THE INFLUENCE OF DIVERSITY AND SIZE OF STANDARD SETTING ORGANISATIONS AND STANDARDS CONSORTIA ON STANDARD SUCCESS

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By

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Preface

It is with a great sense of accomplishment that I present this thesis, where I study the influence of diversity and size of standard setting organisations on standard success. This work represents the end of my 6 year long journey at the Technical University of Delft. In addition, this thesis represents the culmination of Management of Technology program, that was part of my double degree, after already completing Chemical Engineering. I feel like the Management of Technology program was an extremely useful part of my education. As always being a chemistry guy, it felt refreshing to immerse myself in the social sciences. Moreover, the program prepared me well for the thesis project, with various courses that talked about statistical analysis, how to effectively set up research in the field of social sciences and of course about standardisation. Next to being educational, to me, the courses were fun as well, with dedicated teachers who lectured in an engaging way. I am grateful for all the support and guidance I have received from all teachers, supervisors, councillors, and other students that I have met in the last 6 years. For thesis in particular I would like to thank a select few.

First of all, Sander Smit, the first supervisor, who has helped me extremely well throughout this thesis with weekly or bi-weekly meetings where I could express my struggles, ask questions and have discussions about the subject matter. His valuable feedback and the insightful discussions have helped me to think critically and look critically at my own work as well. Additionally, I feel like he really helped me to create clear structure and purpose in my thesis. I think these skills will help me further in my personal and professional life.

Secondly, I would like to thank Geerten van de Kaa, the chair of the committee. I remember when I first approached Geerten back in 2022 about a potential thesis topic, he immediately had several interesting ideas and pushed me to think about new ideas as well. Several of his insights were pivotal for this thesis and his enthusiasm is contagious and admirable. I also really liked the discussions we have had over the last months.

Thirdly, I would like to thank Irene Grossman, even though we have not spent too much time together, I highly appreciate that she was willing to help us out when we were in dire need of a second supervisor. This project quite literally could not have happened without her. The moments we did spent together were always insightful, and she always had thoughtful and encouraging remarks.

Lastly, I would like to thank my girlfriend Floor, and my friends and family, for always supporting me, not only during this thesis, but throughout my entire academic career. I am truly grateful for having such a tight circle that is always there for me.

It kind of feels surreal that my university career has come to an end, in the coming months I will continue to work at my current job, Eindsprint, a company that prepares high school students for their upcoming exams, until the start of 2024. In the mean time I will look for jobs in the sector, hopefully I am able to find something that combines both the technical side of Chemical Engineering and the social side of Management of Technology.

Executive summary

Standardisation plays a crucial role in driving long-term productivity, competitive growth, and innovation in various industries. Its primary objective is to streamline processes by establishing consensus among different stakeholders, such as firms, users, academia and governments. Standards provide classifications such as quality, compatibility, safety, or measurements to ensure that products and procedures meet specific requirements and can be reliably used across different domains. In spite of the importance of standardisation, there is a lot to learn about the factors that influence standard success. As of now, literature in this field is mostly exploratory in nature. This study investigates the factors influencing the success of standardisation efforts, in particular, it examines the impact of technological diversity and geographical diversity within standard setting organisations (SSOs) or standards consortia on achieving standard success. Additionally, the study explores the role of the size of these SSOs or standards consortia in influencing the likelihood of standard success. Next to that, the influence of the definition of standard success is also examined, by providing three different theoretical definitions for standard success. This study adds on to the literature by providing larger scale qualitative research in an attempt to better understand the dynamics of standard success. In this study an original dataset was created of standards consortia in the context of Renewable Energy (RE) and Sustainability, Efficiency, and Green Initiatives (SEG). The chosen context is significant for addressing the global climate problem, a complex and multifaceted wicked problem that requires collaborative efforts. Therefore, the understanding of which factors influence the success of standards is essential to tackle climate change's adverse impacts. Standards are important in providing universal guidelines, products and protocols that are needed to combat climate change. The results indicate the presence of a U-shaped relationship between technological diversity and standards success, this result has not yet been found earlier and implies that instead of an optimum range of diversity, managers should to be at either extreme end of the technological diversity spectrum. Moreover, we observe a positive relationship between consortium size and standard success, meaning that whenever possible, managers should aim to increase consortium size. This study provides a better understanding of how the characteristics of standards consortia influence standard success which can also aid managers in making well-educated choices when setting up standards consortia.

Keywords: Standardisation, standards consortia, technological diversity, geographical diversity, consortium size, standard success

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1. Introduction

Standardisation has been defined as an essential force behind long-term productivity, competitive growth (Acemoglu et al., 2012; Blind et al., 2020; Su et al., 2021), and innovation (Blind, 2004; Swann, 2001). The main objective of standardisation is reduce the complexity and inefficiency that arises from having multiple solutions for the same problem. This process is based on the consensus of different parties that include firms, users, interest groups, standards organizations and governments (Xie et al., 2016). For example, in the manufacturing of electric vehicle charging infrastructure, standardisation plays an important role. Just as standardized electrical outlets make sure that every electrical device can plugged into any socket, industry-wide standards and protocols for charging stations and connectors of electrical vehicles increases the likelihood of adoption immensely. So, standards define classifications such as quality, compatibility, safety or measurements (Blind, 2004; Farrell & Saloner, 1992; Nickerson & Zur Muehlen, 2006). These standards aim to ensure that certain products or procedures meet specific requirements, adhere to quality standards, and can be reliably used across different industries, regions or organisations.

While standardization may limit product variety, inhibiting the emergence of new product variations, standardisation can also lead to specialisation. The consistency and uniformity that is created by standardisation enable businesses to focus on specific areas of expertise and specialisation, knowing that their products will be compatible with others following the same standards. Specialization enables mass production, leading to cost reduction and subsequently lower prices. This, in turn, expands the potential customer base. Additionally, standardization offers the potential advantage of concentrating research and development efforts on a select few product options, which creates a lesser market risk (Blind, 2004). Moreover, Standardization promotes the use of common terminology and methods, allowing researchers and innovators to build upon existing knowledge and insights. By having standardized practices and benchmarks, it becomes easier to identify areas for improvement and make incremental advancements based on past experiences and lessons learned. This shared foundation enables collaboration, and allows innovation to grow (Su et al., 2021). Successful examples of standardization efforts include USB-C, WiFi, or ISO standards who either won the battle for standardisation and have become the widely accepted standard in their respective industries or set numerous quality and safety standards in countless fields.

Several studies have highlighted the need for collaborations and interfirm relationships in the standardisation process. These relationships can create a larger installed base for the standard, as well as increase the availability of complementary goods. Which has been shown to increase the likelihood of standard success (M. Schilling, 1999; M. A. Schilling, 2003). In addition, cooperating tactics such as licencing alliances can also help to increase the installed base and thus increase the likelihood of standard success (Somaya et al., 2010). One example of collaboration in the field of standardisation are standards consortia. A consortium is a group of companies, organisations and sometimes individuals that join together for the purpose of coordinating technology and market growth. Consortia can pool resources, expertise and knowledge to create new standards. Unlike traditional business relationships which are often formal, a consortium operates informally. This flexibility in dealing with rules and procedures gives the members of the consortium the freedom to turn their economic and political power into firm-level benefits (van de Kaa et al., 2015). On the flip side, standardisation in alliances requires cooperation and compromise, therefore, these consensus based standards are often compromised solutions instead of optimal solutions for industry development (Leiponen et al., 2008; Ranganathan et al., 2018; Wen et al., 2020). Although many scholars have examined interfirm standards battles and firm survival (Suarez, 2004; Suárez & Utterback, 1995; van de Kaa & de Vries, 2015), the characteristics of standards consortia and their effect on standards success has not been studied extensively. Understanding how the characteristics of standards consortia influence the likelihood of standard success can help to identify best practices and areas for improvement. This benefits the managers of consortia as well as the consumers and industries.

