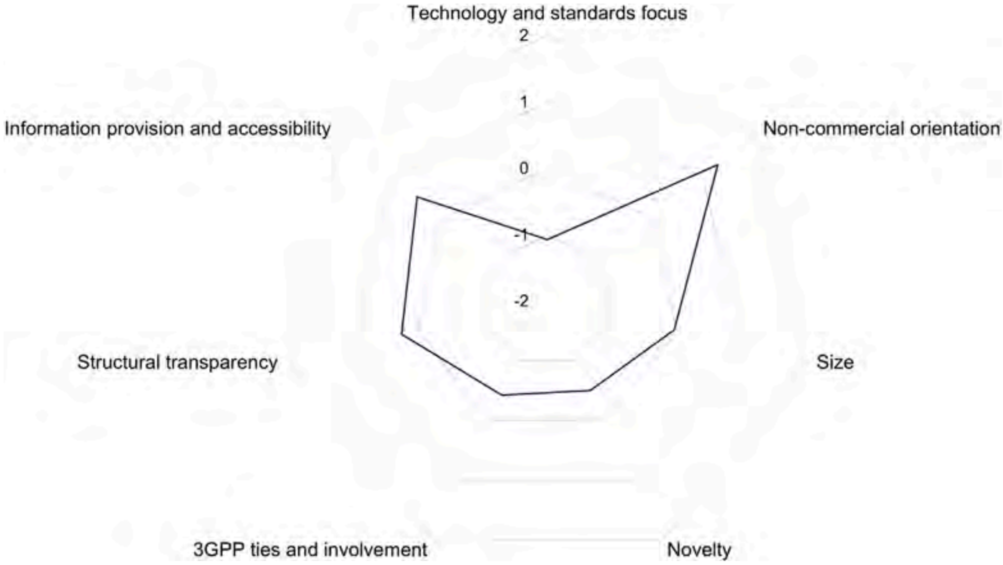

Fig. 6. Average factor scores for Cluster 2 - *High-level concept developers*.

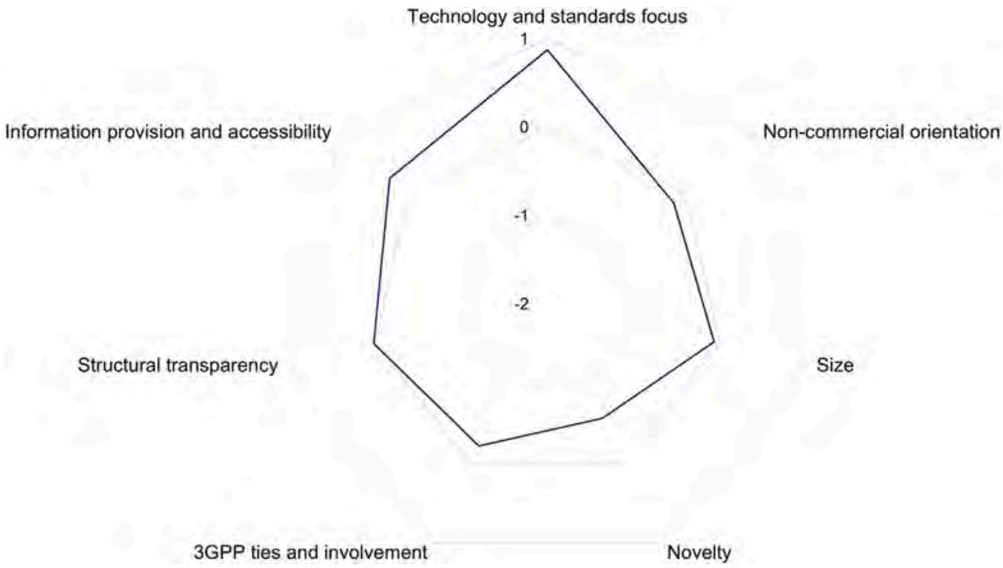

Fig. 7. Average factor scores for Cluster 3 - *Established standards developers*.

