Success in ICT Standards Development: Analysing the Effects of Consortium Size and Diversity

MSc Thesis

Giorgio Basile

Delft University of Technology

TU Delft

Success in ICT Standards Development: Analysing the Effects of Consortium Size and Diversity

MSc Thesis

by

Giorgio Basile

in fulfilment of the requirements for the degree of

Master of Science
in Management of Technology

at the Delft University of Technology,
to be defended publicly on May 22, 2025

First supervisor	Dr. Sander Smit
Second supervisor	Dr. Karolien van Nunen
Chair	Dr. Geerten van de Kaa

An electronic version of this thesis is available at http://repository.tudelft.nl/.

TU Delft

Preface

This MSc thesis represents the final step of my academic journey, which spanned six years and took me through two very different faculties, first *Aerospace Engineering*, and then *Technology, Policy and Management*. This second chapter truly broadened my horizons and allowed me to explore new knowledge domains that I believe are fundamental for my future career and, in general, for my personal development.

The study I have been working on in the last months fits the profile of my Master's program, *Management of Technology*, as it presents a quantitative, empirical analysis of consortia involved in ICT standardisation, a key technological domain. It views technology as a resource to shape industry standards and examines how organisational choices, such as consortium size and diversity, affect strategic outcomes. This aligns with the MoT perspective on managing innovation and technology in a corporate context.

My sincere thanks go to my supervisors, Sander Smit, Karolien van Nunen, and Geerten van de Kaa, who have guided me over the past six months. Without your support, I would not have been able to complete this MSc thesis and successfully finish my studies. I truly appreciated your supervisory approach, each piece of feedback was thoughtful, constructive, and clearly aimed at helping me improve my work and reach this milestone. I have always believed that the committee is one of the most important, if not the most important, elements of an MSc thesis. Now, as I approach the end of this process, I can say that this belief has proven to be true.

I am deeply grateful to my parents, who unconditionally supported me in these years. You were always there for me, allowing me to spend six beautiful years as a student in Delft. You will not regret any of the sacrifices you have made for me, I promise.

Next, to my second family, the larger one, made up of all the friends I made over the years. To Marco, with whom I lived for four years, to the point where we were mistakenly (or maybe not) registered as a couple. To Geko, Alfo, Tony, Gigi, Sergio, and Silvio, no need to even say a word, it would be unnecessary, you are Delft for me. To Şerban, one of the closest friends I have, we shared quite a few crazy stories both nationally and internationally. To Niccoló, probably the person most similar to me, it feels like we've known each other forever. To Elena, with whom I can always share either a laugh or a deep conversation, but never admit I was wrong. To Marta, Emir, and Paolo, who have always been there, even when I passed by Novara for less than a day, my trademark. To Pizza and all of the people who shared these years with me and know the struggles I've had, thank you.

Giorgio Basile
Delft, May 2025

Executive Summary

In the information and communication technology (ICT) sector, industry consortia play a critical role in developing compatibility standards that enable interoperability, drive innovation, and shape competitive dynamics. These consortia vary widely in size and composition and are often created to establish de facto standards through market-based coordination. While the literature suggests that structural features, such as the size of the consortium and the diversity of its members, can influence standardisation outcomes, empirical evidence quantifying these effects remains limited.

This thesis investigates how the size and industry diversity of ICT consortia affect their success, defined through two key dimensions: the longevity of the consortium and its output productivity in generating technical deliverables. Drawing on theories of network effects, resource pooling, and complementary assets, the study hypothesises that both size and diversity follow an inverted-U shaped relationship with success, offering benefits up to a point, beyond which coordination complexity may reduce effectiveness.

To test these relationships, a novel dataset of 92 ICT consortia was compiled using publicly available sources and automated data collection, including manual research and web scraping. Consortium size was measured by the number of decision-making members, and diversity was assessed using a Herfindahl-Hirschman Index based on industry representation. Multiple linear and negative binomial regression models were used to test linear, quadratic, and interaction effects.

The results reveal that neither size nor diversity significantly affects success when measured as a composite index. However, when disaggregating the components, both larger size and higher diversity are negatively associated with output productivity, contradicting the expected inverted-U shape. Moreover, the interaction between size and diversity further amplifies this negative effect, suggesting that highly complex consortia may struggle with internal coordination, reducing their ability to produce outputs efficiently. No significant relationship was found between either factor and longevity.

These findings have important implications for both theory and practice. For practitioners, the study challenges the assumption that larger or more diverse consortia are inherently more effective. Instead, it underscores the importance of strategic governance, subgroup structures, and internal alignment to manage complexity and maintain productivity. Managers forming or joining consortia should carefully weigh the trade-offs between inclusiveness and coordination, and explore alternative ways to access knowledge and complementary assets without overextending consortium structure.

This thesis contributes to the empirical literature on standardisation by providing new insights into how consortium composition shapes performance in the ICT sector and offers actionable guidance for firms navigating the complexities of collaborative standard-setting.

Contents

1
Introduction

Standards and standardisation are deeply embedded and longstanding aspects of our society (Grillo et al., 2024). Nearly every organisation relies on standards, whether for their products or services, operational processes, or management systems. Many businesses also participate in the creation and refinement of these standards, which have been widely acknowledged to play a fundamental role in economic, social, and technological development (Grillo et al., 2024; ISO, 2021).

Standards can be considered the language that enables the efficient development of technologies and interoperability of components across sectors, particularly in the ICT domain (Bhatt et al., 2021). As such, standards serve as a key medium for knowledge and technology diffusion and are essential for the emergence and deployment of innovation (ISO, 2021; Bhatt et al., 2021). In addition to their technological role, standards are closely linked to the economic growth of the industries and countries in which they are embedded, even when not directly developed with that goal in mind (Brem et al., 2016; ISO, 2021; Bhatt et al., 2021). It is therefore crucial for companies to understand how standards are developed, how they gain dominance, and how participation in standardisation processes can yield strategic advantages.

Standards, which can be broadly defined as a set of specifications that provide solutions to common problems (Grillo et al., 2024; Kim et al., 2018), come in different forms: variety-reducing, measurement, quality, and compatibility/interface standards (van de Kaa, 2023; ISO, 2021; David and Greenstein, 1990; Suarez, 2004; Wiegmann et al., 2017). Compatibility standards, in particular, are essential in today's complex technological systems. They allow different components, systems, or devices to work together seamlessly (David & Greenstein, 1990), facilitating interoperability and enhancing value through network externalities (Kim et al., 2018; Gallagher and Park, 2002; Pohlmann, 2014). These dynamics often lead to the emergence of dominant designs and de facto industry standards (Anderson and Tushman, 1990; Murmann and Frenken, 2006).

Such standards are often developed not by formal standardisation bodies alone, but by consortia, temporary collaborations of firms and stakeholders with shared technological interests. These range from informal alliances to highly structured organisations with significant resources (Pohlmann, 2014; Teubner et al., 2021; Baron et al., 2014; Kamps et al., 2017; Baron and Pohlmann, 2013). Consortia are especially prominent in fast-moving, technology-driven sectors like ICT, where they enable quicker and more flexible standard development (Teubner et al., 2021; Blind and Gauch, 2008). By gathering firms from different industries, consortia facilitate knowledge exchange, shared R&D, and coordinated promotion of standards (Wiegmann et al., 2017; Leiponen, 2008; Soh, 2010). Increasing technological complexity and the demand for cross-sectoral expertise further elevate the importance of consortia in shaping compatibility standards (Shin et al., 2015; Schilling, 2020; Beck and Schenker-Wicki, 2013).

Research has shown that the characteristics of a consortium, such as its composition, governance, and strategic orientation, can play a decisive role in determining whether the standards it develops will succeed (Wiegmann et al., 2022; van de Kaa et al., 2015; Bhatt et al., 2021). Consortia aim for standard dominance for a variety of reasons: achieving competitive advantage, increasing profitability, or influencing industry trajectories (Kamps et al., 2017; Papachristos and van de Kaa, 2021). As a result, understanding which characteristics of consortia contribute to standard success is of both academic and managerial interest.

While prior literature offers several conceptual frameworks linking consortium characteristics to standardisation outcomes (Leiponen, 2008; Afuah, 2013; Sakakibara, 2001), empirical, quantitative testing of these relationships remains limited (Beck and Schenker-Wicki, 2013; Leiponen, 2008; Sakakibara, 2001). Much of the work to date has been theoretical or case-based, leaving a gap in systematically measuring the effects of key variables such as size and diversity. The lack of such studies may be due to data availability and the methodological complexity of capturing structural consortium characteristics across cases. This MSc thesis addresses this gap by using a structured empirical approach to test how consortium size and diversity affect standardisation success, both individually and in combination. The goal is to bring clarity to theoretical expectations and offer actionable insights to firms engaged in standard-setting consortia.

The literature identifies three mechanisms through which consortia characteristics may affect success: (1) pooling of knowledge and resources, (2) network effects, and (3) access to complementary assets (den Hartigh et al., 2016; Baron et al., 2014; Shin et al., 2015; Wiegmann et al., 2022). Size enhances these mechanisms by expanding the pool of available expertise and increasing visibility and influence (Leiponen, 2008; van den Ende et al., 2012), while diversity contributes by enabling cross-sectoral learning, attracting a broader user base, and increasing access to a wider ecosystem of products and services (Soh, 2010; Gallagher and Park, 2002; Beck and Schenker-Wicki, 2013). However, both size and diversity also introduce potential downsides, such as coordination complexity or strategic misalignment.

This thesis seeks to empirically test the effects of consortium size and diversity on success by analysing a dataset of ICT consortia. The results will offer both theoretical validation and practical guidance for stakeholders involved in standard-setting.

In summary, this MSc thesis has the objective of testing and quantifying, through empirical analysis, the effects of consortia's size and diversity, individually and in combination, on consortia's success. To guide this research, the following question is defined:

"To what extent do the size and diversity of standard developing consortia have an effect on consortia's success?"

Furthermore, to address this question, two sub-questions are formulated:

Sub-question 1: *"What role do the size and diversity of standard developing consortia play in shaping their success?"*

Sub-question 2: *"Do the empirical results support the theoretical expectations regarding the effects of size, diversity, and their interaction on consortia success?"*

This study focuses on the ICT sector, where compatibility/interface standards are primarily developed by consortia, and market-based standardisation dominates. In this environment, the interoperability of components is essential to ensure the global functionality of communication technologies and support economies of scale in production (Bhatt et al., 2021). As such, it offers a fitting empirical setting to explore the factors influencing consortia success in standardisation.

In chapter 2, a conceptual framework is developed to establish the expected relationships and define the hypotheses. In chapter 3, the empirical strategy and data sources are described. chapter 4 presents the statistical results, and chapter 5 discusses their implications and conclusions.

2

Theoretical background

This chapter will present the necessary background knowledge about standards, consortia, and their dynamic in the ICT industry. This will lead to defining the mechanisms behind their success and creating a set of hypotheses related to the effect of consortia's composition on their success, which will be later tested.

2.1. Standardisation in the ICT industry

Standards, as was explained in chapter 1, are sets of specifications which define the solutions for a common problem (Lyytinen and King, 2006; Brem et al., 2016; Grillo et al., 2024) and can also be seen as the language that allows for the development of compatible technologies (Yee-Loong Chong and Ooi, 2008; Kim et al., 2018; van de Kaa et al., 2014). A proper definition of standards, which is compatible with every type and every academic discipline, sees *standardization* as "the activity of establishing and recording a limited set of solutions to actual or potential coordination problems, expecting that these solutions will be repeatedly or continuously used, over time, by a substantial number of the parties for whom they are meant", and the "resulting set of solutions, often expressed in the form of a written document, is the *standard*" (Grillo et al., 2024).