The literature shows that diversity, in particular, technological and geographical diversity are important factors to consider in alliances. Geographical diversity refers to the variation of geographic locations of collaborating partners (Van Beers & Zand, 2014). Technological diversity refers to differences in expertise, knowledge and expertise among the members of a consortium (Hinds & Bailey, 2003; Stuart Bunderson & Sutcliffe, 2002). One study (Jiang et al., 2010) proposed that increased technological and geographical diversity in collaborations can provide a broader range of knowledge and learning opportunities. However, research on collaborations between universities and industry has shown that low geographical diversity can increase the likelihood that tacit knowledge, that is, knowledge that is not easily codified, is transferred between collaborating parties due to increased informal, face-to-face interactions (Craig Boardman & Corley, 2008; Kato & Odagiri, 2012). Thus, we think that geographical diversity is an important characteristic of consortia to consider when it comes to its influence on standard success. Additionally, a high degree of technological diversity has also been shown to lead to new combinations of different technologies, which are then more likely to reach higher quality, which can give firms the technological edge they need to reach standard success (Carnabuci & Operti, 2013; Utterback & Abernathy, 1975). However, too much diversity can be a challenge as well (Cheng Guan & Yan, 2016). There must be some understanding of each other's technology. In the event that technological diversity is too high, parties may fail to understand each other and not be able to effectively collaborate and innovate. Therefore, due to the mixed results presented in literature, technological diversity is also an important characteristic of consortia to consider when it comes to its influence on standard success. Next to that, consortium size is an important characteristic of standards consortia. An increase in consortium size can give rise to greater pool of resources, knowledge and capabilities. This can lead to an increase in installed base of the standard. This leads to a bandwagon effect, where more members adopt the technology. As the number of users increase, third-party support for the technology also grows, which attracts even more new users. This positive feedback loop strengthens the initial lead, which eventually drives out competitors and other standards (Hill, 1997). However, literature also shows that as the number of actors in alliances increases, the likelihood of consensus decreases (Rada, 2000; Vercoulen & Van Wegberg, 1998). Thus, geographical diversity, technological diversity and size all show to have mixed results in literature, but seem to be important characteristics to consider, as they could have an effect on the likelihood that a standard succeeds. This thesis, therefore, focusses on the effect diversity and size of standards consortia have on the likelihood of standard success. This is important as it provides new insights into what influences standard success, which adds to the standardisation literature. Additionally, this could help managers of consortia with more informed decision making.

Only a few studies have looked at the direct influence of characteristics of standards consortia on standard success. Classically, Weiss and Cargill (1992) suggested the importance of an optimal size of the consortium in relation to standard success. As groups that are too large may find increased difficulty in coordination and efficiency. One study has looked at the influence of commitment and internal competition inside standards consortia on standard success (Kamps et al., 2017). They have proposed that it may be more beneficial to have a limited number of parties with higher degree of revenue than several smaller parties, where revenue is split among all these smaller parties. This could be due to the fact that in the formation of interfirm linkages, the value of commercial capital may be rated more highly than the value of technological capital (Ahuja, 2000a). However, they also found that openness to new members increases the likelihood of standard success. They propose that the influx of new members may increase the diversity of the consortium, which increases chances of standard success. This ties in with the research done by Van de Ende *et al.* (2012), who have looked at the influence of technological diversity of consortia, and the number of companies that support the standard, or the consortium size, on standard success. They proposed that technological diversity may have an effect on the amount of companies that support the standard, which increases the installed base as well as the availability of complementary goods, which in turn increases standard success. A more recent study had similar findings (Kim & Kim, 2022). In their study, they propose that it is beneficial for consortia to keep expanding and keep their membership open. Primarily due to the increased technological perspectives it can bring. In other words, they find that an increase in consortium size and technological diversity may lead to an increase in standard success.

Although Weiss and Cargil (1992), Kamps (2017), Van de Ende (2012) and Kim and Kim (2022) have studied several characteristics of standards consortia on standard success, these studies are exploratory in nature. Even though the literature suggests that there is a relationship between geographical diversity and the transfer of tacit knowledge, to our knowledge, no studies have been conducted that directly look at the influence of geographical diversity of consortia on standard success. Standardisation is considered a knowledge-sharing and knowledge-creating activity (Blind et al., 2012), as geographical diversity facilitates knowledge sharing, it is logical to consider this relationship in our study.

We have thus located a gap in the literature, this study contributes to the existing literature by studying both the influence of geographical and technological diversity of standards consortia on standard success as well as the influence of size of standards consortia on eventual standard success in larger scale quantitative research. Doing so will allow for easier generalizability of the results due to the larger sample size and provide new insights on the influence of geographical diversity of consortia on standard success. Our Next to that as the term standard success presents difficulties, success can defined in many different ways, meaning that way in which one defines success influences the effect of other variables. This study will look at different ways in which standard success can be defined and what influence that has on the results. To the best of our knowledge, no study has considered to define standard success in multiple ways, in spite of its relevance. Therefore, this study contributes to the literature in that is it the first that shows the impact that the definition of standard success has.

Our results show that there is a U shaped relationship between technological diversity and standard success. This is an unexpected result and has not been found before. Additionally, consortium size also shows to have a significant effect on standard success. Our results thus show the importance of the definition of standard success, because the aforementioned effects appear and disappear based on our definition.

Moreover, this work can aid firms that want to engage in standard setting activities in a consortium in making several choices. Firstly, the size, or the amount of parties that will be involved in the consortium. Secondly, educated choices can be made regarding the industry these parties come from as well as the geographical location of the collaborating firms. Managers have difficult choices to make on a daily basis, this work help in making educated choices, these choices can influence the efficiency, and impact of the standards development process.

We formulate the following research question: "To what extent do geographical diversity, technological diversity, and consortium size influence standard success?"

2. Hypotheses

This work focuses on the organisations that are involved in the formation of standards. Nowadays, especially in the ICT sector, the creation of new standards is highly influenced by standards consortia or Standards Setting Organisations (SSOs), with many large companies being involved in several standards consortia (Hawkins, 1999). A consortium is a group of companies, organisations and sometimes individuals that join together for the purpose of coordinating technology and market growth. An SSO is a group that creates and promotes technology standards. This can be done by the SSO itself or they can adopt them from other SSOs. An SSO differs slightly from a standard consortium. Standards consortia are private institutions that serve as a platform for businesses to collaborate and conduct research and development on a specific standard. This standard is then created and released by an SSO (Baron & Pohlmann, 2013b; R. N. A. Bekkers et al., 2014; Leiponen et al., 2008). SSOs coordinated the development of standard setting, firms that manufacture proprietary and patented technologies join SSOs to have it approved as formal, industry standard (R. Bekkers et al., 2002). There is thus a technological rivalry in this standard development, meaning that the number of patents has grown drastically over the last decades (Baron & Pohlmann, 2013a; Simcoe & Rotman, 2005). Due to the high costs that are associated with this technological competition in SSOs due to, for instance, the duplication of R&D (Farrell & Simcoe, 2012), firms may opt to join less formal, standards consortia in order to collaborate closely with the other firms in the standardisation process (M. Weiss & Cargill, 1992). Standards consortia may also double as SSO as well as issue their own standards, such as Blu-Ray or WC3 (M. Weiss & Cargill, 1992). However, most consortia choose to avoid competition and choose to coexist with SSOs (Baron & Pohlmann, 2013a; Blind & Gauch, 2008). It has been shown that these standards consortia contribute to fostering technological development, this is due to the fact that collaboration with peers or competitors allows for knowledge spillovers, which may lead to technological superiority over other standards (Baron et al., 2014; Baron & Pohlmann, 2013a). Additionally, consortia allow groups of standardisation participants to discuss standard related topics such as implementation, certification and technological specifications (Baron & Pohlmann, 2013a). In other words, consortia enable more a more efficient way of coming to a consensus in decision making. More efficient decision making can lead to being able to seize new opportunities more quickly, which can in turn lead to a greater likelihood that a standard becomes successful. The basis premise of the influence of alliances on standardisation success is that initially, a technology gains an initial lead in installed base due to the alliance. This leads to a bandwagon effect, where more members adopt the technology. As the number of users increase, third-party support for the technology also grows, which attracts even more new users. This positive feedback loop strengthens the initial lead, which eventually drives out competitors and other standards (Hill, 1997). To summarise, SSOs and standards consortia play a crucial role in the standard setting environment in the ICT sector and allow for greater efficiency and success in standard setting.

Next to that, there is incentive for cooperating with both complementors as well as rivals in standards consortia. One view in literature is that consortia are alliances between like-minded peers (Axelrod et al., 1995; M. B. H. Weiss & Sirbu, 1990). In standardization processes involving competition among firms to provide technology components, forming coalitions can significantly enhance a company's bargaining position during negotiations for technology selection. Research by Leiponen demonstrates that being a member of a relevant consortium enhances the firms ability to influence voting behaviour of other companies with the organisation (Leiponen et al., 2008). Consortia can be a means for firms to form alliances, which will increase the likelihood that their patented technology will develop into a formal standard (Pohlmann & Blind, 2011). However, it can also be beneficial to directly cooperate with competitors. Due to the fact that rivalling companies often develop similar technologies. Only the technology that eventually becomes the industry standard benefits from returns on investment (Rysman & Simcoe, 2008). Therefore, it is beneficial for rivalling firms to coordinate before investing in R&D, to avoid duplicate costs, and making sure that R&D actually aids in the development of the standard instead of going to waste (Aggarwal et al., 2011). Standards consortia allow for this coordination to happen, and can make sure that in the case of overinvestments in R&D, they reduce the amount of related patenting (Baron et al., 2014; Baron & Pohlmann, 2013a). We believe that it is crucial that firms actively take part in standard setting organisations with both competitors and complementors to ensure that they are involved in creating, developing the industry standard. It is therefore essential to study what influence the characteristics of SSOs and standards consortia have on standard success.