We call **Cluster 4** (Fig. 8) the "young technology specialists." In contrast to the other clusters, the majority of consortia in this cluster works on novel technology. They include Open Source organizations such as CloudFoundry, Eclipse, and Open Platform for NFV (OPNFV). Many of these organizations are part of the Linux Foundation (which thus can be seen as an umbrella consortium in the sense of Biddle, 2018).

Most of the consortia are involved with software development, and standards development is not much of a concern. They are smaller than the average consortium in the sample (107 members on average) and of young age (mean founding year 2013, corresponding to an average age of five years). Transparency levels are high, especially regarding work documentation; many organizations have openly accessible depositories or Wikis. Although participation is usually easy, we did find restrictions regarding access to leadership positions. The 14 consortia in this cluster are mostly independent of 3GPP, and exhibit below-average 3GPP meeting representation.

Cluster 5 (Fig. 9), the "small industry and technology influencers", pursue a mixture of industry development, economic and societal objectives. In rare cases, technology development is part of the mix. Many consortia focus on high-level technology concepts rather than specific technologies, and sometimes do marketing and certification. The consortia in this group are small (90 members

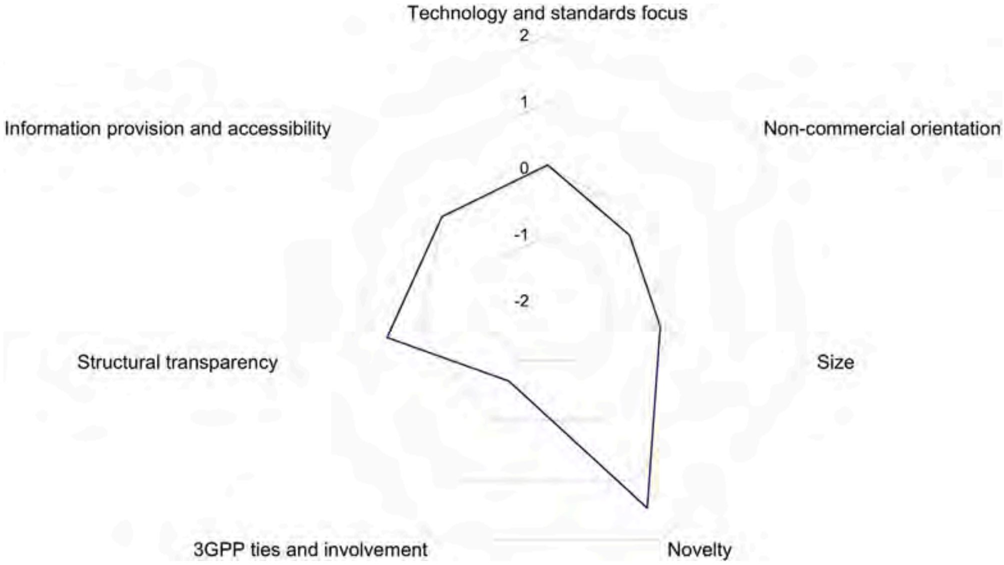

Fig. 8. Average factor scores for Cluster 4 - *Young technology specialists*.