Specifically to *interface/compatibility standards*, since they are the focus of this MSc thesis, they define the interrelations between entities and the specifications that allow them to work together (van de Kaa et al., 2011; van de Kaa et al., 2014). These standards ensure that different components and systems can work together effectively (van de Kaa et al., 2014; Teubner et al., 2021) and therefore are essential for interoperability between the various elements of a system (van de Kaa et al., 2014; Bhatt et al., 2021; Lyytinen and King, 2006; van de Kaa, 2017; Grillo et al., 2024). As a consequence, they play a crucial role in fostering innovation (Bhatt et al., 2021; Grillo et al., 2024) and facilitating the development of technological platforms (van de Kaa, 2017; den Hartigh et al., 2016; Papachristos and van de Kaa, 2021). An example of such interface standards is the Universal Serial Bus, commonly known as USB, which was introduced in 1996 to simplify and standardise the connections of peripheral devices such as keyboards or printers (Papachristos & van de Kaa, 2021). By defining common connectors, communication protocols, and power supply specifications, the USB standard enables interoperability between a wide range of hardware components and host systems, regardless of manufacturer (van den Ende et al., 2012). The Video Home System (VHS) is another example of such standards. Although not developed within the ICT domain, VHS is relevant as an early illustration of how interface standards can drive market dominance through interoperability. VHS allowed video tapes recorded on one device to be played on any VHS-compatible player, regardless of brand, thanks to shared technical specifications across manufacturers (van de Kaa, 2017; Papachristos and van de Kaa, 2021).

In the ICT sector, these standards are mostly developed by consortia, which represent the central entity of this study. They are alliances of companies mostly from the private sector, which collaborate to develop and promote technical standards and the eventual related products and services (Pohlmann, 2014). Consortia tend to be industry-driven, meaning that they come together from the initiatives of commercial entities, all of which are like-minded and share interests in standardising the same technologies (Pohlmann, 2014; Teubner et al., 2021). Another common characteristic is their flexibility and speed in the standard-setting process (Teubner et al., 2021; Pohlmann, 2014). The need to adapt to the fast evolving technological landscape and overcome what were considered slow standardization processes of official bodies in the late 1980s, fostered the creation of these groups of companies which could address those needs in a much quicker and more effective way (Pohlmann, 2014; Teubner et al., 2021; Blind and Gauch, 2008). Furthermore, their focus on de facto standards is a fundamental aspect to consider, differentiating them from formal standard-developing organisations (SDO) developing de jure standards (Weiss and Cargill, 1992; Wiegmann et al., 2017).

The second type, namely de jure, are formal standards developed and approved by SDOs through explicit communication, negotiation and official practices (Grillo et al., 2024). They arise from administrative or political procedures and sometimes are supported by law, such as in those cases where they are mandated by the government (Grillo et al., 2024; van de Kaa and de Vries, 2015; Wiegmann et al., 2017). The ISO9001 is a good example of such de jure standards developed by the International Organisation for Standardisation (ISO) (Wiegmann et al., 2017), which codifies the requirements for a material object and the assessment criteria. In contrast to these organised practices, de facto standards emerge through market-based standardisation (Grillo et al., 2024; van de Kaa and Greeven, 2017; Gallagher and Park, 2002; Wiegmann et al., 2017) and characterise the ICT industry, corresponding to the domain of this MSc thesis. Instead of being officially defined and recognised, the facto standards exploit mechanisms such as the passive acceptance of specifications promulgated by a single entity or consortia or through competition among different formats where consumer choice ultimately determines dominance (Grillo et al., 2024; van de Kaa and Greeven, 2017; Gallagher and Park, 2002; Wiegmann et al., 2017; Van de Kaa et al., 2017). Referring to the previously mentioned VHS vs Betamax battle, that is a classic example of a de facto standard arising from consumer preference and the availability of complementary products rather than formal approval by an SDO (Grillo et al., 2024; Wiegmann et al., 2017; Gallagher and Park, 2002; Van de Kaa et al., 2017; Papachristos and van de Kaa, 2021; van de Kaa et al., 2015).

Consortia aim at sponsoring, developing, and standardising technologies, particularly in rapidly evolving fields such as the ICT sector (Pohlmann, 2014; Teubner et al., 2021). They are often formed to achieve specific objectives such as defining crucial technical specifications for interoperability (Lyytinen and King, 2006; Kim et al., 2018), but they also pursue broader goals, including setting multiple standards to foster the evolution of new business services and product categories (Teubner et al., 2021). A key objective is to coordinate markets and cultivate business communities around particular technologies, often by focusing on establishing platform standards that facilitate the development of complementary goods (Blind and Gauch, 2008; van de Kaa et al., 2015). Ultimately, consortia strive to bring together companies that possess a specific interest in standardisation and a significant market stake in a particular technology, aiming for standard dominance and the related profitability that can arise from it (Jakobs, 2017; Leiponen, 2008; Teubner et al., 2021).

As previously mentioned, consortia focus on de facto standards, which emerge through market-based standardisation, a very common process in the ICT industry. This is a process where standards achieve dominance through competition and acceptance in the marketplace (van de Kaa et al., 2011; Wiegmann et al., 2017). In this mode, various technologies and the entities supporting them compete for widespread adoption, with the winning one often becoming a de facto standard (Shin et al., 2015). In this environment, the success of a standard is influenced by elements like its existing user base, the availability of compatible products and services, and the presence of network effects (van de Kaa et al., 2011, van de Kaa and de Vries, 2015), where the value of the technology increases with the number of users (Shin et al., 2015, Banton et al., 2024). Another important aspect is that any actor can develop and introduce a potential standard into the market, and its fate is determined by the users' choice and the related competition.

Two other main standardisation modes exist, namely committee-based and government-based (Wiegmann et al., 2017). The first one differs from market-based standardisation since it relies on collaboration and consensus among diverse stakeholders within SDOs (Wiegmann et al., 2017) and results in de jure standards (Grillo et al., 2024; van de Kaa and Greeven, 2017). This mode emphasises cooperation and inclusivity in the formulation of standards rather than competition between the firms (Wiegmann et al., 2017). The third mode, government-based, involves regulatory bodies using their authority to mandate specific standards in a top-down approach (Grillo et al., 2024). Unlike market-based standardisation, which emerges from decentralised market dynamics, government-based standardisation is driven by regulatory decisions (Wiegmann et al., 2017).

The prevalence of market-based standardisation in the ICT sector is linked to the rapid speed of technological advancements and the dynamic nature of this industry (Blind and Gauch, 2008; Baron and Pohlmann, 2013; Pohlmann, 2014). As a consequence, industry-driven consortia have become significant players in the ICT standardisation landscape (Blind and Gauch, 2008; Weiss and Cargill, 1992; Pohlmann, 2014). Their ability to react more flexibly and potentially faster than formal bodies to emerging technologies further highlights the market-driven nature of standardisation in this domain (Teubner et al., 2021; Blind and Gauch, 2008). Strictly related to this standardization mode is the type of output that these consortia produce. They aim for de facto standards which can also eventually evolve into formal standards (Wiegmann et al., 2017; Pohlmann, 2014). However, they produce a range of heterogeneous outputs that support or help the development of the standards themselves, such as technical specifications, technical papers, white papers and so on (Pohlmann, 2014). This aspect is very important for this MSc thesis given that looking for and analysing only the actual standards produced by a consortium would clearly underestimate their activity and the resulting success metrics. Therefore, it is important to consider the heterogeneous outputs as building blocks in the development of standards.

In summary, the development of interface standards in the ICT sector is characterised by the presence of consortia engaging in market-based standardisation. These consortia produce de facto standards as well as a variety of heterogeneous outputs with the scope of achieving sustained technological development and related standard dominance. Understanding this environment and its dynamics, where competition is a central aspect, is crucial to uncover the mechanisms behind the consortia's success and, as a consequence, make inferences on how their composition may affect this success. The following sections will explore these mechanisms and develop the hypotheses that will be later tested.

2.2. Consortium success

Consortia success has been examined in various studies and, importantly, can be defined in multiple ways (Kamps et al., 2017; Mannak et al., 2023; Weiss and Cargill, 1992; Baron and Pohlmann, 2013; Pohlmann, 2014; van den Ende et al., 2012; van de Kaa and de Vries, 2015; Wiegmann et al., 2017). Depending on the context and objectives of the research, success can take on different meanings, none of which are inherently right or wrong (Jakobs, 2017).

Given the dynamic and rapidly evolving nature of the ICT sector, where standards often achieve dominance through market-based competition (Grillo et al., 2024), two perspectives on consortia success are particularly relevant (Shin et al., 2015; Bhatt et al., 2021; Shin et al., 2015; van de Kaa and de Vries, 2015; Wiegmann et al., 2017). The first is the consortium's impact on standardisation, intended as its ability to develop and promote technical standards or specifications that achieve market dominance (Kamps et al., 2017). This is particularly relevant in ICT contexts, where interoperability and compatibility are essential for adoption and diffusion (Shin et al., 2015; Bhatt et al., 2021; Grillo et al., 2024). A successful ICT consortium is therefore one that contributes to the development of relevant (de facto) standards, often indicated by widespread market adoption (van den Ende et al., 2012; Kamps et al., 2017; den Hartigh et al., 2016; Pohlmann, 2014).

The second perspective focuses on the longevity or survival of the consortium itself (Kamps et al., 2017). Longevity reflects the consortium's continued relevance to its members and its ability to adapt to technological and market changes. As discussed by Kamps et al. (2017), consortia that endure are more likely to build strong relationships and trust among members (Yee-Loong Chong and Ooi, 2008; Schilling, 2020), enabling more effective collaboration and knowledge sharing.

Accordingly, this thesis defines consortia success as a combination of two dimensions: the longevity of the consortium and its ability to develop outputs that contribute to standard dominance. These dimensions are reflected in proxies such as years of activity, market adoption, and the production of technical deliverables (den Hartigh et al., 2016; van den Ende et al., 2012; van de Kaa et al., 2011; Pohlmann, 2014; Blind and Gauch, 2008; Soh, 2010; van de Kaa et al., 2015).

Among the many factors that influence consortia success, the structure and composition of the consortium itself, specifically its *size* and *diversity*, have received particular attention in the literature (van den Ende et al., 2012; van de Kaa et al., 2015; Afuah, 2013; Afuah, 2013; Wiegmann et al., 2022; Beck and Schenker-Wicki, 2013). Size, generally measured by the number of members, is assumed to enhance resource availability, legitimacy, and network reach (den Hartigh et al., 2016). Diversity, typically defined in terms of the industry backgrounds of members, is expected to increase knowledge heterogeneity and the scope of complementary assets (den Hartigh et al., 2016; van den Ende et al., 2012; Sakakibara, 2001; Beck and Schenker-Wicki, 2013; van de Kaa and de Vries, 2015). These structural characteristics are therefore considered key antecedents of the mechanisms that may lead to consortia's success.

To better understand how size and diversity influence outcomes, the literature identifies several mechanisms that mediate this relationship (Mannak et al., 2023; van de Kaa et al., 2015; Murmann and Frenken, 2006; Papachristos and van de Kaa, 2021). In the context of ICT standards, three mechanisms are particularly relevant: (1) network effects acting on the developed standard, (2) the availability of complementary assets (also known as indirect network effects), and (3) the pooling of knowledge and resources within consortia (Baron et al., 2014; Shin et al., 2015; van den Ende et al., 2012; Suarez, 2004; Lyytinen and King, 2006; van de Kaa et al., 2015; Wiegmann et al., 2022; Leiponen, 2008.

Historical standard battles help illustrate how these mechanisms operate. The VHS vs. BetaMax case shows how JVC's broader alliances and open licensing created a larger installed base and more complementary products, tipping the balance in favour of VHS despite BetaMax's technical superiority (Jakobs, 2017; van de Kaa and de Vries, 2015; van de Kaa et al., 2014; Ehrhardt, 2004). Similarly, the competition between WiFi and HomeRF demonstrates how WiFi's greater diversity of backers and technological flexibility supported its eventual dominance (van de Kaa et al., 2015; van den Ende et al., 2012). In contrast, the QWERTY vs. Dvorak example highlights how early adoption, switching costs, and network externalities can lock in a less efficient standard due to momentum rather than technical merit (van de Kaa et al., 2019; Gallagher and Park, 2002; Schilling, 2003).