In the following sections hypotheses will be formulated that highlight the relationship between geographical diversity, technological diversity, size of consortia and standard success. The literature shows a mixed bag of results regarding these relationships, given the complexity of these relationships we believe that more research is needed in this field. The research that has been done, have mostly tested these relationships in case studies and are exploratory in nature, we aim to test the conceptual model shown in Figure 1, that is derived by the theory, by larger scale quantitative research.

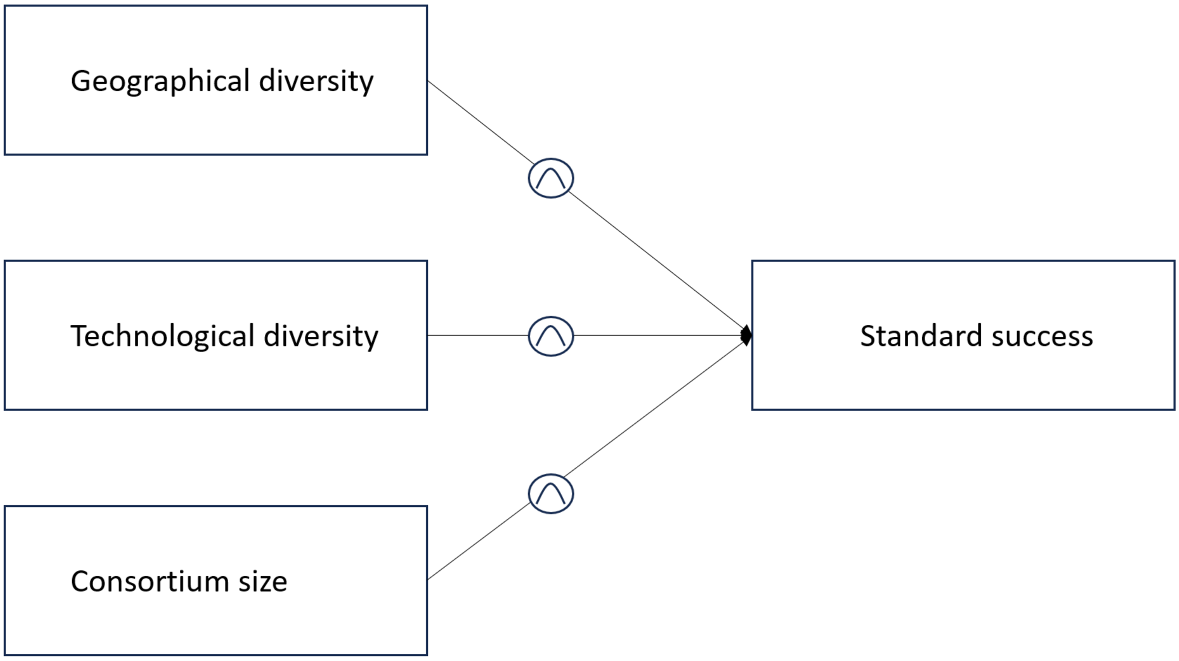

Figure 1 - Conceptual model linking geographical diversity, technological diversity and consortium size to standard success.

2.1 Standard success

The term ‘ standard success’ brings inherent ambiguity, determining the level of success of a standard is subjective and influenced by the perceptions and perspectives of organisations and individuals. In literature, multiple ways to define standard success have been proposed. We believe that there is no one-size-fits-all measure for standard success and that multiple approaches should be considered.

Firstly, we can look at whether or not a committee has reach an agreement on a standard. In other words, a standard can be formally considered successful when a committee has agreed on a standard and has put forth this standard to the public (Kim & Kim, 2022). This would be the first phase of standard success, with the second phase being the commercial adoption of the standard.

Secondly, we can thus consider that a standard is successful when other players in industry or academia adopt the standard. Thus, when the industry adopts the standard and commercializes the standard (Kim & Kim, 2022). Whether or not the standard becomes adopted depends on various factors that have been studied extensively in literature (M. A. Schilling, 2003; Suarez, 2004; van de Kaa & de Vries, 2015). Factors such as the installed base of a standard, technological superiority, the availability of complementary goods, and R&D intensity all play a role on the likelihood of standard success. Moreover, according to Wiegmann et al. (Wiegmann et al., 2017), standardisation "aims to resolve situations where involved actors prefer a common solution to a problem but have not yet agreed which option to choose." Therefore, one would say that indeed the standard that is adopted by companies or used by scholars to foster innovation is considered successful. In several case studies we indeed see that standard success is defined by the adoption of the standard (Gallagher, 2012; M. A. Schilling, 2003).

Thirdly, we can look at consortium survival as a measure for standard success. Meaning that a standard is successful is if it survives a certain period of time (Kamps et al., 2017). This is an alternative that measurement of standard success that can be useful because it is often hard to determine a market for a certain standard. This is especially true in markets where standards compete with each other on some aspects while collaborate on other aspects, examples include USB and Bluetooth (Kamps et al., 2017).

Additionally, because of the difficulty that comes with defining standard success, literature has focused on which factors influence standard dominance instead of standard success (Suarez, 2004; Van de Kaa et al., 2011). However, just because a standard has not achieved dominance in a market, this does not necessarily mean that the standard is not successful. An early mover in a new market may achieve dominance early on, but fail to maintain this position and cease to exist. Meaning initial standard dominance does not necessarily lead to standard success.

As put before, there is no one-size-fits-all measure for standard success. Each definition of standard success has its own strengths and weaknesses and therefore we should consider each measure and see what influence that has.

2.2 Geographical diversity of SSOs

Geographical diversity refers to the variation of geographic locations of collaborating partners (Van Beers & Zand, 2014). It is measure of the distribution of different places or countries represented in for instance companies, teams or consortia. Low geographic diversity has been shown to contribute to knowledge spillovers (Audretsch et al., 1996). Moreover, cluster effects that arise from low diversity can lead to interactive learning in local networks (Belussi et al., 2010) and can also increase the ease with which information and knowledge is transferred among companies and its employees (Bell & Zaheer, 2007). Clusters of companies have been found to positively influence collaboration, innovation (Alecke et al., 2006).

Studies that have examined geographical diversity of consortia have mainly focused on how individual consortium members interact among each other (Bercovitz & Feldman, 2011; Dornbusch & Neuhäusler, 2015). Most knowledge that is essential for innovation is not easily codified and tacit in nature (Agrawal et al., 2006; Bishop et al., 2011; Geerts et al., 2018). This knowledge is difficult to transfer. Now, Low levels of geographic diversity can enhance this transfer of tacit knowledge. For example, low diversity can lead to higher levels of face-to-face communication (Craig Boardman & Corley, 2008; Ganesan et al., 2005; Kato & Odagiri, 2012), this increases the chances that knowledge is exchanged between parties (Audia et al., 2006; Vásquez-Urriago et al., 2016). The availability and transfer of this knowledge among the members of standard setting organisation could provide insights, and problem solving abilities among the members which can lead to technological superiority of the standard which in turn may lead to eventual standard success. All these factors together could thus mean that standard setting organisations with low geographical diversity among its members have the edge over their competitors. In other words, a low amount of diversity can be key for finding standard success.

However, others have shown that entrepreneurs and firms are actually offput by low geographical diversity, as they find that individuals may act passively in their own ecosystem and therefore refuse to collaborate and innovate together (Ben Letaifa & Rabeau, 2012, 2013). Boschma (Boschma, 2005), amongst others, introduces the concept of geographical proximity, which is the spatial closeness to one another. Boschma shows that geographic proximity can be an obstacle rather than a positive influence on innovation. Too much proximity can actually hinder interactive learning and innovation. Regions may become excessively focused on themselves and their own affairs. As there is a limit to the amount of knowledge the members of a consortium can take in (Pouder & St. John, 1996), when most knowledge comes from their, close, trusted relationships, the ability to learn from external sources and adapt to new developments weakens (Xavier Molina-Morales et al., 2011). As a result, their capacity for innovation diminishes, and they struggle to keep up with the latest advancements and changes. Moreover, although local knowledge can be easier to understand and absorb, knowledge from international collaborations can be more advanced and may lead to more innovative solutions, although it is more difficult to absorb this knowledge (Qiu et al., 2017). In other words, too little geographical diversity may actually hamper the ability to innovate and therefore the likelihood of a standard becoming successful. Other studies had similar conclusions, where low geographical diversity hampers innovation due to little external knowledge coming in (Preston et al., 2017).

In addition, it has been found that in specific regions, local idiosyncrasies can cause differences in approach with regard to knowledge creation, innovation and research even though they operate in the same technological domain (Phene et al., 2006). Therefore, this indicates that geographical diversity in a consortium could lead to the sharing of different approaches towards knowledge creation, innovation and research. This could give the created standard technological superiority over other products, which in turn could lead to standard success.