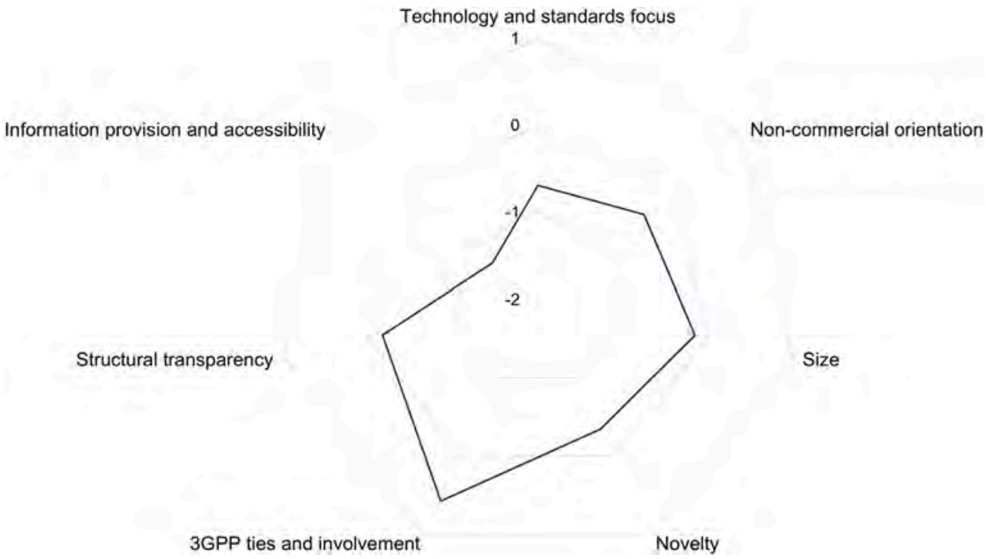

Fig. 9. Average factor scores for Cluster 5 - *Small industry and technology influencers*.

on average) and their mean age is slightly above the sample average (mean founding year 2004, corresponding to an average age of 14 years). They score relatively low for transparency, especially in providing key information on their organizations, and documents such as bylaws and IP rules. As some impose very high restrictions on access to membership tiers, new members are often denied access to the highest tiers. Additionally, certain (groups of) firms have greater leadership privileges, and application processes can be unclear. Many consortia in this group have formalized ties with 3GPP, and aim to formally contribute to standards. We found relatively high 3GPP meeting representation. There are 15 consortia in this cluster, including the 5G Automotive Association (5GAA), Next Generation Mobile Networks (NGMN), and MulteFire.

The consortia in **Cluster 6** (Fig. 10), the "SSO-hosted industry drivers", pursue various goals, such as industry development and early technology and standards development. Most consortia are very small (28 members on average) and of very young age (mean founding year 2014, corresponding to an average age of four years). In terms of transparency, the picture is mixed. Comprehensive information on membership structures and participation options is sometimes hard to find, as is work documentation. Although it is easy to access and be a part of SSO-hosted industry drivers, not all membership tiers are accessible to new members. All eight of the consortia in this cluster are ETSI ISGs, and thus hosted by ETSI. They are often supported or populated by non-corporate entities,

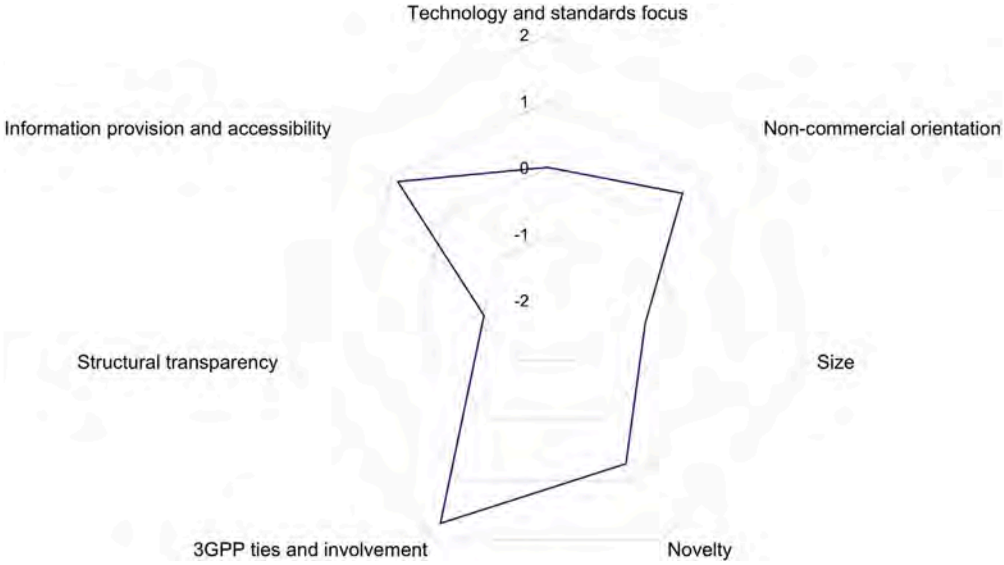

Fig. 10. Average factor scores for Cluster 6 - *SSO-hosted industry drivers.*

such as multi-laterals or government agencies. Non-ETSI members, however, are restricted in the activities and positions available to them. There are also formalized 3GPP co-operations, and a large share of members regularly participate in 3GPP meetings.