In addition to network effects and complementary assets, knowledge pooling is another crucial mechanism in consortia settings (Schilling, 2020; Beck and Schenker-Wicki, 2013). In high-technology sectors, where innovation requires a range of specialised expertise and resources, no single organisation is likely to succeed alone (Schilling, 2020). By bringing together diverse firms, consortia can reduce R&D costs, share risks, and facilitate the exchange and integration of knowledge (Sakakibara, 2001). This can lead to the development of more robust, widely applicable standards and enhance the innovation potential of the group as a whole (Beck and Schenker-Wicki, 2013; Leiponen, 2008; Garcia-Vega, 2006).

In summary, this section defined consortia success as a combination of longevity and impact on standardisation outcomes, and identified size and diversity as key structural characteristics influencing this success. The mechanisms of network effects, complementary assets, and knowledge pooling provide a theoretical explanation of how these characteristics may affect performance. The following sections will build on this foundation by examining the specific theoretical expectations related to the effects of size and diversity on consortia success.

2.3. Size of consortia

The size of a consortium is a widely studied structural characteristic which in the literature has been defined mainly as the number of different member organisations or firms. Teubner et al. (2021) and Leiponen (2008) use the number of members as a key characteristic to categorise consortia into different groups, like large or small consortia. Also Pohlmann (2014) explicitly discusses "member quantity" and notes that most consortia have less than 100 participants, and finds that larger consortia tend to survive the longest. While the number of members is the most common definition of consortia size, there are other approaches like that of Weiss and Cargill (1992), which considers the economic scale or influence of the member firms as a dimension for a consortium's size or potential impact. This is because "the larger the net assets of the members of the consortium, the greater the impact of the consortium in the standards development process" (Weiss & Cargill, 1992). van den Ende et al. (2012) define the size in the context of standardisation networks (which include consortia) as the "number of companies that supported the standard". This definition focuses on the number of companies actively backing the standard, which could be broader than just the consortium members.

The focus of this thesis is on the effect of size on consortia's success, and for this, the literature provides different approaches, as was seen earlier. Based on the different definitions used, and on the scope of this research, the size is defined as the number of firms or organisations in a consortium which contribute to the development of the standards, as is widely done in the literature. This definition was chosen because it more accurately reflects the actors that actively shape the standardisation process, and therefore are more likely to influence the success of the consortium. Including only these members avoids inflating the size metric with passive or affiliate members who may not be directly involved in core technical or strategic activities

Size is most directly linked to two of the three theoretical mechanisms: network effects and knowledge/resource pooling. First, in relation to network effects, a larger consortium increases the potential installed base of the standard (den Hartigh et al., 2016; Weiss and Cargill, 1992; Soh, 2010). By including more firms, especially those with existing market presence, the consortium enhances the standard's perceived legitimacy and adoption potential (den Hartigh et al., 2016; Schilling, 2020). This contributes to both direct and indirect network effects, as a wide support base generates early user momentum, reinforcing positive feedback loops (van den Ende et al., 2012; Suarez, 2004; Van de Kaa et al., 2017).

Second, knowledge and resource pooling benefits significantly from size (Schilling, 2020; Beck and Schenker-Wicki, 2013; Afuah, 2013). Larger consortia typically have access to more diverse expertise, financial resources, and technical capabilities, which facilitates R&D collaboration and reduces the risks and costs associated with innovation (Leiponen, 2008; Schilling, 2020; Sakakibara, 2001). This greater capacity can also enable more consistent and professional management of standard development (Schilling, 2020).

The third mechanism, availability of complementary assets, is only indirectly related to size. While more members may collectively bring a wider variety of products and services, this depends heavily on the consortium's diversity. Size alone does not ensure complementarity unless the members operate across different domains (Beck & Schenker-Wicki, 2013).

Despite these advantages, large size introduces potential downsides that may hinder consortium effectiveness (Weiss and Cargill, 1992; Afuah, 2013; Schilling, 2020). As membership increases, coordination becomes more complex, with higher administrative overhead and greater effort required to manage interactions across multiple firms (Schilling, 2020; Pohlmann, 2014). Communication inefficiencies are likely to emerge as more actors participate in discussions and decision-making processes become slower and more fragmented (Pohlmann, 2014). Strategic misalignment and free-riding behaviours are also more prevalent in large consortia, where individual contributions may become less visible or influential (Weiss and Cargill, 1992; Wiegmann et al., 2022). Members may benefit from the outputs of the consortium without actively engaging or investing proportionally, reducing overall productivity and weakening group cohesion. Therefore, drawing on network effects theory, the value of a network can follow an inverted U-shape in relation to size, not a continuous positive correlation (Afuah, 2013; Schilling, 2020; Beck and Schenker-Wicki, 2013). Therefore, the effect of consortium size on success is likely non-linear, with benefits eventually being offset by increasing challenges. Therefore, this thesis proposes the following hypothesis:

Hypothesis 1: *"The effect of a consortium size on the success of the consortium follows an inverted-U shape"*

2.4. Diversity of consortia

Consortium diversity refers to the heterogeneity of its member organisations, and can be expressed in terms of industries, technologies, or organisational roles. In this study, diversity is defined as the industry variety among consortium members, which is widely considered a proxy for the range of knowledge, resources, and market perspectives available within the group (Soh, 2010; van den Ende et al., 2012; Sakakibara, 2001).

Diversity is most directly linked to two of the three theoretical mechanisms: complementary assets and knowledge pooling. First, in terms of the availability of complementary assets, diversity plays a critical role (van de Kaa et al., 2015; van den Ende et al., 2012). Members from different industries bring distinct but compatible products, services, or technologies that can reinforce the value of the developed standard (Sakakibara, 2001; van den Ende et al., 2012). This heterogeneity enables the formation of an ecosystem of complements that supports adoption and enhances market attractiveness (Gallagher and Park, 2002; van de Kaa et al., 2015; Soh, 2010). For example, a consortium involving firms from the hardware, software, and telecom sectors is well equipped to ensure a broad and interoperable standard.

Second, knowledge and resource pooling can also benefit from diversity (Schilling, 2020; Soh, 2010). Cross-industry participation introduces a wider array of expertise, perspectives, and innovation routines, potentially fostering knowledge recombination and creativity (Sakakibara, 2001; Beck and Schenker-Wicki, 2013; Garcia-Vega, 2006). Leiponen (2008) notes that heterogeneous consortia can generate novel solutions through the integration of diverse capabilities. While size contributes to knowledge pooling by increasing the overall volume of resources and expertise, diversity enhances the variety of knowledge domains and perspectives, making it more likely that novel or cross-disciplinary solutions emerge.

Diversity's role in network effects is more indirect. While it does not expand the installed base on its own, diversity can enhance the perceived relevance of a standard, increasing its legitimacy and appeal across sectors (van den Ende et al., 2012). This can make external actors more willing to adopt the standard, especially when they see their industry represented in the consortium.

However, these benefits come with significant risks. Diversity may also create coordination difficulties due to differing terminologies, priorities, and strategic goals (Wiegmann et al., 2022; Weiss and Cargill, 1992; Schilling, 2020). Conflicts may arise when members have incompatible incentives or unequal influence over the standard's direction. As Beck and Schenker-Wicki (2013) argue, high levels of diversity can make it more difficult for consortium members to develop a common understanding of goals and projects, potentially leading to lower group cohesion, increased decision-making complexity, and hindering consensus-building. In extreme cases, these tensions may lead to diluted or delayed outputs, especially when collaboration across domains is poorly managed (Weiss and Cargill, 1992; van den Ende et al., 2012).

Taken together, diversity can offer valuable advantages for standardisation, but only when the associated coordination challenges remain manageable. This implies a non-linear relationship, where moderate diversity maximises positive effects, and excessive diversity introduces diminishing returns or even harms performance. The following hypothesis is therefore proposed:

Hypothesis 2: *"The effect of a consortium diversity on the success of the consortium follows an inverted-U shape"*

Finally, beyond their individual effects, consortium size and diversity may also interact to influence success. While each can introduce coordination challenges when taken to an extreme, their combination may also generate synergies. A larger consortium may be better equipped to integrate diverse perspectives due to greater resources, management capacity, and formal structures (Soh, 2010; Teubner et al., 2021). Likewise, diversity may complement size by broadening the technological and market scope of the consortium, enabling more effective knowledge recombination and enhancing external legitimacy (Leiponen, 2008; van den Ende et al., 2012). This interaction could therefore lead to superior outcomes when both attributes are present at moderate to high levels, under the assumption that their benefits are mutually reinforcing rather than conflicting. Accordingly, the following hypothesis is formulated:

Hypothesis 3: *”The interaction between consortium size and diversity has a positive effect on the success of the consortium.”*

3 Data and Methodology

The global ICT sector is the empirical setting for this MSc thesis, a sector characterised by the presence of consortia and market-based standardisation. The data regarding consortia and their members are collected from the website ConsortiumInfo.org and LinkedIn, and analysed using multiple linear regression and negative binomial regression. Given the nature of the data, this study consists of a quantitative, empirical research employing observational data.

3.1. Data Sources

The data needed to test the hypotheses defined in chapter 2 are collected starting from ConsortiumInfo.org, which is a website hosted by Gesmer Updegrove LLP containing information on more than 1000 consortia. It provides a comprehensive list of consortia with details such as their industry and links to their website. This website has also been used in the past by other researchers in the same context, namely the ICT industry. (Baron et al., 2014; Baron and Pohlmann, 2013; Biddle et al., 2017; Pohlmann, 2014).

As part of a bigger project, data on 20 consortia have been gathered from this website and merged with an existing dataset to enrich the current one, creating a dataset with a total of 92 observations, which will be used for this study. The first step consists of filtering the list of consortia to obtain only those operating in the ICT sector. Next, 20 consortia were randomly selected, this is done to avoid selection bias and to ensure fairness and objectivity in the research. In case the needed information related to a consortium was not found, that specific consortium was eliminated from the set, and another one was randomly selected, this ensured that 20 new consortia could be added to the external dataset to properly enrich it. The information related to the consortia was gathered manually from their websites. These are the number and type of outputs, the members, and the year of establishment of the consortia. Collecting this information required carefully searching each consortium's website to identify which technical outputs should be recorded. The structure of the websites and the way outputs were classified varied significantly across consortia, adding an extra layer of complexity to this step of the data-gathering process. Once this step was completed, the information regarding every member of the consortium was collected from LinkedIn with the help of a Python script. The industry, size (in terms of employees), foundation year, and headquarter location are the information taken from the "About" section on the LinkedIn page of the single members. Gathering the members' information from the same source, namely LinkedIn, ensured that variables such as the industry of each company were collected from a consistent source, allowing for uniform classification across all entries. To ensure that the correct LinkedIn page was selected for each member of the various consortia, the list of company names used by the Python script was created by carefully verifying how each company was listed on LinkedIn. Although this step increased the time and effort required for the process, it was necessary to guarantee the accuracy of the automated data collection. It is important to highlight that LinkedIn classifies industries following the NAICS scheme, a standard classification approach adopted in the U.S. In conclusion, a dataset containing information on 92 consortia operating in the ICT industry constitutes the raw material for the analysis, which aims to draw inferences about the impact of consortia size and diversity on their success.

3.2. Dependent Variable: Consortium Success

The dependent variable of this study is the success of the consortia. This concept has been addressed in section 2.2, where it was highlighted how the relevant perspectives in this context are related to the ability to develop and promote standards and to their ability to survive for longer periods of time.

The literature suggests that if a consortium continues to exist, its efforts in developing and promoting a standard are likely ongoing and relevant, showing stability and effectiveness. For example, Kamps et al. (2017) focuses on the survival of consortia to measure the success of their standardisation efforts, using this quantity as a key indicator of performance. Also Pohlmann (2014), with a study on 435 consortia in the ICT sector, utilise survival rates to assess which consortia are successful and how their characteristics are linked to their termination. Therefore, longevity, intended as the number of years of activity, is chosen as the first measure of success.