Geographical diversity is thus a double edged sword, it can be both beneficial and detrimental to standard success. At low levels of geographical diversity, it is easier to exchange tacit knowledge due to more face-to-face communication. However, there may be limited exposure to different perspectives, ideas, and resources. As geographical diversity increases, individuals or organizations can benefit from a broader range of knowledge, skills, and experiences. Different backgrounds and experiences can lead to unique insights and solutions. This initial increase in diversity thus enhances standard success. However, beyond a certain point, as diversity continues to increase, the benefits may start to diminish. Coordination challenges, communication barriers, and cultural differences might arise, which can hinder productivity and performance. It can be difficult to find common ground, managing a (too) high degree of diversity may require a lot of resources, time and effort.

Thus, an optimal level of diversity may exists where standard success is maximized. At the optimal level of geographical diversity, the benefits of diverse perspectives and resources are maximized. This level allows for effective knowledge exchange, innovative thinking, and collaboration among all the parties involved. Standard success may be at its peak as the right balance is found between leveraging the advantages of geographical diversity and managing the disadvantages. Therefore, we formulate the following hypothesis:

"Geographical diversity of consortia has an inverse U-shaped relation with standard success."

2.3 Technological diversity of SSOs

Technological diversity refers to differences in expertise, knowledge and expertise among the members of a consortium (Hinds & Bailey, 2003; Stuart Bunderson & Sutcliffe, 2002). These differences arise from the different industries these members represent (Jiang et al., 2010).

Many scholars today draw from the ideas of Schumpeter that new ideas are formed by recombining elements from different technical domains (Carnabuci & Operti, 2013; Corredoira & Banerjee, 2015; Fleming & Sorenson, 2004). "Recombinative innovation" was coined as the term that refers to this idea (Gallouj & Weinstein, 1997). New combinations of different technologies are more likely to reach higher quality, which can give firms the technological edge they need to reach standard success (Carnabuci & Operti, 2013; Utterback & Abernathy, 1975). It seems that collaborating parties need some knowledge of the opposing parties technology for efficient collaboration, this creates easier exchange of ideas and increases innovation quantity in their respective technological domains (Cohen & Levinthal, 1990; Makri et al., 2010). Nooteboom *et al.* (2007) refers to technological diversity as 'cognitive distance', where cognition refers to the a broad spectrum of mental activity, including perception, sense making, categorisation, inference, value judgements, and feeling an emotions which build on each other. How one interprets the world leads to different life path and therefore to cognitive difference between people. Now, how does this apply to firms? Individual workers do not have to have the same believe system to achieve a common goal. However, they do need to agree on some basic perceptions and values to align their competencies and motives (Nooteboom et al., 2007). A certain organisational focus is needed to accomplish this (Nooteboom, 2000). Differences in these organisational focusses leads to cognitive distance. Similarity in knowledge creates clear communication and allows for exploitation of this existing knowledge (Nooteboom et al., 2007). However, for innovative recombination to be effective, and create truly novel ideas, there needs to be variety in knowledge (Carnabuci & Operti, 2013). There needs to be sufficient cognitive distance so that both parties gain novel information and can create new innovation, using the knowledge from the other's technological domain. If the knowledge bases are too similar, this can limit the amount of recombination and therefore the degree of innovation (Galunic & Rodan, 1998). Moreover, the degree of novelty is much higher when the technological diversity is higher (Keijl et al., 2016). Therefore, technological diversity seems to increase the likelihood that new innovations are put forth, which can lead to technological superiority, which can successively lead to standard success.

However, too much diversity can be detrimental, as diversity increases, parties may fail to understand each other and fail to engage in recombinative innovation (Cheng Guan & Yan, 2016). Several studies have proposed that high technological diversity can indeed hamper the extent at which capabilities are transferred (Gilsing et al., 2008; Nooteboom et al., 2007; Schoenmakers & Duysters, 2006) due to the vast differences in knowledge, parties are unable to access each other's knowledge base. In other words, when technological diversity increases, parties cannot effectively share novel ideas and perspectives, which may decrease the likelihood of standard success.

So, when technological diversity is low, there is a limited range of technologies involved, which simplifies knowledge integration and coordination. As technological diversity increases, different technologies and perspectives come into play, providing opportunities for innovation and synergies. This initial increase in technological diversity enhances standard success as it enables access to a broader range of capabilities and solutions. However, beyond a certain point, as technological diversity continues to rise, the complexity of all different perspectives can become challenging. The coordination between all of the knowledge bases may introduce inefficiencies and compatibility issues, which can hinder standard success. Therefore, there seems to be an optimum for technological diversity as well. We can formulate the following hypothesis:

"Technological diversity of consortia has an inverse U-shaped relation with standard success."

2.4 Consortium size

Consortium size refers to the companies that support the standard, for instance by adopting the standard (van den Ende et al., 2012). The size of a consortium can influence its network effects and collaboration opportunities. As the consortium size increases, there is a greater pool of resources, knowledge, and capabilities that can be leveraged to develop and promote the standard. This larger consortium can attract a broader range of influential organizations and industry players. In other words, the consortium has a wider network reach, essentially creating a potentially larger installed base for the standard, which has been shown to increase the likelihood of standard success (M. Schilling, 1999; M. A. Schilling, 2003).

Additionally, one study (Van De Kaa et al., 2019) proposes that increased size of a committee can actually lead to quicker decision making. They propose three reasons that size can positively influence the rate of consensus. Firstly, they state that in cases where committee size is not limited and everyone can enter, such as the Wifi case (Van De Kaa & De Bruijn, 2015) a multi-actor setting emerges, where more actors actually increases the amount of interactions which results in faster decision making due to opportunities for collaboration. Moreover, these actors all propose their own technical solutions, all these different solutions provide potential connections between them and incentives for cooperation. In game theory, this is known as broadening the negotiation agenda, which can, by introducing more issues lead to room to compromise and therefore to faster decision making (de Bruijn & ten Heuvelhof, 2018; Koppenjan & Klijn, 2004).

Intuitively, one would think that as the size of a consortium grows, it becomes increasingly harder to reach a consensus. With many different perspectives and ideas, satisfying each and every member seems difficult to do. Two studies that have examined this phenomenon in the field of standardisation, proposing that as the number of actors increases, the likelihood of consensus decreases (Rada, 2000; Vercoulen & Van Wegberg, 1998). This is due the forming of cliques and small subgroups in the initial group. In addition, coordination and communication of the group becomes increasingly difficult as size increases. These effects may decrease efficiency and the likelihood that new standards are formed. Furthermore, Mooney *et al.* (2007) found that there is a greater tendency towards conflict in larger teams, again, due to the increase in different perspectives and ideas. This tendency towards conflict makes it more difficult to reach a consensus and can even cause aforementioned fragmentation and formation of cliques inside the team or organisation.

Thus, the size of a consortium could have both positive and negative effects on standard success. Initially, as the size of a consortium increases, the benefits of increased communication, coordination, and diverse perspectives contribute to higher standard success. However, beyond a certain point, the challenges of managing a larger consortium, and the risk of conflict, losing focus and becoming fragmented start to outweigh the advantages. Consequently, standard success declines as the consortium grows excessively large. Therefore, there seems to be an optimum size for consortia. We can formulate the following hypothesis:

"The size *of consortia has an inverse U-shaped relation with standard success."*

To summarize, our model studies the influence of three important characteristics of standards consortia on standard success. We hypothesise an inverted U-shape between each of the variables and standard success. By testing this model, we can garner better understanding of the mechanisms that influence standard success. Next to improving our understanding of the mechanisms at play, the results can help managers make more informed decisions when setting up and managing standards consortia.

3. Research Methodology

In this chapter I will outline what kind of data I use, in what context the study takes place, the independent, dependent and control variables and the relationships between them.

3.1 Empirical setting

Standard setting organisations and standards consortia play an important role in establishing and promoting standards. These organisations exist in various sectors, such as ICT, healthcare, and manufacturing.

The context of this project is SSOs in the fields of Renewable energy (RE) and Sustainability, Efficiency and Green Initiatives (SEG). Many different industries are represented and this is a high technology market with fast pace, growing at a high rate, high uncertainty and increasing demand. In addition, the context is chosen for its significance in addressing the global climate problem, which is characterized as a wicked problem. Wicked problems are complex, multifaceted issues that are difficult to define and have no straightforward solutions (Rittel & Webber, 1973). The climate problem embodies these characteristics, as it requires collaborative efforts to mitigate the adverse impacts of climate change. In this context it is essential that successful standards are formed to tackle these problems. Standards play a crucial role in guiding and aligning collaborative efforts across diverse stakeholders. These collaborations take shape in the form of standard setting organisations and standards consortia. As most standards that are produced in this sector come from these organisations, this makes for an excellent research context. Additionally, in these consortia companies from all over the world and from all kinds of different technological backgrounds come together, meaning it is an ideal context to study the influence of diversity, both geographically and technologically, on standard success.

Consortiuminfo.org has created a database of all known SSOs and standards consortia in several industries in the areas of information and communications technology. This site contains links to theirs and the pages to where their standards may be accessed. This site has the most complete lists of SSOs and standards consortia. By selecting the fields of RE and SEG we can safely assume that we have the most up to date list of consortia in these industries. Therefore, we used this site to establish all the consortia in the specific context. The title and link of the website was collected from this site. For some consortia on this site, the link was no longer available or the site had dismantled. For these cases we used the WayBackMachine to access older versions of the site. If no older links were available, these consortia were excluded from the data.