Overall, consortia clearly have a very diverse range of objectives as well as characteristics. They differ not only in "obvious" characteristics, such as size and age, but also in transparency, accessibility, and exclusiveness.

We discovered that although not every consortium is involved with standards development or contributions, they are not necessarily irrelevant to standard setting. Some organizations still have formal co-operations with 3GPP, and/or a high presence in 3GPP meetings (see small industry and technology influencers). In contrast, consortia that develop, maintain or enhance their own standards (see established standards developers) are often independent from and may even compete with 3GPP. Many Open Source organizations (see young technology specialists) also do not formally interact with 3GPP, however, their technologies can still serve as a kind of add-on or competition to 3GPP.

There are also large differences between the groups with strong 3GPP ties, either via formalized co-operations or meeting presence (see SSO-hosted industry drivers, large industry and technology influencers, small industry and technology influencers). They differ in their scope, as they work on specific novel or mature technologies, but also broad concepts. Interestingly, unlike the other groups, they are exclusive regarding access to membership tiers and leadership positions. Thus a firm newly entering a consortium may often not be able to become an upper-tier member and consequently will have less influence in assigning leadership positions or not be allowed to nominate candidates.

7. Conclusions and implications

To better understand the phenomenon of industry consortia, we first explored the reasons why firms establish and join industry consortia. We find that even though there is a large body of literature tending to strategic (technology) alliances, and other forms of inter-firm cooperation of collaboration, firms' rationales for their involvement in consortia in particular has not been systematically and comprehensively analyzed yet. Based on semi-structured interviews with industry experts, we identify five rationales for joining and forming industry consortia. Some of these rationales are related to (perceived) shortcomings of established (quasi-)formal SSOs, and hence point toward a substitutive relationship with them; however, other rationales indicate that consortia have a supplementary character, that is, they constitute additions to the existing landscape of (quasi-)formal SSOs.

The diversity of roles that consortia can fulfill suggests a large variety of such organizations, in terms of both objectives and organizational set-up. This is indeed what we find in our classification of 100 consortia active in the field of mobile telecommunications. Our taxonomy yielded six groups: (1) large industry and technology influencers, (2) high-level concept developers, (3) established standards developers, (4) young technology specialists, (5) small industry and technology influencers, and (6) SSO-hosted industry drivers. What facilitates the diversity of consortia is the fact that they are more flexible than formal SSOs in shaping their structures and processes, and determining what one interviewee called the "rules of engagement". This diversity chiefly relates to transparency, accessibility, and exclusiveness. Interestingly, legal status, which is the basis of the categorization used by Biddle (2018), does not correlate with our cluster allocation, and thus appears to be an independent dimension. Overall, we believe the solid insights into the diversity of industry consortia that our study provides will improve our understanding of industry dynamics and standardization in particular.

In addition to the taxonomy of consortia, our study yields several other interesting finding. First, some consortia's officially proclaimed goals and focus areas might not entirely match their actual work. Some goals are formulated in a rather vague fashion,[29] which leaves outsiders wondering about the actual nature of a consortium's work. This seems to be the case for some consortia claiming to pursue broad industry, societal, and economic development goals (rather than actual technical work).

Second, some consortia restrict the acceptance of new members, or restrict their subsequent influence. This restrictiveness can in some cases be related to founding members securing advantages for themselves: In the Telecom Infra Project consortium, only the firms belonging to the member category "sponsors" can appoint representatives for the board of directors, and the number of sponsors is limited to nine. The bylaws[30] also state that "all new sponsors must be approved by a majority vote of all current sponsors". In the case of 5GAA, platinum members can nominate board members, and gold members can propose candidates for the board.[31] To put this in context, platinum membership is limited to twelve organizations, eight of these founding members. Interestingly, consortia that impose restrictions on new members often have strong ties with (quasi-)formal SSOs. We therefore believe that such consortia are especially influential for the standard setting route and overall technological advancements. Also, the restrictiveness of these organizations allows a few leading firms to enjoy substantial steering and shaping freedom. Thus, even though we recognize the need for industry consortia and their contributions, it may be prudent for policymakers to closely monitor and assess consortia. Our taxonomy can help inform this monitoring and assessment. It can then also help policymakers identify areas and consortia that require their attention—for instance because due to their rules and structures, they allow certain firms to obtain sizeable advantages. Furthermore, our taxonomy could be valuable for bodies such as the European Multi Stakeholder Platform on ICT Standardisation (MSP), which has the role to advice the EC on the identification of ICT standards (which, once approved, can then be referenced in European public procurement).