The second approach to define success can be more difficult to operationalise compared to defining longevity with the number of years of activity. As stated above, success is also considered in terms of the ability to develop and promote standards or any of the heterogeneous outputs a consortium can produce (Kamps et al., 2017). Since the setting of this research is an environment where market-based standardization is central and standards often come out as de facto standards (Grillo et al., 2024; Wiegmann et al., 2017), considering the full body of supporting material the consortia produce is fundamental to not underestimating their activity (Pohlmann, 2014). The number of outputs produced can be a significant indicator of success because it often reflects the consortium's ability to fulfil its core objective of developing and promoting technical specifications (Kamps et al., 2017; Pohlmann, 2014; Baron et al., 2014). A broader output can better influence the market and the standard scenario and can also attract more members to the consortium, which, as seen before, is a measure of success. It follows that the number of outputs that a consortium has produced is the second measure for success (Kamps et al., 2017).

The number of activity years (longevity) of every consortium has been collected manually from their websites and registered in the dataset. Similarly, the number of outputs has been collected after analysing the consortia's websites. As mentioned before, if the information was not available in the sources, the consortium under examination was eliminated from the dataset, and another one was randomly selected from the list of consortia in the ICT sector.

Once the data had been collected and merged with the existing dataset to enrich it, a consistency check was performed. It was found that a few consortia were registered with an extremely high number of outputs, a value that appeared inconsistent with the newly gathered data. This discrepancy is believed to stem from a different definition of outputs used during the collection of the previous dataset. Output values around 10,000 or more were likely the result of counting every publication on a consortium's website, including blog posts and news articles, which do not contribute to the creation of standards. After careful inspection, 12 consortia with these extreme values were removed from the dataset. This decision was further supported by the fact that these observations would have been considered highly influential in the regression analyses presented in chapter 4, as indicated by a calculated Cook's Distance exceeding the commonly accepted threshold, as will be shown in section 3.5.

3.3. Independent Variables

As it was explained in chapter 2, the scope of this MSc thesis is to quantify the effect that a consortium's size and diversity have on its success. Therefore, the independent variables of interest are the consortia's size and diversity.

3.3.1. Consortium Size

Consortia can include a diverse range of members, spanning both the public and private sectors (Wiegmann et al., 2022). Many operate with tiered membership structures, offering different levels of rights and obligations (Teubner et al., 2021; Biddle et al., 2017; Wiegmann et al., 2022). While they generally aim to be inclusive of relevant market players, consortia often have the flexibility to define their own membership rules and restrict access to certain tiers or impose specific membership fees (Weiss and Cargill, 1992; Teubner et al., 2021). For the purpose of this study, only members who have control over the developed standards and technologies, or who hold voting rights in consortium decisions, are considered and counted to define the consortium's size.

Here as well, the data are gathered manually from the consortia's websites and inserted into the dataset. The size is therefore defined as the number of members with control over the developed standards or with voting rights in the consortium's decisions.

3.3.2. Consortium Diversity

The diversity of a consortium is defined based on the variety of its members' industries, as explained in section 2.4. To assess this, consortium-level information was first collected manually, and then the individual members' data were web scraped from LinkedIn using a Python script. This script, which uses the Selenium package, reads the previously created dataset, which includes the consortium name, number and type of outputs, and member names, and extracts the content found in the "About" section of each member's LinkedIn page. The script then augments the existing dataset with the newly gathered information. In total, data for 416 members were collected.

LinkedIn was chosen as the data source because it offers a consistent and centralised platform for gathering the necessary information, enabling a uniform classification of members' industries. The platform uses the North American Industry Classification System (NAICS), which is the standard employed by U.S. federal statistical agencies to classify businesses (NAICS Association, 2023). This system follows a three-tier hierarchical structure: the top level represents broad categories (e.g., "Professional Services"), the second level has more specific classifications (e.g., "IT Services and IT Consulting"), and the third level provides the most detailed classification available (e.g., "IT System Testing and Evaluation"). After collecting data for 416 members, 38 distinct industries were identified.

To calculate the level of diversity within a group, in this case a consortium, the Herfindahl-Hirschman Index (HHI) is applied. This index measures how concentrated or imbalanced a population is across different categories, which, for this study, corresponds to the industries represented by consortium members. Although HHI is most commonly used to assess market concentration and competitiveness in economics (Bromberg et al., 2024), it can also be applied in this context (Garcia-Vega, 2006; Kamps et al., 2017), where the focus is on industry concentration rather than market share. The HHI is calculated by summing the squares of the proportions of each group within the total population (Bromberg et al., 2024), using the following formula:

$$\mathrm{HHI} = \sum_{i=1}^{N} p_i^2$$

Where:

- p_i is the proportion of industry i
- N is the total number of industries in that consortium

Furthermore, to have a measure that is more intuitive, the diversity measure will be calculated as

$$Diversity = 1 - \mathrm{HHI}$$

This is to ensure that a very diverse group has a higher value for the diversity measure. This is simply a choice to make the measurement easier to grasp. For example, if there is a consortium with 4 members, 2 of which are in industry A, and the remaining 2 are in industry B and C, the HHI would be calculated as follows:

$$\mathrm{HHI} = 0.5^2 + 0.25^2 + 0.25^2 = 0.375$$

$$Diversity = 1 - \text{HHI} = 0.625$$

In this case, the maximum value would be 0.75 if there were 4 companies from 4 different industries, and the minimum would be 0 if all of them belonged to the same industry.

Since the consortia will not have the same number of members, it is important to use a normalised measure to be able to compare the diversity measure across them. In the scenario where consortia have different sizes, which is almost certain to be the case, the max value of HHI would be the same, namely 1, while the minimum would vary even if all the members belong to different industries. That is why a normalised version of the index is needed. The formula for the normalised HHI is the following:

$$\text{HHI}_{norm} = \frac{HHI - \frac{1}{N}}{1 - \frac{1}{N}}$$

Where N is the number of distinct industries in the consortium. Therefore, the diversity measure will be calculated as

$$Diversity = 1 - \text{HHI}_{norm}$$

3.4. Models

The models used to investigate the effects of the consortia's characteristics on their success are a multiple linear regression and a negative binomial regression model, both with quadratic terms and an interaction term, as shown below

$$\begin{aligned} Y_i = &\beta_0 + \beta_1 \text{Size}_i + \beta_2 \text{Size}_i^2 + \beta_3 \text{Diversity}_i + \beta_4 \text{Diversity}_i^2 + \beta_5 (\text{Size}_i \times \text{Diversity}_i) + \\ &+ \beta_6 \text{YearEstablished}_i + \beta_7 \text{InternalData}_i + \beta_8 \text{ICT}_i + \varepsilon_i \end{aligned} \tag{3.1}$$

Where Y_i is the success of consortium i, which is defined based on the number of outputs and the longevity as explained before in section 3.2. The quadratic terms $Size_i^2$ and $Diversity_i^2$ are included to capture the inverted-U shape. Regarding the interaction term $Size_i \times Diversity_i$, it is included to test whether the effect of one predictor depends on the level of the other one. For example, if β_5 is negative, it would indicate that the positive effect of size becomes weaker as the diversity increases, and vice versa. This dependency is also seen in the studies by den Hartigh et al. (2016), Soh (2010), Gallagher and Park (2002), and Kamps et al. (2017), among others, where the size and diversity of a network are not factors independent of each other in determining success. The model also includes control variables: the year in which the consortium was established (YearEstablished), whether the observation comes from the newly gathered data or from the previously existing dataset (InternalData), and whether the consortium operates strictly within the ICT sector (ICT), which is relevant as the previous dataset may include consortia from other sectors. It can happen that a consortium operates in a not-so-clearly defined area and, as a consequence, might be considered an ICT consortium. This control variable ensures that those assigned a value of 1 are clearly operating within the sector. *InternalData* and *ICT* are dummy variables, meaning they can only have a value of 1 or 0.

The appropriate regression model is selected based on the type of dependent variable. Multiple linear regression is used when the dependent variable is continuous, while negative binomial regression is more suitable for count variables with only positive values. The first model is run with $Y = Success$, a composite index that combines both productivity (number of outputs) and longevity, as shown in Equation 3.3. Given the continuous nature of this variable, multiple linear regression is used to test the hypotheses and assess the effects of size and diversity. Subsequently, the regression is run with $Y = Longevity$ and $Y = Outputs$ to analyse the impact of the independent variables on the two components of success separately. Since these are count variables, negative binomial regression is the appropriate method. This approach ensures that the effects of the predictors are examined not only on the individual success metrics but also on the composite measure.

The combined *Success* measure is built in the following way: it standardises the number of outputs and longevity using z-scores and computes their average.

$$\text{Success}_i = \frac{Z_{\text{Outputs},i} + Z_{\text{Longevity},i}}{2} \tag{3.2}$$

Where the Z-scores are calculated as follows

$$Z_{\text{Outputs},i} = \frac{\text{Outputs}_i - \overline{\text{Outputs}}}{\text{SD}_{\text{Outputs}}} \tag{3.3}$$

And the same is done for $Z_{Longevity}$

This approach ensures that both dimensions contribute equally to the final metric, despite being measured on different scales, and therefore allows for comparison across consortia. This composite success measure reflects the idea that an effective consortium should not only produce results but also sustain operations over time.

3.5. Steps before regressions

Before running the regressions and studying the results, some key steps have been implemented. The first consisted of checking for outliers based on Cook's Distance, a metric telling how much influence a data point has on the regression model. This quantity combines two things: the so-called leverage, which represents how far an observation's X values are from the mean, and the residual, which indicates how far its Y prediction is from the true value. The entries that had a Cook's Distance (D) higher than a certain threshold were removed from the dataset. The common threshold adopted by scholars is $D > \frac{4}{n}$, where n is the sample size, in this case 92. Therefore, values that had a $D_i > 0.043$ were flagged as outliers and were inspected to assess whether they could still be considered as valid observations or not. It was found that these outliers were consortia with extremely high values for *Outputs* and, as previously explained, they were consequently removed from the dataset. A total of 12 observations were removed, resulting in a new dataset with 80 entries.

After dealing with outliers, the independent variables *Size* and *Diversity* were standardised to enable comparability between coefficients and to address potential multicollinearity, especially when including squared and interaction terms. Following these preparatory steps, three sets of regressions were run for each dependent variable, *Success*, *Outputs*, and *Longevity*, and the assumptions needed to ensure a reliable regression are checked. The following are checked for OLS regression:

- Homoscedasticity: the variance of the errors should be constant for all values of the predictor
- Normality of errors: the residuals should be normally distributed around the regression line
- No Multicollinearity: the predictors should not be highly correlated with each other

After running the regression on *Success* using OLS methods, it was found that the homoscedasticity and multicollinearity assumptions were met, while the other assumption was violated. To deal with the Normality of errors, the model was redefined using robust standard errors, which adjust the standard errors to remain reliable even when residuals are non-normally distributed or heteroscedastic (Ford, 2020).

Regarding the regressions run on *Outputs* and *Longevity*, different checks were required due to the use of negative binomial regression. As with the previous models, multicollinearity among the predictors was examined, and it was found that the assumption was not violated for any of them. Another crucial check was performed on the overdispersion of the dependent variables, a fundamental condition for the use of negative binomial regression. This check confirmed that the adoption of this method was appropriate.

After these steps have been implemented, the regressions were run on the newly defined models, and the results were studied to make inferences on the effects of size and diversity on the consortia's success. The results of this analysis are presented in the following chapter.

4

Analysis and Results

This chapter presents the result of the statistical tests run with the scope of testing the hypotheses defined in chapter 2 and making inferences on the effect of consortia composition on their success.

Descriptive statistics and bivariate correlations for all study variables are presented in Table 4.1. The means, standard deviations, minimum and maximum values indicate a broad range of consortium characteristics. Specifically, Longevity ranged from 0 to 136 years ($M = 23.01$, $SD = 26.37$), and Outputs ranged from 0 to 6,630 ($M = 687.35$, $SD = 1{,}388.36$), demonstrating considerable variation across consortia. The composite success measure, created by standardising and averaging longevity and outputs, was centred around zero ($M = 0.00$, $SD = 0.68$), reflecting the standardisation procedure. Both independent variables, Size and Diversity, were standardised, and therefore have ($M = 0.00$, $SD = 1.00$).