3.2 Measurements

Standard success

In the theory we have defined three definitions of standard success, these are *Agreement*, *Survival,* and *Adoption*. In this section we will explain how each of these measures is operationalised.

Agreement

Firstly, to assess the success of the standard set up by the consortium, similar to Kim & Kim (Kim & Kim, 2022) we looked at if the consortium was able to reach an agreement. We did this by looking at available media coverage. The argument is that once a consortium has reached an agreement, they will either publish that they have done so, or tell the media that they have done so. Therefore available media coverage or publications by the consortium indicate a measure for standard success. The aim was to identify any relevant publications or references to the standard within these sources. In addition, the websites of consortia was reviewed for any references to the standard, such as news releases, press coverage, or dedicated sections outlining the standard's objectives, milestones, or achievements. To determine the success of the standard, we formulated a specific criterion based on the presence of publications or references in the collected data. We defined the standard as successful if we found any publication, whether in the form of news articles, blog posts, or official announcements, that explicitly mentioned or discussed the standard established by the consortium or mention of the consortium achieving its goal. For example, the Wireless Power Consortium is mentioned many times in news releases as being a successful organisation, in addition to their several publications of products on their website. We consider a successful standard if there is any presence of publications in the press or by the consortium. This is a binary variable, with either a 'Yes' or 'No' outcome. If there is any presence of a news article or publication by the consortium, this is present as "Yes" in the data, if there are no articles or publications, this is present as "No" in the data. We employed a data collection process that involved searching through news articles and the official website of the consortium to look for available media coverage.

Survival

Secondly, we looked at consortium survival as a measure for standard success. in other words, determined whether a standard is successful by seeing if the consortium is still around. Consortium survival as a measure for standard success has also been used before (Kamps et al., 2017) in literature. In this research, we consider that a standard is successful if the consortium has existed for 7 years or longer. The Wireless Power Consortium was founded in 2008 and is still active as of today, meaning that the WPC is classified as a successful case. This is therefore also a binary variable, with either a 'Yes' or 'No' outcome. In the event that consortia disengage or cease operations due to them accomplishing their goals, or merging with another consortium, even though they did not survive the threshold of 7 years, we do treat these as successful cases. In this measure, consortia that have been founded in 2017 or later are not taken into account and therefore excluded from the data.

Adoption of scientific community and industry

Thirdly, we looked at the adoption of the scientific community and industry, also inspired by Kim & Kim (Kim & Kim, 2022). We used Google Scholar to look at patents or research that mention the standard setting organisation, we did this by using quotation marks around the name of the consortium, meaning the exact term has to be present in the paper or patent. Patents and published research both provide objective indicators of whether a given standard contributes to innovation and adoption. Looking at patents is useful because they reflect the efforts of inventors and organizations to implement the standard's principles and specifications into practical solutions. In addition, academic papers and reports can provide insights into the benefits, challenges, and potential improvements related to the standard. One example is again the Wireless Power Consortium, where they have been mentioned in various academic papers (Treffers, 2015; Van Wageningen & Staring, 2010). In this case we look at the rate of adoption, therefore, a consortium that has more publications and patents has a higher rate of adoption. We are thus dealing with a continuous variable.

Technological diversity of consortia

The first independent variable is technological diversity. Technological diversity can be measured by using industry codes(Jiang et al., 2010) . This shows the technological heterogeneity of firms. The SIC was classification is used to represent the amount of "closeness" between industries (Griliches, 1991). This measure also represents the market competition among the individual firms in the consortia. However, the SIC codes have since been replaced by NAICS codes in North America. In addition, in Europe, NACE codes are used. Furthermore, the ISIC codes, developed by the United Nations are used all over the world for classifying economic activities. Whenever possible, I gathered the NAICS for North American companies and the NACE code for European companies. These were gathered from either the websites of NAICS, NACE or from the company's website. From these codes I deduced the ISIC codes, for instance, the NAICS code for Microsoft is 513210 – Software Publishing, from this code I can deduce that the ISIC code is 5820 – Publishing of Software. Similarly, whenever codes were not readily available, I looked at the product or service the company provides and deduced the NAICS/NACE/ISIC code from that. For example, Mitsubishi has not officially declared their ISIC code, however, knowing that Mitsubishi is a well-known automobile manufacturer, I can deduce that the ISIC code would be 2910 – Manufacture of Motor vehicles. In the ISIC code, the first two digits represent the industry of the company, for Mitsubishi, this would be 29 - Manufacture of motor vehicles, trailers and semi-trailers, the remaining digits further specify the niche of this industry. Looking at all 4 digits would produce a too fine-grated sample. Therefore, to provide a meaningful analysis, we only use the first two digits of the ISIC codes.

We used the Blau index (Blau, 1977) to calculate the technological diversity:

$$D_{tech} = 1 - \sum_{i=1}^{N} p_i^2$$

With *p* the proportion of firms belonging to industry *i*. With N the number of industries.

The Blau index itself has a potential flaw. It has been suggested that the values are not validly comparable if the number of categories is not identical across diversity variables because the maximum value is not dependent on the group size. Additionally, as the amount of categories approaches infinity, the maximum value approaches 1. Therefore, we used the correction for diversity indexes put forth by Solanas (Solanas et al., 2012), where we calculate the maximum value of the Blau index for a certain group size *n* and amount of categories *k*:

$$B_{(\max)} = \frac{n^2(k-1) + a(a-k)}{kn^2}$$

With *a*:

$$a = n - k\ int(\frac{n}{k})$$

And then normalize by:

$$B_{tech} = \frac{D_{tech}}{B_{(\max)}}$$

This way the variety is controlled for the number of categories.

Geographical diversity of consortia

The second independent variable was geographical diversity. Geographical diversity can be measured by looking at the different regions each individual member of the consortia represent. For this we distinguish on the level of countries.

In order to quantify geographical diversity we again used the Blau (Blau, 1977) index of diversity:

$$D_{geo} = 1 - \sum_{i=1}^{N} p_i^2$$

With *p* the proportion of the firms belonging to location *i*. With *N* the number of locations of firms.

Again, we used the correction for diversity indexes put forth by Solanas (Solanas et al., 2012), where we calculate the maximum value of the Blau index for a certain group size *n* and amount of categories *k*:

$$B_{(\max)} = \frac{n^2(k-1) + a(a-k)}{kn^2}$$

With *a*:

$$a = n - k\ int(\frac{n}{k})$$

And normalise:

$$B_{geo} = \frac{D_{geo}}{B_{(\max)}}$$

Consortium Size

Taken from van de Ende et al. (van den Ende et al., 2012), we take consortium size as the number of companies that support the standard by supporting the consortium that produces the standard. We measured this by looking at all the companies that are mentioned as members on the consortium's website. Every company or organization that is involved with the consortium is taken into account.

Control variables

Control variables are variables that are kept constant throughout the research to prevent their influence on the dependent variable. In this case, standard success. This way we can isolate the effects of diversity and consortium size on standard success. The control variables in this research are *commitment, Economic Crisis,* and *Type of Standard.*

Commitment

The first control variable was the *commitment*. We have chosen this variable because it has been found that a certain degree of commitment influences the likelihood that a standard reaches success (Kamps et al., 2017). We stated that the members of the board of directors are fully committed to the cause of the consortium. Therefore, the degree of commitment is represented by the number of companies present in the board of directors. It should be noted that it could be that the amount of members of the board of directors was determined beforehand, which could show a lower degree of commitment where this might not be the case.

Economic Crisis

The second control variable was *economic crisis.* A consortium founded in the midst of economic distress may suffer consequences in their pursuit of standard development. Thus, standard success may be lower in times of economic crisis, in order to control for this we included this variable. We defined four different periods of economic recession (Kose et al., 2020): 1974-1975, 1981-1982, 1990-1991, 2008-2009. If the founding year of a consortium is in one of these periods, this datapoint will be a 1 in the data, if not, it will be a 0. Thus, we are dealing with a binary variable.

Type of Standard

The type of standard could influence the outcome of standard success. A quality standard might be easier to form than a de facto compatibility standard. In order to control for this we include this variable. Different types of standards of exist, as denoted by Blind (Blind, 2004), we can divide the standards in different categories. In our data we divided the type of standard in either *Compatibility/interface* or *Quality/safety*. If the standard was *Compatibility/interface* we denoted this a 1 in the data, if it was *Quality/safety,* it was denoted as 0. Again, we are dealing with a binary variable.

3.3 Analysis

Because we are dealing with a binary outcome for *Media Coverage* and *Survival* , where the answer to whether a standard is successful can either be yes or no, we used logistic regression. Logistic regression estimates the probability of the standard becoming successful based on the independent variables. For *Adoption* we are dealing with a continuous variable, therefore we used ordinary least squares analysis (OLS) regression. Models 1.1, 2.1 and 3.1 include only the control variables. Next, the models 1.2, 2.2 and 3.2 include the main effects of the independent variables. Whenever necessary, a log transform is used to deal with outliers in the observed data.