Third, some consortia may help technological advancements in the industry, and hence societal progress. This is the case where consortia aiming to advance novel and promising technologies meet substantial resistance from major industry players. However, some small firms may not possess the necessary means or momentum in the market to initiate consortium activities and promote their technologies. Our interviews even suggest it may in some cases make sense to restrict and limit access to a consortium, and especially to leadership positions—for instance, in cases where political resistance from a number of firms is to expected, but the technology to be developed or promoted looks promising. Being open to participation from all firms may then imply that interesting technologies could be blocked by powerful parties.

Our taxonomy can also help scholars understand the consortia landscape, and its impact and role in the industry. It can also support firms in deciding which consortia to establish or join, because participation is costly, especially in terms of manpower. Our interviewees emphasized that belonging to a wide variety of consortia benefits firms in the industry as this helps them anticipate and impact key technological developments. A taxonomy can thus help identify various types of consortia of interest to a firm.

Our study's approach and outcomes have several limitations. While we believe that our focus on 3GPP-related consortia is well justified and allows us to observe all important motives to engage in standardization, it may still present a limitation in terms of our findings being representative for other technological fields. Thus, a careful analysis of consortia in other fields could be interesting for comparison. Future studies could also incorporate a time dimension in the analysis, have a dynamic view of when firms enter consortia, and observe changes in consortia's operations over time. Moreover, we did not include 15 of the 100 consortia in our sample in the final clusters. This is because we only classified consortia in an overlap between at least two clusters of two different solutions. Adopting this approach, 15 consortia did not really fit any cluster. Finally, from general impressions, one would expect many consortia to promote standards, and put this forward as a primary objective. However, this objective was not emphasized by our interviewees, and does not explicitly follow from our analyses of consortia website. Still, the objectives of "marketing" and "certification" essentially amount to promoting a standard. Overall, by including a multitude of dimensions and consortia characteristics in our analysis, and triangulating quantitative data with interviews, we hope to get as close to the actual goals and activities of consortia as possible.

Declaration of competing interest

One or two of the authors have been involved in past studies and projects related to standardization in telecommunications, an advisory function for Standard Setting Organizations, and IP-related court cases as expert witnesses. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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[29] For instance, the Alliance for Internet of Things Innovation (AIOTI) says they "aim to strengthen the dialog and interaction among Internet of Things (IoT) players in Europe, and to contribute to the creation of a dynamic European IoT ecosystem to speed up the take up of IoT" (see http://aioti.eu/ retrieved March 2020); Next Generation Mobile Networks (NGMN) states they give "guidance to equipment developers and standardization bodies, leading to the implementation of a cost-effective network evolution" (see http://www.ngmn.org/about-us/vision-mission.html, retrieved March 2020).

[30] See http://cdn.brandfolder.io/D8DI15S7/as/q7rnyo-fv487k-d2tvpc/Bylaws_-_Telecom_Infra_Project.pdf (retrieved on 28-07-2020).

[31] See http://5gaa.org/membership/5gaa-membership/ (retrieved on 28-07-2020).

Annex A. List of consortia and their cluster allocation

Table 2 presents the consortia in the sample and their cluster allocation according to our cluster analysis.

Table 2
Consortia in the sample and their cluster allocation.