Several key patterns emerged from the correlation matrix. First, Success correlated positively and strongly with both Longevity ($r = 0.68$, $p < .01$) and Outputs ($r = 0.68$, $p < .01$), validating the appropriateness of combining these two dimensions into a composite measure. Regarding the independent variables, Size showed a small but significant positive correlation with Longevity ($r = 0.22$, $p < .05$), suggesting that larger consortia tend to survive longer. However, Size was not significantly correlated with Outputs or Success. Diversity correlated negatively, though modestly, with Success ($r = –0.21$, $p < .10$), indicating that greater diversity may be associated with lower success, although this relationship is only marginally significant. Diversity was not significantly correlated with Longevity or Outputs individually.

Among the control variables, YearEstablished (the year when the consortium was established) showed strong negative correlations with Longevity ($r = –0.99$, $p < .01$) and Success ($r = –0.69$, $p < .01$), as expected, since younger consortia had shorter lifespans and lower accumulated outputs.

Thus, the initial correlation analysis provides some preliminary support for a positive relationship between Size and Longevity, but limited support for Diversity's expected role. However, these bivariate correlations do not account for potential curvilinear (inverted-U) effects or interactions, which are explicitly tested in the regression analyses that follow.

To test Hypothesis 1 (that size has an inverted-U effect on success) and Hypothesis 2 (that diversity has an inverted-U effect on success), a multiple linear regression model was conducted using a standardised composite measure of Success (average z-scores of Longevity and Outputs). Additional negative bivariate regressions examined the two components, Longevity and Outputs, individually to investigate where significant effects may be concentrated.

4.1. Results on Combined Success

Ordinary least squares (OLS) regressions were conducted to examine the relationship between the consortia's size and diversity, and their overall success, measured as a composite metric of Longevity and Outputs. The analysis was carried out sequentially across three models: Model 1 included only control variables, Model 2 added linear and quadratic terms for Size and Diversity, and Model 3 further introduced their interaction term. The results of this regression are presented in Table 4.2.

Model 1, containing only YearEstablished, InternalData, and ICT as controls, explained a substantial portion of the variance in Success ($R^2 = .520$, Adj. $R^2 = .501$). In Model 2, the standardised Size and Diversity variables, along with their squared terms, were added. This led to a slight increase in explained variance ($R^2 = .537$, $\Delta R^2 \approx 0.017$), but none of the new predictors achieved statistical significance. The coefficients for Size ($\beta = -0.10$, p = .435) and Size_sq ($\beta = 0.04$, p = .500) were both non-significant, providing no evidence of either a linear or curvilinear (inverted-U) effect of Size on Success. Similarly, Diversity ($\beta = -0.20$, p = .152) and Diversity_sq ($\beta = -0.12$, p = .234) were not significant, suggesting that Diversity also did not have a meaningful linear or quadratic relationship with Success at this stage. Model 3 introduced the interaction term between Size and Diversity. Although the R^2 value increased slightly to .547 ($\Delta R^2 \approx 0.010$), the interaction term Interaction ($\beta = -0.07$, p = .519) was not statistically significant. This indicates that the combined effect of Size and Diversity does not significantly predict changes in Success. Notably, Diversity approached marginal significance in Model 3 ($\beta = -0.24$, p = .092), suggesting a weak trend where greater diversity might be associated with slightly lower levels of Success. However, this effect remains statistically marginal and cannot be interpreted as definitive support for a curvilinear relationship.

Based on these results, Hypothesis 1, which proposed an inverted-U shaped relationship between Size and Success, is not supported, as neither the linear nor the quadratic terms for Size were significant. Similarly, Hypothesis 2, proposing an inverted-U relationship between Diversity and Success, is not supported, since Diversity did not show a significant curvilinear effect, and the marginally significant linear trend observed was negative rather than inverted-U shaped. The interaction between Size and Diversity was also not significant.

Table 4.1: Descriptive Statistics and Correlations

Variable	**MIN**	**MAX**	**M**	**SD**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Longevity	0.00	136.00	23.01	26.37	-							
2. Outputs	0.00	6630.00	687.35	1388.36	-0.08	-						
3. Success	-0.66	2.07	-0.00	0.68	0.68**	0.68**	-					
4. Size	-1.12	2.89	0.00	1.00	0.22*	-0.13	0.07	-				
5. Diversity	-2.27	0.83	-0.00	1.00	-0.17	-0.12	-0.21†	-0.14	-			
6. YearEstablished	1889	2024	1999.78	25.25	-0.99**	0.05	-0.69**	-0.21†	0.19†	-		
7. InternalData	0.00	1.00	0.25	0.44	-0.13	-0.27*	-0.29**	0.34**	0.24*	0.16	-	
8. ICT	0.00	1.00	0.54	0.50	-0.24*	-0.21†	-0.34**	0.07	0.30**	0.23*	0.54**	-

Note. Size and Diversity have been standardised.
*$p < .05$, **$p < .01$, $^{\dagger}p < .10$.

Table 4.2: Regression Results Predicting Success as Combined Measure of Longevity and Outputs

Variable	Model 1	Model 2	Model 3
(Intercept)	34.51 (3.19)**	36.50 (3.31)**	35.88 (5.16)**
YearEstablished	-0.02 (0.00)**	-0.02 (0.00)**	-0.02 (0.00)**
InternalData	-0.20 (0.10)*	-0.12 (0.10)	-0.08 (0.10)
ICT	-0.16 (0.15)	-0.21 (0.16)	-0.21 (0.16)
Size		-0.10 (0.13)	-0.12 (0.12)
Size_sq		0.04 (0.06)	0.04 (0.06)
Diversity		-0.20 (0.14)	-0.24 (0.14)†
Diversity_sq		-0.12 (0.10)	-0.14 (0.10)
Interaction			-0.07 (0.11)
R^2	0.520	0.537	0.547
ΔR^2	–	–	0.010
F	89.40**	33.55**	25.62**
n	80	80	80

Note. Standard errors in parentheses.
** $p < .01$, * $p < .05$, † $p < .10$

4.2. Results on Longevity

The effect of Size and Diversity on the Longevity of consortia have been tested with negative binomial regressions. Again, three models were tested as before, first with only the controls, then with the main independent variables, and lastly with the interaction term as well. The results are shown in Table 4.3.

Model 1, containing only the controls, explained a substantial proportion of variance in Longevity (Pseudo $R^2 = .473$). Model 2 introduced the linear and quadratic terms for Size and Diversity. The addition of these predictors led to only a slight increase in the model's explanatory power (Pseudo $R^2 = .479$, ΔPseudo $R^2 \approx 0.006$). None of the new predictors was statistically significant. The coefficients for Size ($\beta = 0.12$, p = .590) and Size_sq ($\beta = -0.05$, p = .704) were non-significant, providing no evidence of either a linear or a curvilinear relationship between Size and Longevity. Similarly, Diversity ($\beta = 0.19$, p = .493) and Diversity_sq ($\beta = 0.06$, p = .735) were not significant, suggesting that Diversity also did not meaningfully predict longevity. Model 3, as before, added the interaction term Interaction. The overall model fit improved slightly again (Pseudo $R^2 = .485$), but the interaction was not statistically significant ($\beta = 0.12$, p = .306).

Based on these results, Hypothesis 1 is not supported, as neither the linear nor the quadratic terms for Size reached significance. Similarly, Hypothesis 2, about the relationship between Diversity and Longevity, is not supported, since Diversity and its squared term were both non-significant. In this regression as well, the interaction between Size and Diversity was also not statistically significant.

Table 4.3: Negative Binomial Regression Results Predicting Longevity

Variable	Model 1	Model 2	Model 3
(Intercept)	63.35 (9.25)**	63.28 (10.07)**	63.82 (10.15)**
YearEstablished	-0.03 (0.00)**	-0.03 (0.01)**	-0.03 (0.01)**
InternalData	0.11 (0.32)	-0.02 (0.36)	-0.10 (0.36)
ICT	-0.12 (0.28)	-0.11 (0.29)	-0.11 (0.29)
Size		0.12 (0.23)	0.16 (0.23)
Size_sq		-0.05 (0.12)	-0.06 (0.12)
Diversity		0.19 (0.28)	0.27 (0.28)
Diversity_sq		0.06 (0.17)	0.10 (0.17)
Interaction			0.12 (0.12)
Pseudo R^2	0.473	0.479	0.485
Log-Likelihood	-307.00	-306.54	-306.07
n	80	80	80

Note. Standard errors in parentheses.
** $p < .01$, * $p < .05$, † $p < .10$

4.3. Results on Outputs

The same approach as for the regression on Longevity is followed for the one on Outputs, namely a negative binomial regression with the 3 sequential models.

In Model 2, the standardised Size and Diversity variables, along with their squared terms, were introduced. The addition of these predictors improved the model fit slightly from that of Model 1 (Pseudo R^2 = .698, ΔPseudo $R^2 \approx 0.054$). Among the predictors, Size (β = –0.45, p = .040) was significant and negative, while Size_sq (β = 0.23, p = .056) approached significance, suggesting a possible curvilinear pattern. Diversity (β = –1.05, p < .01) and Diversity_sq (β = –0.57, p < .01) were both statistically significant, but the negative sign of the squared term indicated a monotonically decreasing relationship, rather than the expected inverted-U. Model 3 introduced the interaction term between Size and Diversity. With this addition, the model's explanatory power further improved (Pseudo R^2 = .711). The interaction term Interaction (β = –0.29, p = .011) was statistically significant and negative, indicating that the combined effects of Size and Diversity influence output levels, although not necessarily in a simple curvilinear or synergistic way. Notably, in this model, Size (β = –0.65, p < .01), Size_sq (β = 0.28, p < .05), Diversity (β = –1.30, p < .01), and Diversity_sq (β = –0.69, p < .01) all remained statistically significant.

Taken together, these findings show partial deviations from the hypothesised patterns. Hypothesis 1, predicting an inverted-U shaped relationship between Size and Outputs, is not supported. Although Size and its squared term were both significant in Model 3, the pattern did not conform to a clear inverted-U shape, and the negative linear coefficient suggests that larger consortia tended to produce fewer outputs initially, rather than reaching an optimal point. Similarly, Hypothesis 2, proposing an inverted-U relationship between Diversity and Outputs, is not supported. Diversity exhibited a significant negative effect both linearly and quadratically, implying a consistent decline in Outputs as Diversity increased, rather than the expected curvilinear pattern. Finally, the significant interaction between Size and Diversity indicates that their combined effect influences output production. However, this interaction reflects a compounding negative effect rather than the balanced or optimal relationship originally hypothesised.

Table 4.4: Negative Binomial Regression Results Predicting Outputs

Variable	Model 1	Model 2	Model 3
(Intercept)	11.37 (9.16)	24.16 (9.94)*	11.99 (9.99)
YearEstablished	-0.00 (0.01)	-0.01 (0.01)	-0.00 (0.01)
InternalData	-2.97 (0.31)**	-2.60 (0.35)**	-2.14 (0.35)**
ICT	-0.31 (0.27)	-0.61 (0.28)*	-0.55 (0.28)†
Size		-0.45 (0.22)*	-0.65 (0.22)**
Size_sq		0.23 (0.12)†	0.28 (0.12)*
Diversity		-1.05 (0.27)**	-1.30 (0.28)**
Diversity_sq		-0.57 (0.16)**	-0.69 (0.16)**
Interaction			-0.29 (0.12)*
Pseudo R^2	0.644	0.698	0.711
Log-Likelihood	-561.35	-554.73	-553.00
n	80	80	80

Note. Standard errors in parentheses.
** $p < .01$, * $p < .05$, † $p < .10$

The predicted curves shown in Figure 4.1 illustrate the relationship between standardised Size and Diversity and the number of outputs produced by consortia, based on the full Negative Binomial regression model. Since the independent variables are standardised (mean = 0, standard deviation = 1), a one-unit change in Size or Diversity corresponds to a one standard deviation change in the original variable. Although the regression estimates are based on the logarithm of the expected number of outputs, the predicted values shown in the plots are back-transformed to the original Outputs scale. Therefore, both the observed data points and the fitted prediction curves are displayed in terms of the actual number of outputs rather than their logarithm. In the first graph, as standardised Size increases, the predicted number of outputs initially declines and then slightly bends upward at very large Size values, indicating a minor U-shaped pattern, although the general trend remains negative. In the second graph, standardised Diversity shows a very small increase at low diversity levels, followed by a strong and consistent decline as Diversity increases. Overall, these plots suggest that higher Size and higher Diversity are associated with lower expected outputs, with no evidence of an inverted-U shaped relationship for either variable.

