Standardization: an interdisciplinary scientific field
Connecting economics, management, and other disciplines

Grillo, F.

DOI
10.4233/uuid:7a164cc0-97d6-4a95-a8e3-d95c7d0be126

Publication date
2025

Document Version
Final published version

Citation (APA)
Grillo, F. (2025). *Standardization: an interdisciplinary scientific field: Connecting economics, management, and other disciplines*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:7a164cc0-97d6-4a95-a8e3-d95c7d0be126

Standardization: an interdisciplinary scientific field

Connecting economics, management, and other disciplines

Filippo Grillo

Standardization: an interdisciplinary scientific field

Connecting economics, management, and other disciplines

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology,

by the authority of the Rector Magnificus, prof.dr.ir. T.H.J.J. van der Hagen,
chair of the Board for Doctorates,
to be defended publicly on

Monday 15th December 2025 at 17.30 o' clock

by

Filippo GRILLO

Master of Science in Innovation and Industrial Management,

University of Gothenburg, Sweden

Master of Science in Management,

LUISS Guido Carli University, Italy

born in Rome, Italy

This dissertation has been approved by the promotors.

Composition of the doctoral committee:

Rector Magnificus,	chairperson
Dr. G. van de Kaa	Delft University of Technology, promotor
Prof. dr. ir. ing. R. N. A. Bekkers	Eindhoven University of Technology, promotor
Prof. em. dr. ir. H. J. de Vries	Erasmus University Rotterdam / Delft University of Technology, promotor

Independent members:

Prof. dr. ir. N. Bharosa	Delft University of Technology
Prof. dr. W. Dolfsma	Open University
Dr. A. Fried	Linköping University, Sweden
Dr. N. Abdelkafi	Politecnico di Milano, Italy
Prof. dr. J.R. Ortt	Delft University of Technology, reserve member

TU Delft Delft University of Technology

Research for this dissertation was funded by the Netherlands Standardization Institute NEN (all chapters), and the International Organization for Standardization ISO (Chapter 5).

Cover design by: Lara Ippolito

Printed by: Gildeprint

ISBN: 978-94-6496-496-7

An electronic version of this dissertation is available at https://repository.tudelft.nl/

Contents

List of Figures

List of Tables

List of Equations

Summary

About a century ago, scientists began to investigate standardization, a phenomenon that has characterized civilizations since ancient times. Throughout history, individuals and organizations needed to develop common technical specifications and use them repeatedly to achieve coordination across a wide range of contexts. Early examples of standards include common units of measurement and the specification of exchange currencies. Their reach grew dramatically with the standardization of assembly lines in factories during the first industrial revolution, and today standards permeate our lives, from standardized paper sizes to freight containers, from test methods for product safety to physical and digital standardized interfaces for our computers.

The development of standardization research underwent three main stages. First, standardization research formed a standalone *academic discipline*, mostly connected to management and engineering. Later, it evolved into a *multidisciplinary scientific field*, especially with the surge of environmental, sociological, and legal investigations on standards. Nowadays, standardization can be considered in all effects an *interdisciplinary scientific field*. The progressive use of interdisciplinary approaches (i.e., combining elements of two or more disciplines in the same studies) is uncovering a set of common theories (which science philosopher Imre Lakatos called "protective belts") about the process of standardization, from the development of standards to their adoption and impact.

However, the development of standardization research is not linear, since the divergence of approaches and terminologies employed by the different research communities is undermining the consistency of the field. This dissertation aims to bring order to this "interdisciplinary" stage of this development. It does so through a twofold research objective: first, it aims to explore the extent to which research on standardization is interdisciplinary; second, it aims to illustrate possible avenues for interdisciplinary research. For this purpose, the dissertation adopts a multi-method approach that spans from literature-based research (both bibliometric and conceptual) to quantitative and qualitative research. The dissertation is organized into an interdisciplinary literature review (Chapter 2) and three illustrative interdisciplinary studies (Chapters 3-4-5).