Consortium	Cluster
Global Certification Forum (GCF)	1 - Large industry and technology influencers
GSM Association (GSMA)	
oneM2M	
TM Forum	
Wi-Fi alliance	
5G Infrastructure Public Private Partnership (5G PPP)	2 - High-level concept developers
Alliance for the Internet of Things Innovation (AIOTI)	
ARTEMIS Industry Association	
DigitalEurope	
Intelligent Transportation Society of America (ITS America)	
International Wireless Industry Consortium (IWPC)	
NetWorld2020	
North American Network Operators Group (NANOG)	
Organization for the Advancement of Structured Information Standards (OASIS)	
Wireless Innovation Forum	
Wireless World Research Forum	
Bluetooth Special Interest Group (SIG)	3 - Established standards developers
Broadband Forum	
CalConnect	
Car Connectivity Consortium	
DECT Forum	
Digital Video Broadcasting (DVB)	
Distributed Management Task Force (DMTF)	
Global Platform	
HomeGrid Forum	
International Multimedia Telecommunications Consortium (IMTC)	
JEDEC Solid State Technology Association	
LoRa Alliance	
Metro Ethernet Forum (MEF)	
Mobile Industry Processor Interface (MIPI) Alliance	
NFC (Near-Field Communication) Forum	
Open Connectivity Foundation (OCF)	
Open Mobile Alliance (OMA)	
Open Networking Foundation (ONF)	
Open Services Gateway Initiative (OSGI)	
PCI Industrial Computer Manufacturers Group (PICMG)	
Peripheral Component Interconnect Special Working Group (PCI SIG)	
PoweRline Intelligent Metering Evolution (PRIME) Alliance	
RapidIO	
SD Card Association (SDA)	
SIP Forum	
Small Cell Forum	
The Linux Foundation	
The Open Group	
Ultra HD Forum	
WiMax Forum	
Wireless Power Consortium	
ZigBee Alliance	
5G Test Network (5GTN)	4 - Young technology specialists
Automotive Grade Linux	
Cloud Native Computing Foundation (CNCF)	
CloudFoundry	
Eclipse	
EdgeXFoundry	
Industrial Internet Consortium	
Open Compute Project (OCP)	
Open Network Automation Platform (ONAP)	
Open Platform for NFV (Network Function Virtualization) (OPNFV)	
Open Stack	
OpenDaylight Foundation	
OpenFog Consortium	
Telecom Infra Project	

(continued on next page)

Table 2 (*continued*).

Consortium	Cluster
5G Americas 5G Automotive Association (5GAA) Car 2 Car Communication Consortium CBRS (Citizens Broadband Radio Service) Alliance Cellular Operators Association of India (COAI) Cellular Telecommunications and Internet Association (CTIA) Global Mobile Suppliers Association (GSA) Global TD-LTE Initiative MulteFire Alliance Next Generation Mobile Networks (NGMN) Alliance Open Automotive Alliance (OAA) Quality Excellence for Suppliers of Telecommunications (QuEST) Forum TETRA and Critical Communications Association (TCCA) Wireless Broadband Alliance Wireless Technology Association	5 - Small industry and technology influencers
ETSI ISG Embedded Common Interface (ECI) ETSI ISG Intelligent Compound Content Management (CCM) ETSI ISG Millimetre Wave Transmission (mWT) ETSI ISG Mobile and Broadcast Convergence (MBC) ETSI ISG Multi-access Edge Computing (MEC) ETSI ISG Operational Energy Efficiency for Users (OEU) ETSI ISG Quantum Key Distribution (QKD) ETSI ISG Surface Mount Technique (SMT)	6 - SSO-hosted industry drivers
App Quality Alliance (AQuA) Communications Alliance ERTICO IST (Intelligent Transportation System) Europe ETSI ISG Information Security Indicators (ISI) ETSI ISG IPv6 Integration ETSI ISG Network Functions Virtualisation (NFV) ETSI ISG Next Generation Protocols (NGP) i3 forum IPSO (Internet Protocol for Smart Objects) Alliance Mobey Forum Object Management Group (OMG) Optical Internetworking Forum (OIF) Storage Performance Council (SPC) Taiwan Association of Information and Communication Standards (TAICS) Trusted Computing Group (TCG)	n/a

Annex B. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.telpol.2020.102059.

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