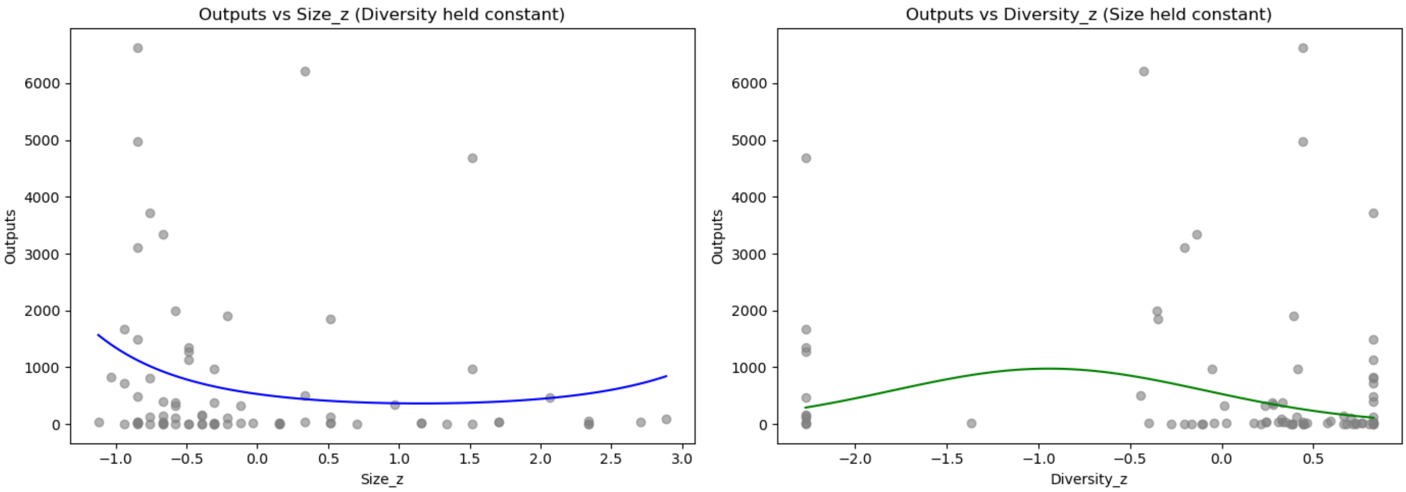

Figure 4.1: Fitted curve of regression on Outputs

4.4. Analysis Takeaways

In summary, the analyses provided no support for the proposed hypotheses regarding the curvilinear effects of consortium size and diversity on success. When success was examined as a standardised composite measure combining longevity and outputs, neither Size nor Diversity, nor their squared or interaction terms, emerged as significant predictors. Similarly, when success was disaggregated into longevity and outputs, the hypothesised inverted-U shaped relationships were not supported. For longevity, none of the predictors showed significant effects, and no curvilinear patterns were detected. In the case of outputs, Size, Diversity, and their interaction were significant predictors, but the direction of effects differed from expectations. Specifically, higher Size was associated with a decrease in output production, although the positive sign of the quadratic term suggests a slight flattening at very large sizes. Higher Diversity was strongly associated with lower outputs, and the negative quadratic term indicated that this declining trend accelerated as Diversity increased. Moreover, the significant negative interaction between Size and Diversity suggests that consortia that are both large and diverse tend to experience even greater reductions in output production. This finding corresponds to Hypothesis 3, which expected a positive interaction between size and diversity. Although the hypothesis is not supported, the significant negative result reveals that structural complexity may become particularly problematic when both size and diversity are high. Overall, these findings suggest that while consortium structure does influence certain aspects of performance, the nature of these effects is not curvilinear as originally hypothesised. Instead, the results point to a more complex, generally negative relationship between structural complexity and productivity, highlighting the need for further research to clarify these dynamics.

These results are summarised in Table 4.5, where it is indicated which hypotheses were rejected related to the dependent variables and the statistical tools used. The colour red indicates that the hypothesis is rejected and that no statistically significant predictors were found. The orange colour indicates that even if the hypothesis is rejected, statistically significant predictors allow for new inferences to be made regarding their effects on the success measure. These inferences and discussions will be presented in chapter 5.

Table 4.5: Summary of Hypotheses Testing Across Dependent Variables

Dependent Variable	**Success**	**Longevity**	**Outputs**
Hypothesis 1	**Rejected**	**Rejected**	**New Implications**
Hypothesis 2	**Rejected**	**Rejected**	**New Implications**
Hypothesis 3	**Rejected**	**Rejected**	**New Implications**
Method	**OLS**	**NBR**	**NBR**

OLS = Ordinary Least Square
NBR = Negative Binomial Regression

5

Discussion & Conclusions

This study wants to empirically investigate how the composition of standard-developing consortia influences their success in the ICT sector. In particular, after studying the literature, it was highlighted how the size and diversity of consortia are among the most important determinants of their success. This led to the development of the research question for this MSc thesis, which is the following: *To what extent do the size and diversity of standard developing consortia have an effect on consortia's success?*

Success was operationalised both as a composite measure (standardised combination of longevity and outputs) and as its two components separately. The size has been intended as the number of member companies which can take part in the decision process, while diversity was measured with respect to the concentration of diverse industries in a consortium. Based on theoretical mechanisms such as resource pooling, network effects, and the availability of complementary assets, the study tested three central hypotheses proposing that the effects of size and diversity on success follow an inverted-U shape.

To test these hypotheses and answer the research question, empirical data on 92 consortia have been gathered both manually and with the help of a web scraping code written in Python. Those data have then been used to run regressions, which gave the following results. When success was considered in its combined, standardised form, neither consortium size nor diversity, nor their squared terms or interaction, were significant predictors. This suggests that no clear curvilinear or linear effect of these structural features can be detected when longevity and productivity are aggregated. Consequently, Hypothesis 1 and Hypothesis 2 were not supported for the composite success measure.

However, disaggregating the components of success revealed additional insights. In the model predicting longevity, no statistically significant relationships with either size or diversity were found. Thus, Hypothesis 1 and Hypothesis 2 remained unsupported in this context. Conversely, in the model predicting outputs, both size and diversity exhibited significant negative effects, with an additional significant negative interaction between them. This indicates that larger and more diverse consortia tend to produce fewer outputs, and that the combination of high size and high diversity further exacerbates this effect. This finding directly relates to Hypothesis 3, which proposed a positive interaction between size and diversity. However, the result contradicts this expectation, suggesting that the complexity introduced by combining these two structural features may hinder, rather than enhance, productivity. Nevertheless, no evidence was found supporting the hypothesised inverted-U shaped relationships, leading to the rejection of both hypotheses for the output dimension as well.

5.1. Implications for the Theory

The findings of this thesis have several implications for the theoretical understanding of how consortium size and diversity influence standardisation outcomes. While the theoretical framework in chapter 2, based on mechanisms such as network effects, availability of complementary assets, and knowledge pooling, suggests that these structural characteristics can enhance success up to a point (Beck and Schenker-Wicki, 2013; van de Kaa et al., 2015; Soh, 2010), the empirical results of this study provide a more nuanced perspective that calls for refinement of existing models.

First, the absence of support for the hypothesised inverted-U shaped relationships challenges a key assumption found in much of the literature: that the benefits of increased size and diversity are eventually offset by coordination costs and strategic misalignment (Afuah, 2013; Schilling, 2020). While this trade-off has been conceptually supported, particularly in studies highlighting tensions within heterogeneous groups (Beck & Schenker-Wicki, 2013), the results of this thesis do not reveal the expected curvilinear effects. Instead, size and diversity, particularly when combined, are associated with consistent declines in output productivity. This suggests that coordination costs may emerge earlier or more strongly than previously theorised, and that the positive effects of structural scale and heterogeneity are not as universally robust as often assumed.

Second, the significant negative interaction between size and diversity offers empirical grounding for concerns raised in the literature regarding internal complexity. Studies such as those by Wiegmann et al. (2022) and Weiss and Cargill (1992) warn that large and diverse consortia may suffer from fragmented goals, reduced cohesion, and administrative inefficiencies. The findings of this thesis empirically confirm that these factors may indeed interact to further reduce effectiveness, particularly in producing technical deliverables. As a result, theoretical models should more explicitly consider interdependencies between structural variables, rather than treating size and diversity as independent inputs into consortium success.

Third, these findings question the strength of the assumed link between structural composition and the three core mechanisms discussed in chapter 2, network effects, availability of complementary assets, and knowledge pooling. While the literature proposes that larger and more diverse consortia can strengthen all three (Leiponen, 2008; Soh, 2010), the observed negative effects on output suggest that these mechanisms may not automatically materialise in structurally complex consortia. This points to a need for theory to better account for the conditions under which these mechanisms are enabled or inhibited, such as effective governance, goal alignment, or trust among members (Schilling, 2020; Sakakibara, 2001).

Finally, the findings also imply that structure-based explanations alone are insufficient to predict consortium success. While past research has focused on measurable attributes like number of members or industry representation, this study suggests that the absence of structural effects on longevity and the negative effects on productivity highlight the likely importance of processual and contextual factors. These may include leadership structure, internal decision-making procedures, or the role of dominant actors within the consortium, factors that have been suggested but not yet fully integrated into existing models (Jakobs, 2017; Blind and Gauch, 2008).

In sum, this thesis contributes to the theoretical literature by reinforcing the idea that consortium success is not determined by structural features alone, and by empirically validating concerns about the coordination burdens of complexity raised in earlier conceptual work. Future theory development should build on these insights by incorporating mediating variables such as governance effectiveness, member engagement, and task design to better explain when and how size and diversity contribute to successful standardisation outcomes.

5.2. Practical Implications

The results of this study also offer relevant practical implications for industry professionals and firms participating in standard-setting activities. While the literature often presents large and diverse consortia as potentially advantageous due to resource richness and broader market appeal, the empirical findings of this thesis suggest that such structural features can hinder productivity, particularly in terms of output generation. This highlights the need for more strategic decision-making in the formation and management of consortia.

For practitioners involved in designing or joining consortia, these results suggest that more is not always better. Simply increasing the number of participating firms or expanding the diversity of industry backgrounds may not lead to better performance. Instead, attention should be paid to the coordination mechanisms, decision-making structures, and goal alignment within the consortium. Firms should carefully evaluate whether the potential benefits of a broad coalition outweigh the added complexity, particularly when the consortium's primary objective is to efficiently produce technical deliverables.

Additionally, these findings encourage firms to consider alternative ways to access complementary assets and knowledge without necessarily expanding the size or diversity of the formal consortium. For example, firms may benefit from creating strategic subgroups or working committees focused on specific outputs, which could retain the benefits of diversity while minimising coordination costs. Furthermore, the observed negative interaction between size and diversity suggests that when both factors are high, extra attention must be paid to governance processes, conflict resolution mechanisms, and clarity of roles and responsibilities.

Overall, these insights can inform both the formation phase of a new consortium and the ongoing management of existing ones. By moving beyond assumptions of scale-based advantage and instead focusing on organisational design and internal dynamics, consortia may be better positioned to achieve their standardisation objectives.

5.3. Strengths, Limitations, and Future Work

This section reflects on the methodological strengths of the study and outlines the key limitations that may affect the interpretation of its findings. It also highlights opportunities for future research that could build on this work to further improve our understanding of how consortium characteristics influence success in ICT standardisation.

Despite its constraints, this study presents several strengths that reinforce the reliability and generalisability of its findings. First, the research is based on a systematic and transparent data collection process. The use of a consistent source, LinkedIn, for collecting member-level data ensured uniform classification of industries according to the NAICS standard. This approach enhances the comparability and replicability of the diversity measure used in the analysis.