4. Results

4.1 Descriptives and correlations

Table 1 presents the descriptive statistics of the sample consortia. The first two measures for standard success, agreement and survival show values of 0.82 and 0.85, which shows the proportion of successful consortia that are successful, meaning that quite a large percentage of consortia is successful with these measures. Consortium size ranged from 5 members to 270,000 members, where the last three values where 270,000, 70,000 and 2013, the other values were all below 1500. Thus, to deal with the outliers we used a log transform. Similarly, *Adoption* ranged from 140,000 to 0, where 0 means that no companies or scholars have adopted the standard. The highest values, 140,000, 60,800 and 46,800 while all other values are below 20000. To deal with outliers we again used a log transform.

The Blau index for both geographical and technological diversity is higher than 0.65, meaning that there is a reasonable spread of different industries and location. A value of 0 means an equal distribution of firms across all categories, whereas a value of 1 means that all firms are in 1 single category. Therefore, our values still suggest that certain industries and locations may have a larger concentration of firms than others. For commitment and economic crisis the standard deviation is higher than the mean. In the case of commitment, we have one extreme outlier of 190 members, which greatly influences the standard deviation and skews the value of the mean. Additionally, in the case of economic crisis, as only 15% of cases is in an economic crisis, this data is slightly skewed as well.

Correlations show that there is a small negative correlation between geographical diversity and commitment, $r(72) = -.23$, $p = .046$. Meaning that consortia that have more firms from different locations also have a lower degree of commitment. There is a moderate positive correlation between Agreement and Consortium size $r(72) = .39$, $p < .001$. This suggests that as the size of the consortium increases, the level of agreement among its members also tends to increase. In other words, larger consortiums are more likely to have higher levels of agreement among their members. There is a moderate positive correlation between Adoption and Consortium size $r(72) = .43$, $p < .001$. This indicates that as the size of the consortium increases, the rate of adoption increases as well. Meaning that larger consortia are associated with higher rates of adoption. Additionally, there is a moderate positive correlation between Adoption and Survival $r(71) = .29$, $p = .012$. This suggests that a higher level of adoption of a certain standard is associated with a higher likelihood of survival for the organization. Moreover, there is a small negative correlation between survival and type of standard $r(71) = -.25$, $p = .030$. This means that *Quality/safety* standards are associated with higher rates of survival than *Combability*/*interface* standards. Lastly, there is a small positive correlation between technological diversity and type of standard $r(72) = .27$, $p = .019$. This means that consortia with higher technological diversity are more likely to develop *Combability*/*interface* standards instead of *Quality/safety* standards.

Table 1 - Means, standard deviations, and correlations. N = 74 for 1 and 3-9, N = 73 for 2.

	Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8
1. Agreement	0.82	0.38	0	1								
2. Survival	0.85	0.36	0	1	.20							
3. Adoption[a]	5526	18495	0	140000	.39	.29*						
4. Geographic diversity	0.66	0.37	0	1.00	.002	.01	.06					
5. Technological diversity	0.70	0.35	0	1.00	−.04	−.03	.02	.001				
6. Consortium size[a]	4785	32290	5	270000	.39*	.15	.43*	−.19	.16			
7. Commitment	14	23	2	190	.10	−.03	.18	−.23*	.01	.14		
8. Economic crisis	0.15	0.36	0	1.00	.10	.1	.10	.12	.19	.01	−.05	
9. Type of Standard	0.62	0.49	0	1.00	−.14	−.25*	−.38*	.04	.27*	−.23	−.19	.09

[a] Log transformed for correlations

* $p < .05$

4.2 Hypothesis tests

The hypothesis tests were conducted using logistic regression for models 1 and 2, and OLS regression for model 3. Table 1 presents the means, standard deviations and the correlations between the variables used in the analysis. In Table 2 the results of the hypothesis tests are presented. The objective was to examine the relationship between the independent variables, *geographical diversity, technological diversity* and *consortium size* and the dependent variable, *standard success,* while controlling for other variables. A robustness check for models 2.1 and 2.2, where 6 years or longer and 8 years or longer were included, was done and is shown in appendix A.

Hypothesis 1 postulate an inverted U-shaped relationship between geographical diversity and standard success. Models 1.2, 2.2 and 3.2 in Table 2 show these results. The squared geographical diversity term show no statistically significant results ($b_{geographical\ diversity\ sq\ 1.2}$ = 1.3635, $p > .05$; $b_{geographical\ diversity\ sq\ 2.2}$ = 0.8266, $p > .05$; $b_{geographical\ diversity\ sq\ 3.2}$ = 1.4369 $p > .05$). Thus hypothesis 1 is not supported.

Hypothesis 2 postulate an inverted U-shaped relationship between technological diversity and standard success. Models 1.2 and 2.2 in Table 2 show no statistically significant result ($b_{technological\ diversity\ sq\ 1.2}$ = −3.7262, $p > .05$; $b_{technological\ diversity\ sq\ 2.2}$ = 1.5862, $p > .05$). Model 3.2 shows that there is indeed a statistically significant result between technological diversity and standard success. We see a negative correlation between technological diversity and standard success ($b_{technological\ diversity2.2}$ = −3.9907, $p < 0.05$). Additionally, we see a positive relationship between the squared term of technological diversity and standard success, this result indicates a U-shaped relationship instead of a inverted U-shaped relationship ($b_{technological\ diversity\ sq\ 3.2}$ = 4.1154, $p < .05$). Therefore hypothesis 2 is not supported.

Hypothesis 3 postulates an inverted U-shaped relationship between consortium size and standard success. Model 1.2 in Table 2 show that there is an positive effect that is statistically significant between size and standard success ($b_{size\ 1.2}$ = 5.8332, $p < .01$). Therefore hypothesis 3 is not supported. However, we do find the positive effect size and standard success if the measure for standard success is that of agreement.

Table 2 - Results of logistic regression for models 1-4 and OLS regression for models 5 and 6 predicting standard success[a]

Variables	Standard Success					
	Model 1.1	**Model 1.2**	**Model 2.1**	**Model 2.2**	**Model 3.1**	**Model 3.2**
Step 1: controls						
Constant	1.5160* (0.7833)	−3.6556* (2.1543)	3.6625*** (1.2559)	2.3344 (1.4865)	2.8440*** (0.2725)	0.9530 (0.7933)
Commitment	0.0400 (0.0442)	0.0077 (0.0394)	−0.0131 (0.0140)	−0.0131 (0.0140)	0.0066 (0.0065)	0.0062 (0.0060)
Economic crisis	1.0077 (1.1109)	0.5860 (1.2840)	0.8538 (1.1266)	0.4572 (1.2255)	0.5299 (0.4067)	0.1022 (0.3844)
Type of standard	−0.7939 (0.7833)	−0.4448 (0.9842)	−2.3806* (1.2264)	−2.3344 (1.4865)	−1.0297*** (0.3034)	−0.4962 (0.3155)
Step 2: main effects						
Geographical diversity		−0.5885 (4.6759)		−0.7107 (4.4642)		−0.8045 (1.6021)
Geographical diversity squared		1.3635 (4.2336)		0.8266 (3.9874)		1.4369 (1.4850)
Technological diversity		2.7261 (5.1786)		−1.1129 (4.9385)		−3.9907** (1.6632)
Technological diversity squared		−3.7262 (5.1351)		1.5862 (4.5162)		4.1154** (1.5795)
Consortium size		5.8332*** (2.4439)		1.5894 (1.6313)		0.8987 (0.5566)
Consortium size squared		−0.7488 (0.5406)		−0.2279 (0.3461)		−0.0349 (0.1012)
Log-likelihood	−32.546	−22.905	−27.457	−26.380		
R^2					0.178	0.408
F					5.066***	4.918***
N	74	74	73	73	74	74

[a] Unstandardized coefficients are reported with standard errors in parentheses. * p < 0.1, ** p < 0.05 , *** p < 0.01

To further understand these relationships, we used the procedures used by Aiken *et al.* (Aiken et al., 1991). Figure 2 highlights the relationship between technological diversity and standard success. The figure shows that at first, increased diversity hinders standard success, however, after a certain point the increased diversity actually has a positive influence standard success, which further confirms the U-shaped relationship that was deduced from the regression coefficients.

Figure 3 shows the positive relationship between consortium size and standard success. As consortium size increases the likelihood that the standard succeeds becomes greater, approaching 100% at higher sizes. The relevant sizes (excluding extreme outliers) in the observed data ranged from 0 to 3.0, hence the reason only this range is plotted.