Second, the sample includes a diverse set of ICT consortia, selected randomly to avoid selection bias. The subsequent filtering of outliers based on objective statistical criteria further contributes to the validity of the dataset. These steps support the cautious generalisation of the findings to the broader population of ICT standardisation consortia.

Third, the study employed appropriate statistical methods aligned with the nature of the dependent variables. The use of both linear and negative binomial regression models, as well as standard diagnostic tests, contributes to the internal consistency and robustness of the results.

Together, these strengths provide a solid methodological foundation for the empirical insights developed in this thesis. At the same time, several limitations must be acknowledged, which also offer valuable directions for future research aiming to deepen the understanding of how consortium characteristics influence performance in the context of standardisation.

The first limitation relates to the scope of the model. Although size and diversity were the primary variables of interest, other factors, such as member commitment, technological maturity, or organisational legitimacy, are also likely to influence success. Including such variables as controls would enhance the explanatory power of the model and allow for a more accurate estimation of the independent effects of size and diversity. Future research should therefore seek to integrate additional organisational and contextual variables into a more comprehensive model.

A second limitation concerns the sample. The analysis was based on a dataset of 92 consortia, reduced to 80 after removing outliers. While sufficient for preliminary insights, a larger sample would improve the generalisability of the findings and enable exploration of more complex interaction effects or sector-specific dynamics. Furthermore, the study focused on consortia operating within the ICT sector. Although this is a highly relevant setting for research on market-based standardisation, the results may not fully extend to other sectors where institutional dynamics differ.

A third limitation lies in the operationalisation of success. Longevity and number of outputs are objective and quantifiable, but may not capture all relevant dimensions of performance. Alternative indicators, such as standard adoption rates, market penetration, or influence in regulatory or policy environments, could provide a more strategic or system-level view of success. Future research could benefit from including such measures to develop a more holistic understanding of consortium effectiveness.

Lastly, the operationalisation of diversity presents a methodological limitation. In this study, diversity was measured using a Herfindahl-Hirschman Index based on industry classifications. However, this approach treats all industries as equally distinct, ignoring the actual "distance" between them. For example, "Software Development" and "IT Services" are likely more similar than "Software Development" and "Healthcare." Future work could address this by leveraging the hierarchical structure of the NAICS classification to compute distance-based diversity metrics that better reflect the cognitive or technological spread within consortia.

References

Afuah, A. (2013). Are network effects really all about size? The role of structure and conduct. *Strategic Management Journal*, *34*(3), 257–273. https://doi.org/10.1002/smj.2013

Anderson, P., & Tushman, M. L. (1990). Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change. *Administrative Science Quarterly*, *35*(4), 604. https://doi.org/10.2307/2393511

Banton, C., Mansa, J., & Ecker, J. (2024, August). What Is the Network Effect? https://www.investopedia.com/terms/n/network-effect.asp

Baron, J., & Pohlmann, T. (2013). WHO COOPERATES IN STANDARDS CONSORTIA–RIVALS OR COMPLEMENTORS? *Journal of Competition Law and Economics*, *9*(4), 905–929. https://doi.org/10.1093/joclec/nht034

Baron, J., Ménière, Y., & Pohlmann, T. (2014). Standards, consortia, and innovation. *International Journal of Industrial Organization*, *36*, 22–35. https://doi.org/10.1016/j.ijindorg.2014.05.004

Beck, M., & Schenker-Wicki, A. (2013). *UZH Business Working Paper Series Cooperating with external partners: The importance of diversity for innovation performance.* http://ssrn.com/abstract=2228015http://www.business.uzh.ch/forschung/wps.html

Bhatt, P., Vishik, C., Hariharan, G., & Rao, H. R. (2021). TO PARTICIPATE OR NOT TO PARTICIPATE: AN INVESTIGATION OF STRATEGIC PARTICIPATION IN STANDARDS. *11th International Conference on Standardisation and Innovation in Information Technology (SIIT) - The Past, Present and Future of ICT Standardisation.* https://arxiv.org/pdf/2204.03055

Biddle, B., Curci, F. X., Haslach, T. F., Marchant, G. E., Askland, A., & Gaudet, L. (2017). the Expanding Role and Importance of Standards in the Information and Communications Technology Industry. *Jurimetrics*, (52).

Blind, K., & Gauch, S. (2008). Trends in ICT standards: The relationship between European standardisation bodies and standards consortia. *Telecommunications Policy*, *32*(7), 503–513. https://doi.org/10.1016/j.telpol.2008.05.004

Brem, A., Nylund, P. A., & Schuster, G. (2016). Innovation and de facto standardization: The influence of dominant design on innovative performance, radical innovation, and process innovation. *Technovation*, *50-51*, 79–88. https://doi.org/10.1016/j.technovation.2015.11.002

Bromberg, M., Drury, A., & Velasquez, V. (2024, June). Herfindahl-Hirschman Index (HHI): Definition, Formula, and Example. https://www.investopedia.com/terms/h/hhi.asp

David, P. A., & Greenstein, S. (1990). The Economics Of Compatibility Standards: An Introduction To Recent Research ¹. *Economics of Innovation and New Technology*, *1*(1-2), 3–41. https://doi.org/10.1080/10438599000000002

den Hartigh, E., Ortt, J. R., van de Kaa, G., & Stolwijk, C. C. (2016). Platform control during battles for market dominance: The case of Apple versus IBM in the early personal computer industry. *Technovation*, *48-49*, 4–12. https://doi.org/10.1016/j.technovation.2015.12.001

Ehrhardt, M. (2004). Network effects, standardisation and competitive strategy: how companies influence the emergence of dominant designs. *International Journal of Technology Management*, *27*(2/3), 272. https://doi.org/10.1504/IJTM.2004.003956

Ford, C. (2020, September). Understanding Robust Standard Errors.

Gallagher, S., & Park, S. H. (2002). Innovation and competition in standard-based industries: a historical analysis of the US home video game market. *IEEE Transactions on Engineering Management*, *49*(1), 67–82. https://doi.org/10.1109/17.985749

Garcia-Vega, M. (2006). Does technological diversification promote innovation? *Research Policy*, *35*(2), 230–246. https://doi.org/10.1016/j.respol.2005.09.006

Grillo, F., Wiegmann, P. M., de Vries, H. J., Bekkers, R., Tasselli, S., Yousefi, A., & van de Kaa, G. (2024). Standardization: Research Trends, Current Debates, and Interdisciplinarity. *Academy of Management Annals*, *18*(2), 788–830. https://doi.org/10.5465/annals.2023.0072

ISO. (2021). *Standards & economic growth: ISO members' research on the impact of standards on their national economies* (tech. rep.). International Organization for Standardization. https://library.iso.org/contents/data/standards--economic-growth-iso-m.html

Jakobs, K. (2017). Two dimensions of success in ICT standardization—A review. *ICT Express*, *3*(2), 85–89. https://doi.org/10.1016/j.icte.2017.05.008

Kamps, X., de Vries, H., & van de Kaa, G. (2017). Exploring standards consortium survival in high tech industries: The effects of commitment and internal competition. *Computer Standards & Interfaces*, *52*, 105–113. https://doi.org/10.1016/j.csi.2017.02.002

Kim, K., Jung, S., Hwang, J., & Hong, A. (2018). A dynamic framework for analyzing technology standardisation using network analysis and game theory. *Technology Analysis & Strategic Management*, *30*(5), 540–555. https://doi.org/10.1080/09537325.2017.1340639

Leiponen, A. E. (2008). Competing Through Cooperation: The Organization of Standard Setting in Wireless Telecommunications. *Management Science*, *54*(11), 1904–1919. https://doi.org/10.1287/mnsc.1080.0912

Lyytinen & King. (2006). Standard Making: A Critical Research Frontier for Information Systems Research. *MIS Quarterly*, *30*, 405. https://doi.org/10.2307/25148766

Mannak, R. S., Markus, A., Meeus, M. T., Raab, J., & Smit, A. C. (2023). Network dynamics and its impact on innovation outcomes: R&D consortia in the Dutch water sector. *Social Networks*, *74*, 62–70. https://doi.org/10.1016/j.socnet.2023.02.004

Murmann, J. P., & Frenken, K. (2006). Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. *Research Policy*, *35*(7), 925–952. https://doi.org/10.1016/j.respol.2006.04.011

NAICS Association. (2023). NAICS Code & SIC Identification Tools. https://www.naics.com/search/

Papachristos, G., & van de Kaa, G. (2021). A System Dynamics Model of Standards Competition. *IEEE Transactions on Engineering Management*, *68*(1), 18–32. https://doi.org/10.1109/TEM.2020.2983352

Pohlmann, T. (2014). The Evolution of ICT Standards Consortia. *The DigiWorld Economic Journal*, *3rd Q.*(95).

Sakakibara, M. (2001). The Diversity of R&D Consortia and Firm Behavior: Evidence from Japanese Data. *The Journal of Industrial Economics*, *49*(2), 181–196. https://doi.org/10.1111/1467-6451.00145

Schilling, M. A. (2003). Technological Leapfrogging: Lessons from the U.S. Video Game Console Industry. *California Management Review*, *45*(3), 6–32. https://doi.org/10.2307/41166174

Schilling, M. A. (2020). *Strategic Management of Innovation Technological*.

Shin, D.-H., Kim, H., & Hwang, J. (2015). Standardization revisited: A critical literature review on standards and innovation. *Computer Standards & Interfaces*, *38*, 152–157. https://doi.org/10.1016/j.csi.2014.09.002

Soh, P.-H. (2010). Network patterns and competitive advantage before the emergence of a dominant design. *Strategic Management Journal*, *31*(4), 438–461. https://doi.org/10.1002/smj.819

Suarez, F. F. (2004). Battles for technological dominance: an integrative framework. *Research Policy*, *33*(2), 271–286. https://doi.org/10.1016/j.respol.2003.07.001

Teubner, L. K., Henkel, J., & Bekkers, R. (2021). Industry consortia in mobile telecommunications standards setting: Purpose, organization and diversity. *Telecommunications Policy*, *45*(3), 102059. https://doi.org/10.1016/j.telpol.2020.102059

van de Kaa, G., Fens, T., Rezaei, J., Kaynak, D., Hatun, Z., & Tsilimeni-Archangelidi, A. (2019). Realizing smart meter connectivity: Analyzing the competing technologies

Power line communication, mobile telephony, and radio frequency using the best worst method. *Renewable and Sustainable Energy Reviews*, *103*, 320–327. https://doi.org/10.1016/j.rser.2018.12.035

van de Kaa, G. (2017). Explaining standard dominance: The effect of influential network positions and structural holes. *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2017-January*. https://doi.org/10.24251/hicss.2017.635

van de Kaa, G. (2023). Standards adoption: A comprehensive multidisciplinary review. *Heliyon*, *9*(8), e19203. https://doi.org/10.1016/j.heliyon.2023.e19203

van de Kaa, G., & de Vries, H. J. (2015). Factors for winning format battles: A comparative case study. *Technological Forecasting and Social Change*, *91*, 222–235. https://doi.org/10.1016/j.techfore.2014.02.019

van de Kaa, G., de Vries, H. J., & van den Ende, J. (2015). Strategies in network industries: the importance of inter-organisational networks, complementary goods, and commitment. *Technology Analysis & Strategic Management*, *27*(1), 73–86. https://doi.org/10.1080/09537325.2014.951320

van de Kaa, G., & Greeven, M. (2017). LED standardization in China and South East Asia: Stakeholders, infrastructure and institutional regimes. *Renewable and Sustainable Energy Reviews*, *72*, 863–870. https://doi.org/10.1016/j.rser.2017.01.101

van de Kaa, G., van Heck, E., de Vries, H. J., van den Ende, J., & Rezaei, J. (2014). Supporting Decision Making in Technology Standards Battles Based on a Fuzzy Analytic Hierarchy Process. *IEEE Transactions on Engineering Management*, *61*(2), 336–348. https://doi.org/10.1109/TEM.2013.2292579

van de Kaa, G., van den Ende, J., de Vries, H. J., & van Heck, E. (2011). Factors for winning interface format battles: A review and synthesis of the literature. *Technological Forecasting and Social Change*, *78*(8), 1397–1411. https://doi.org/10.1016/j.techfore.2011.03.011

Van de Kaa, G., Scholten, D., Rezaei, J., & Milchram, C. (2017). The Battle between Battery and Fuel Cell Powered Electric Vehicles: A BWM Approach. *Energies*, *10*(11), 1707. https://doi.org/10.3390/en10111707

van den Ende, J., van de Kaa, G., den Uijl, S., & de Vries, H. J. (2012). The Paradox of Standard Flexibility: The Effects of Co-evolution between Standard and Interorganizational Network. *Organization Studies*, *33*(5-6), 705–736. https://doi.org/10.1177/0170840612443625

Weiss, M., & Cargill, C. (1992). Consortia in the standards development process. *Journal of the American Society for Information Science*, *43*(8), 559–565. https://doi.org/10.1002/(SICI)1097-4571(199209)43:8<559::AID-ASI7>3.0.CO;2-P

Wiegmann, P. M., de Vries, H. J., & Blind, K. (2017). Multi-mode standardisation: A critical review and a research agenda. *Research Policy*, *46*(8), 1370–1386. https://doi.org/10.1016/j.respol.2017.06.002

Wiegmann, P. M., Eggers, F., de Vries, H. J., & Blind, K. (2022). Competing Standard-Setting Organizations: A Choice Experiment. *Research Policy*, *51*(2), 104427. https://doi.org/10.1016/j.respol.2021.104427

Yee-Loong Chong, A., & Ooi, K.-B. (2008). Adoption of interorganizational system standards in supply chains. *Industrial Management & Data Systems*, *108*(4), 529–547. https://doi.org/10.1108/02635570810868371

A

NAICS industry classification

The following is the NAICS hierarchical classification scheme adopted on LinkedIn.