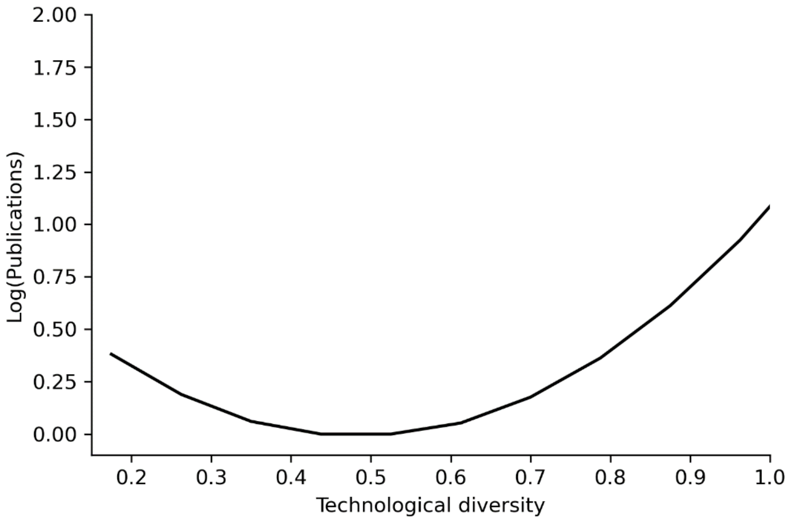

Figure 2 - The influence of Technological Diversity on Standard Success

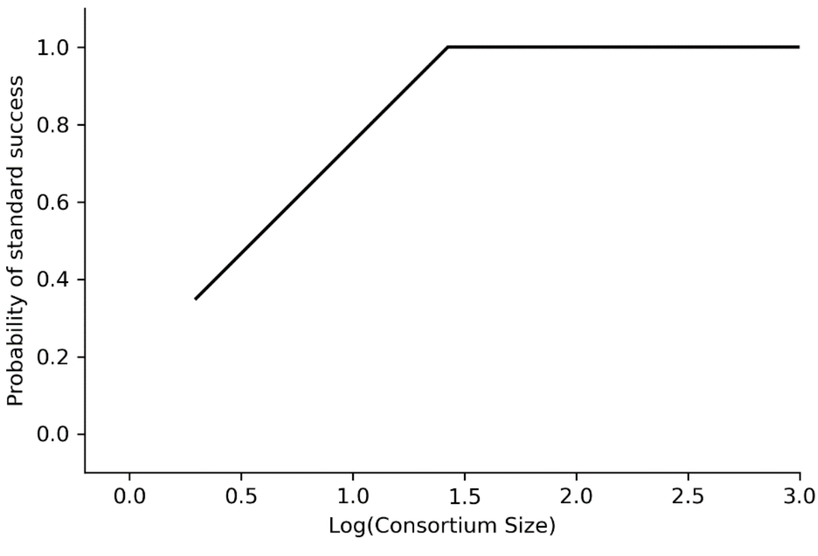

Figure 3 - The influence of consortium size on standard success.

5. Discussion

In the standardisations landscape alliances and collaborations are essential for creating standard success. Collaborations often take place in SSOs or standards consortia. However, the influence of the characteristics of these organisations is not an extensively studied field. The purpose of this thesis was to examine the relationships between geographical diversity, technological diversity, consortium size, and standard success. A dataset was created of 74 consortia in the context of Renewable energy (RE) and Sustainability, Efficiency and Green Initiatives (SEG). The results of the hypotheses are summarized in Table 3.

Table 3 - Summary of hypothesis tests

Hypothesis	Proposed relationship	Supported	Rejected	Actual relationship
1	Inverted U-shape between geographical diversity and standard success		X	No effect was observed in any model
2	Inverted U-shape between technological diversity and standard success		X	Model 3.2 shows a U-shape relationship between technological diversity and standard success
3	Inverted U-shape between consortium size and standard success		X	Model 1.2 shows a positive relationship between consortium size and standard success

5.1 Theoretical implications

Our results have several theoretical implications for the standardisation literature as well as to the literature on alliances and collaborations. We found a U shaped relationship between technological diversity and standard success. This is an intriguing result as it implies the exact opposite of what we hypothesised. Therefore, at the extremes of the spectrum, the likelihood of standard success is the highest. We thus see that at low technological diversity the adoption is higher than at moderate diversity. One reason for this could be that the standard may be more straightforward and easier to adopt, since it addresses a narrower range of technologies. Moreover, at the lower end of the spectrum, we find highly specialized consortia, where every member is from the same industry. It could be that due to this the standards that are developed are therefore exceptionally tailored towards the specific needs of a niche market, which would in turn lead to higher chance of standard success. With all members operating in the same niche market, it might also be easier to reach consensus, as all aim to create a similar standard, whereas increased diversity may lead to more conflict because of different industries being represented. Additionally, because the standard addresses a certain market niche, there is thus a clear market fit, in other words, there is a specific problem that needs fixing or there is a specific target audience for the standard. This means that standard could be more likely to succeed. Tying into that, a clear market fit, could mean that every important player in this market is present in a consortia, which allows for low degrees of competition and in turn for domination in the market. To summarize, at the low extreme, there is potentially a high degree of specialisation. This can lead to minimized conflicts of interest, a clear market fit and domination of that specific market. All these factors can lead to increased likelihood of standard success.

On the other extreme, high technological diversity may increase the likelihood of standard success due the increase in flexibility of the standard. Where flexibility means that the standard is able to adapt quickly and can adjust to possible changes in demand of the market. Van de Ende *et al*. (van den Ende et al., 2012) proposed a reciprocal relationship between technological diversity and flexibility of the standard, where higher flexibility, induced by greater technological diversity, leads to a greater network size, which increases the likelihood of standard success. Although this notion seems inherently paradoxical as flexibility causes temporary instability of the standard, this flexibility eventually contributes to the standard being accepted, which causes stability. It could be that this effect has a more positive influence on standard success than the negative effect of more complex coordination. Therefore, a higher diversity may have a greater likelihood of standard success than moderate diversity. A possible explanation is thus that at low diversity, due to the effective sharing of knowledge bases and ideas, recombinative innovation is high, this decreases at moderate diversity, where after a certain point, the increased diversity increases standard flexibility, and thus network size, to such a point that the likelihood of standard success increases again. Next to that, a highly diverse consortium implies that are a range of different industries represented. This could lead to adoption of the standard in many different industries as well. This can again rapidly increase the installed base, creating the aforementioned network effects, and thus increasing the likelihood of standard success. Additionally, at high diversity, a consortium encompassed a wide range of perspectives, expertise and also different industries. This coverage can result in standards that are able to address complex and multifaceted issues, which are especially present in our context of standards that deal with green initiatives and renewable energy for instance. Therefore, this could mean that at the higher end of the spectrum, the likelihood of standard success is greater.

Now, we only see this effect if we define standard success by adoption, the number of publications and patents that mention the name of the consortium. When it comes to the other definitions of standard success, technological diversity may not be as important a factor towards standard success. When it comes to survival, the focus shifts to longevity and stability of the consortium, other factors, such as organisational structure could be more important for survival. As for agreement, no relation was observed as well, meaning that other factors could be more important for reaching agreement than technological diversity. Similarly, organisational structure could be more important for reaching agreement than technological diversity. Also, there could be several stubborn parties in a consortium that refuse to comprise or collaborate, for reasons unrelated to technological domain.

The positive effects of increased size of a consortium seem to outweigh the possible negative effects when we define standard success by agreement. Although it seems counter-intuitive, Van de Kaa *et al.* (van de Kaa et al., 2019) might thus be correct in assuming that a larger group is actually more proficient in decision making. Therefore, the potential conflict that may arise from larger consortia may be negligible compared to the positive effects this increase in size has. One could also argue that not all members of a consortium actually gather for decision making. Meaning that a smaller group of members, such as the board of directors, gather to come to agreements. Additionally, apparently, there is no significant influence of consortium size on the survival of the consortium or the adoption rate of the standard. As for adoption, one reason could be that industry and academia are more likely to adopt a standard that addresses their specific wants and needs, and have a significant technical quality and usability, which are both not necessarily influenced by consortium size. Survival of the consortium may be much more dependent on other factors, such as again, organisational structure and strong governance.

A reason that we do not find any relationship between standard success and geographical diversity could be due to the emergence of advanced communication technology such as video conferencing and virtual meeting. Several studies have suggested that as long as dialogue is possible, the transfer of tacit knowledge is possible through ICT tools (Cumberland & Githens, 2012; Ignacio Castaneda & Toulson, 2021; Razmerita et al., 2013). Therefore, the rate of transfer of tacit knowledge between parties could be similar in environments that are low in geographical diversity and in environments that are high in geographical diversity. Another reason could be that due to the fact that the industries we studied are highly globalised, geographical diversity may be of less importance. Globalisation can cause markets to become interconnected, products and services that are developed in a certain region are sold and used in other, different regions. Geographical diversity may therefore not be an important factor in ensuring standard success. Additionally, it could very well be that other factors or variables are at play that overshadow the effect of geographical diversity. Consortia with high geographical diversity could producing a product in a very competitive niche, or that niche has strict regulations, not allowing the created product to thrive. Next to that, as mentioned before, internal factors such organisational structure and governance could be a reason for failure or success that could overshadow the effect of geographical diversity. Another reason could be that the industry of the standard is concentrated in a specific part of the world due to availability of resources or because of inertia, meaning that it is difficult to change the location of production and development, simply because it has always been in that location. In those cases, geographical diversity has little influence on the likelihood of standard success.

With regards to the standardisation literature, our study recognises the potential subjectivity and ambiguity in defining standard success. By introducing three different dimensions of standard success we see that the way in which standard success is defined has a strong influence on whether or not statistically relevant relationships are observed. By implementing three different dimensions of standard success, we facilitate a more nuanced understanding of what exactly influences standard success. To the best of our knowledge, no other study has attempted to do this. We have shown that the definition of standard success is of great importance when considering relationships that influence it. We have shown that when we define standard success as adoption, that we find the opposite of what our hypothesis suggested. Instead of an optimum we find that there might actually be two extremes of the spectrum. This a notable result that has not been found before in literature. Next to that, in the other two definitions, this effect disappears, again, highlighting the importance of the standard success definition. Similarly, we see that the positive effect of consortium size is present in one of the models but not in the other two, which again shows how important the definition of standard success is. We have also contributed to the literature by providing larger scale quantitative research on the effects of consortium size, geographical diversity and technological diversity of standards consortia on standard success. This was something that was not done before.

5.2 Limitations and future research

This study focused on a specific context, that standards consortia in the context of Renewable energy (RE) and Sustainability, Efficiency and Green Initiatives (SEG) which may limit the generalizability of the findings. Additionally, consortium size may be more important in new markets, where establishing an installed base quickly is essential. Further research could explore other sectors to examine whether similar patterns emerge or if there are other factors that influence the relationship between diversity and standard success.

One limitation is that in the data several multinationals were represented by a single geographic location, meaning that for instance, several companies that have their headquarters situated in the United States actually do have numerous affiliations and subsidiaries in other countries that also represent different industries. This is a common approach, where subsidiaries are specified at the level of their parent organisation (Ahuja, 2000b; M. A. Schilling & Phelps, 2007; Vanhaverbeke et al., 2012). This approach is known as the 'head office assignment', coined by Birkinshaw, Hood, and Jonsson (1998). The idea behind this concept is that subsidiaries are mostly controlled by their parent organizations (Ciabuschi et al., 2011), the parent organisation controls the strategic objectives and the collaborative efforts that arise from following these objectives. Thus, this view states that the strategy of a subsidiary is mostly formed and influenced by the parent company (Birkinshaw et al., 1998; Faems et al., 2005). Therefore, following this view, it is logical to consider the parent company whenever a subsidiary is present in an alliance. However, another view, coined by Birkinshaw, Hood and Jonsson (Birkinshaw et al., 1998), is the 'subsidiary choice'. This approach states that the subsidiary is actually more autonomous and understands its own strategy better than the parent organisation. In this case, it thus is more logical to consider the subsidiary as its own partner in the alliances as opposed to considering the parent company. In this work, we have thus taken the first approach, future research could implement the second approach and see if that has any influence on the results.

Additionally, the Blau index as a measure for diversity may be an oversimplification of reality, it treats all companies in the same industry and country the same, whereas there may be significant differences in culture, and other social aspects between these companies. Moreover, it treats the company as single entity, whereas individuals within companies may be of various different backgrounds, thus providing diversity within the company. That being said, it is extremely difficult to take this into account, therefore, we believe that the Blau index is the best option in this particular research context.

5.3 Practical implications

Our results could aid in managerial decisions when setting up a successful standards consortium. First of all, the focus on geographical representation should be balanced. Managers should set clear objectives and goals, and define what level of diversity is the goal. It may not always be feasible for managers to increase geographical diversity as the consortium and its members may just be located in USA for example, and focussed on this market. This highlights the importance of an ad-hoc approach, where managers should take into account the feasibility of increasing diversity. Although it may still be important to have a diverse representation of stakeholders from different regions, it should not be the sole criterion for membership. Instead, the emphasis should lie on expertise and knowledge of the members. It should be noted that while balancing geographical representation is a sound approach, it requires skilful management. Managers should make a cost-benefit analysis. Managers should assess the potential cost of bringing in partners from different regions against their technical contributions.

Moreover, as for technological diversity, our results indicate that is wise to make a choice beforehand, whether the consortium is all-in on technological diversity or chooses to represent only a single or a couple industries. In the first case, managers should explore potential synergy between technological domains, and thus find members from different industries that complement each other. In the second case, one should refrain from finding members in too many different industries. It seems as though having the expertise of several players in the same industry can lead to success.

Our results also indicate that whenever possible, managers should aim to increase the amount of consortium members, taken into account the aforementioned technological diversity. This is not always achievable or necessary, literature suggests that in the initial formation of a consortium, it may be more beneficial to start off with a smaller group of actors with essential knowledge for the specific standard (M. A. Schilling, 2002). Thus, in the beginning, managers should not aim to attract any company they come about, members should still be carefully selected, again, based on expertise and knowledge or other benefits that a new member can bring. However, after the initial formation, managers should aim to expand the consortium to increase the installed base and adoption of the standard (van den Ende et al., 2012). This approach acknowledges the importance of focus as well as expansion. First, a group of experts lay a solid foundation of the consortium and for the development of the standard. Subsequently, more members allow for wider industry adoption.

It should be noted that should be enough financial support and capacity to accommodate new members and manage their contributions. Next to that, new members should be aligned with the goals of the consortium in order to avoid conflict. Moreover, managers should take into account that if efficient decision making is already a difficult task, adding more members only makes this more difficult. Therefore, expansions should only be considered if enough resources are available, goals are properly aligned with new members and if internal processes are running smoothly.

6. Reflection

All things considered, this research went well. This project flew by, even though there were a few hiccups along the way, meaning we had to postpone the defence to September, this meant that I went through this project relatively stress free. The Management of technology programme had prepared me well for all the necessary steps that I had to take to make this project a success. From statistical analysis to setting up a project plan to doing a literature review in the field of social sciences, all these things were not new to me when I started this project due to the several courses that prepared me for this.

In hindsight, if were to do it all over again, I would probably try to find to a third supervisor more quickly. Although we were a bit unlucky as well with several supervisor agreeing at first, and then cancelling on us a week later. When we did find a third supervisor it felt as though we could really start the project, even though I had already started a few months prior, the filling out of the starting form and truly beginning the project removed mental blockage and allowed me to work more efficiently. Additionally, in hindsight, I would have preferred to spent less time on data collection in the first months of the project and more on setting a well thought out theoretical basis. The data collection took a lot of time and mental capacity, and maybe should have been split in to two parts, where I would first collect data, then read up on the theory and maybe write up the hypotheses, and then collect the remainder of the data.

That being said, the project was a success, due to the great help of my supervisors and teachers of the MOT programme, it was relatively smooth sailing. I felt like I was well prepared for this project, maybe also due to that fact that I had already completed my Chemical Engineering thesis, I was well aware how much time and energy a thesis project takes.

Appendix A: Robustness check

Table 4 - Robustness check for consortium survival as a measure for standard success[a]

Variables	Standard Success					
	6 years or longer		**7 years or longer**		**8 years or longer**	
Step 1: controls						
Constant	3.4139*** (1.1689)	1.0344 (3.0559)	3.6625*** (1.2559)	2.3344 (1.4865)	3.5920*** (1.2080)	0.6728 (2.2378)
Commitment	−0.0066 (0.0179)	−0.0128 (0.0172)	−0.0131 (0.0140)	−0.0131 (0.0140)	−0.0107 (0.0150)	−0.0221 (0.0169)
Economic crisis	0.5672 (1.1332)	0.3888 (1.2515)	0.8538 (1.1266)	0.4572 (1.2255)	0.1625 (0.8822)	−0.1294 (1.0199)
Type of standard	−1.8933 (1.1515)	−1.9743 (1.4017)	−2.3806* (1.2264)	−2.3344 (1.4865)	−2.4862** (1.1745)	−3.3548** (1.5504)
Step 2: main effects						
Geographical diversity		−0.1140 (4.7599)		−0.7107 (4.4642)		−3.1835 (4.4008)
Geographical diversity squared		0.0704 (4.2515)		0.8266 (3.9874)		3.0079 (3.9249)
Technological diversity		1.7598 (5.3542)		−1.1129 (4.9385)		4.6594 (4.9489)
Technological diversity squared		−1.6971 (5.0010)		1.5862 (4.5162)		−2.9291 (4.5078)
Consortium size		1.6272 (2.7575)		1.5894 (1.6313)		2.2087 (1.7257)
Consortium size squared		−0.7488 (0.5406)		−0.2279 (0.3461)		−0.3485 (0.3767)
Log-likelihood	−25.174	−23.721	−27.457	−26.380	−30.195	−27.558

[a] Unstandardized coefficients are reported with standard errors in parentheses. * p < 0.1, ** p < 0.05 , *** p < 0.01

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