Table A.1: Full Industry Classification Hierarchy

Level 1	Level 2	Level 3
Accommodation and Food Services	Food and Beverage Services	Bars, Taverns, and Nightclubs
		Caterers
		Mobile Food Services
		Restaurants
	Hospitality	Bed-and-Breakfasts, Hostels, Homestays
		Hotels and Motels
Administrative and Support Services	Collection Agencies	
	Events Services	
	Facilities Services	
	Fundraising	
	Office Administration	
	Security and Investigations	
	Staffing and Recruiting	
	Telephone Call Centers	
	Translation and Localization	
	Travel Arrangements	
	Writing and Editing	
Construction	Building Construction	
	Civil Engineering	
	Specialty Trade Contractors	
Consumer Services	Civic and Social Organizations	

Table A.1 – continued from previous page

Level 1	Level 2	Level 3
	Household Services	
	Non-profit Organizations	
	Personal and Laundry Services	
	Philanthropic Fundraising Services	
	Religious Institutions	
	Repair and Maintenance	
Education	E-Learning Providers	
	Higher Education	
	Primary and Secondary Education	
	Professional Training and Coaching	
	Technical and Vocational Training	
Entertainment Providers	Artists and Writers	
	Museums, Historical Sites, and Zoos	Historical Sites
		Museums
		Zoos and Botanical Gardens
	Musicians	
	Performing Arts and Spectator Sports	Circuses and Magic Shows
		Dance Companies
		Performing Arts
		Theater Companies
	Recreational Facilities	Amusement Parks and Arcades
		Gambling Facilities and Casinos
		Golf Courses and Country Clubs
		Skiing Facilities
		Wellness and Fitness Services
	Spectator Sports	Racetracks
		Sports Teams and Clubs
Financial Services	Capital Markets	Investment Advice
		Investment Banking
		Investment Management
		Securities and Commodity Exchanges

Table A.1 – continued from previous page

Level 1	Level 2	Level 3
		Venture Capital and Private Equity Principals
	Credit Intermediation	Banking
		International Trade and Development
		Loan Brokers
		Savings Institutions
	Funds and Trusts	Insurance and Employee Benefit Funds
		Pension Funds
		Trusts and Estates
	Insurance	Claims Adjusting, Actuarial Services
		Insurance Agencies and Brokerages
		Insurance Carriers
Government Administration	Administration of Justice	Correctional Institutions
		Courts of Law
		Fire Protection
		Law Enforcement
		Public Safety
	Economic Programs	Transportation Programs
		Utilities Administration
	Environmental Quality Programs	Air, Water, and Waste Program Management
		Conservation Programs
	Health and Human Services	Education Administration Programs
		Public Assistance Programs
		Public Health
	Housing and Community Development	Community Development and Urban Planning
		Housing Programs
	Military and International Affairs	Armed Forces
		International Affairs
	Public Policy	
	Public Policy Offices	Executive Offices
		Legislative Offices
	Space Research and Technology	
Hospitals and Health Care	Community Services	
	Hospitals	

Table A.1 – continued from previous page

Level 1	Level 2	Level 3
	Individual and Family Services	
	Medical Practices	
	Nursing Homes and Residential Care Facilities	
Manufacturing	Apparel Manufacturing	Fashion Accessories Manufacturing
	Appliances, Electrical, and Electronics Manufacturing	Electric Lighting Equipment Manufacturing
		Electrical Equipment Manufacturing
		Household Appliance Manufacturing
	Chemical Manufacturing	Agricultural Chemical Manufacturing
		Artificial Rubber and Synthetic Fiber Manufacturing
		Chemical Raw Materials Manufacturing
		Paint, Coating, and Adhesive Manufacturing
		Personal Care Product Manufacturing
		Pharmaceutical Manufacturing
		Soap and Cleaning Product Manufacturing
	Computers and Electronics Manufacturing	Audio and Video Equipment Manufacturing
		Communications Equipment Manufacturing
		Computer Hardware Manufacturing
		Magnetic and Optical Media Manufacturing
		Measuring and Control Instrument Manufacturing
		Semiconductor Manufacturing
	Fabricated Metal Products	Architectural and Structural Metal Manufacturing
		Boilers, Tanks, and Shipping Container Manufacturing

Table A.1 – continued from previous page

Level 1	Level 2	Level 3
		Construction Hardware Manufacturing
		Cutlery and Handtool Manufacturing
		Metal Treatments
		Metal Valve, Ball, and Roller Manufacturing
		Spring and Wire Product Manufacturing
		Turned Products and Fastener Manufacturing
	Food and Beverage Manufacturing	Animal Feed Manufacturing
		Baked Goods Manufacturing
		Beverage Manufacturing
		Dairy Product Manufacturing
		Fruit and Vegetable Preserves Manufacturing
		Meat Products Manufacturing
		Seafood Product Manufacturing
		Sugar and Confectionery Product Manufacturing
	Furniture and Home Furnishings Manufacturing	Household and Institutional Furniture Manufacturing
		Mattress and Blinds Manufacturing
		Office Furniture and Fixtures Manufacturing
	Glass, Ceramics and Concrete Manufacturing	Abrasives and Nonmetallic Minerals Manufacturing
		Clay and Refractory Products Manufacturing
		Glass Product Manufacturing
		Lime and Gypsum Products Manufacturing
	Leather Product Manufacturing	Footwear Manufacturing
		Women's Handbag Manufacturing

Table A.1 – continued from previous page

Level 1	Level 2	Level 3
	Machinery Manufacturing	Agriculture, Construction, Mining Machinery Manufacturing
		Automation Machinery Manufacturing
		Commercial and Service Industry Machinery Manufacturing
		Engines and Power Transmission Equipment Manufacturing
		HVAC and Refrigeration Equipment Manufacturing
		Industrial Machinery Manufacturing
		Metalworking Machinery Manufacturing
	Medical Equipment Manufacturing	
	Oil and Coal Product Manufacturing	
	Paper and Forest Product Manufacturing	
	Plastics and Rubber Product Manufacturing	Packaging and Containers Manufacturing
		Plastics Manufacturing
		Rubber Products Manufacturing
	Primary Metal Manufacturing	
	Printing Services	
	Sporting Goods Manufacturing	
	Textile Manufacturing	
	Tobacco Manufacturing	
	Transportation Equipment Manufacturing	Aviation and Aerospace Component Manufacturing
		Defense and Space Manufacturing
		Motor Vehicle Manufacturing
		Motor Vehicle Parts Manufacturing

Table A.1 – continued from previous page

Level 1	Level 2	Level 3
		Railroad Equipment Manufacturing
		Shipbuilding
	Wood Product Manufacturing	
Farming, Ranching, Forestry	Farming	
	Ranching and Fisheries	
	Forestry and Logging	
Holding Companies		
Oil, Gas, and Mining	Mining	
	Oil and Gas	
Professional Services	Accounting	
	Advertising Services	Government Relations Services
		Market Research
		Photography
		Public Relations and Communications Services
	Architecture and Planning	
	Business Consulting and Services	Environmental Services
		Human Resources Services
		Marketing Services
		Operations Consulting
		Outsourcing and Offshoring Consulting
		Strategic Management Services
	Design Services	Graphic Design
		Interior Design
	Engineering Services	
	IT Services and IT Consulting	Computer and Network Security
		IT System Custom Software Development
		IT System Data Services
		IT System Design Services
		IT System Installation and Disposal
		IT System Operations and Maintenance
		IT System Testing and Evaluation

Table A.1 – continued from previous page

Level 1	Level 2	Level 3
		IT System Training and Support
	Legal Services	Alternative Dispute Resolution
		Law Practice
	Research Services	Biotechnology Research
		Nanotechnology Research
		Think Tanks
	Services for Renewable Energy	
	Veterinary Services	
Real Estate and Equipment Rental Services	Equipment Rental Services	
	Real Estate	
Retail	Food and Beverage Retail	
	Online and Mail Order Retail	
	Retail Apparel and Fashion	
	Retail Appliances, Electrical, and Electronic Equipment	
	Retail Art Dealers	
	Retail Art Supplies	
	Retail Books and Printed News	
	Retail Building Materials and Garden Equipment	
	Retail Florists	
	Retail Furniture and Home Furnishings	
	Retail Gasoline	
	Retail Health and Personal Care Products	
	Retail Luxury Goods and Jewelry	
	Retail Motor Vehicles	
	Retail Musical Instruments	
	Retail Office Equipment	
	Retail Office Supplies and Gifts	
	Retail Recyclable Materials & Used Merchandise	
Technology, Information and Media	Book and Periodical Publishing	

Table A.1 – continued from previous page

Level 1	**Level 2**	**Level 3**
	Broadcast Media Production and Distribution	
	Data Infrastructure and Analytics	
	Information Services	
	Internet Marketplace Platforms	
	Movies, Videos, and Sound	
	Social Networking Platforms	
	Telecommunications	
	Software Development	Computer Games
Transportation, Logistics, Supply Chain and Storage	Airlines and Aviation	
	Freight and Package Transportation	
	Ground Passenger Transportation	
	Maritime Transportation	
	Pipeline Transportation	
	Postal Services	
	Rail Transportation	
	Truck Transportation	
	Warehousing	
	Warehousing and Storage	
Utilities	Electric Power Generation	
	Electric Power Transmission, Control, and Distribution	
	Natural Gas Distribution	
	Water, Waste, Steam, and Air Conditioning Services	
Wholesale	Wholesale Alcoholic Beverages	
	Wholesale Apparel and Sewing Supplies	
	Wholesale Appliances, Electrical, and Electronics	
	Wholesale Building Materials	
	Wholesale Chemical and Allied Products	
	Wholesale Computer Equipment	

Table A.1 – continued from previous page

Level 1	Level 2	Level 3
	Wholesale Drugs and Sundries	
	Wholesale Food and Beverage	
	Wholesale Footwear	
	Wholesale Furniture and Home Furnishings	
	Wholesale Hardware, Plumbing, Heating Equipment	
	Wholesale Import and Export	
	Wholesale Luxury Goods and Jewelry	
	Wholesale Machinery	
	Wholesale Metals and Minerals	
	Wholesale Motor Vehicles and Parts	
	Wholesale Paper Products	
	Wholesale Petroleum and Petroleum Products	
	Wholesale Photography Equipment and Supplies	
	Wholesale Raw Farm Products	
	Wholesale Recyclable Materials	