After an Introduction (Chapter 1) describing the status of standardization as a scientific field and its interdisciplinarity, Chapter 2 of this thesis consists of a comprehensive review of the standardization literature. The chapter reviews the

landscape of standardization research and maps its disciplinary breadth over the 2012-2021 decade. This includes a bibliometric and network analysis of the main academic disciplines and topics in standardization research. The results of this analysis provide several insights into the most impactful trends of standardization research and, most importantly, showcase the central role of economics and management as the two most theory-oriented disciplines, connecting all other disciplines and contributing to the theoretical consistency of the field of standardization.

The first of the three illustrative interdisciplinary studies is contained in Chapter 3. The chapter bridges elements from economics/management and sociology by proposing a framework to measure the adoption of standards and platforms in the presence of network effects. The framework integrates economics and management theories of technology adoption with social network theory to rethink how standards and platform technologies gain value as more users adopt them. This involved the use of some mathematical and combinatorics notions to rethink how the structure of networks (such as their density and number of sides) affects their value more than just their size. Besides the theoretical gap in the partial understanding of network structure for standards and platforms, the chapter addresses a practical problem concerning the dominance of technologies based on standards or platforms.

The second illustrative study is presented in Chapter 4 and is a quantitative exploration of the economic effects of standardization. The chapter investigates the participation of firms in the development of standards in the information and communication technology (ICT) sector. Using a dataset on firms' membership in technical standard-setting organizations (SSOs) from 1996 to 2014, the chapter tests how different factors – a firm's participation in any SSO, the level of competition among firms in those SSOs, and the SSO's size – influence the firm's economic performance in terms of productivity. The study zooms in on focused standardization players (FSPs), i.e., firms participating in only one SSO in a given year, and unveils counterintuitive dynamics on how these firms can yield benefits in a setting that is usually dominated by large multi-technology firms.

The last illustrative study presented in Chapter 5 is a qualitative exploration of the role of standardization for place-based and time-based adaptation, taking the case of adaptation to sea-level rise (SLR). Based on the theories of economic geography and climate adaptation, the article sheds light on an important debate about standards and standardization: their ability to address place-specificity and evolving scenarios, labeled as "flexible standardization" in the chapter. The analysis triangulates three rich sources of data: a systematic review of adaptation measures to SLR and their corresponding existing standards, semi-structured interviews with experts in the field, and a Q-method survey to understand consensus among experts' groups. The systematic review unveiled an evident gap in SLR adaptation between what can be standardized and what is already standardized. Based on the deliberation of experts, the study proposes a flexible standardization framework that, considering factors such as morphological features and levels of technological maturity, can adapt to different places and over time.

Across these studies, the dissertation concludes that standardization can be viewed as an interdisciplinary scientific field and that interdisciplinarity helps the field of standardization achieve theoretical consistency more than monodisciplinarity. Besides showing the status of this interdisciplinarity, the thesis illustrates how interdisciplinary approaches facilitate the emergence of common theories across disciplines, which, together with a solid research community, are the basis for a unified and consistent scientific field. The thesis makes a first attempt at establishing some of these common theories in the Conclusions (Chapter 6). These theories, or "protective belts", include the multiple levels of analysis that standardization research can assume (micro, meso and macro, employed in Chapter 3-4-5 respectively), the function of standardization as a coordination mechanism (of individuals, firms, and policymakers), the different types of values it can create (network value in Chapter 3, economic value in Chapter 4, and environmental value in Chapter 5), and the different paradoxes intrinsic to standardization (e.g., the non-linear returns from network effects, the duality between specialized and multi-technology firms during standard setting, and the tension between rigidity and flexibility).

The purpose of this dissertation is not just to show the importance and pervasiveness of standards, but the importance of studying the process behind standards with an all-encompassing lens, understanding their technical contribution but also their economic implications, their legal status, and their ethical, sociological, and environmental impacts. More cross-fertilization of currently isolated communities represents a pivotal step for the progress of the field and for a better understanding of standards. Such an understanding, because of the ubiquity and wide impact of standards, will benefit everyone in our society.

Sommario

Circa un secolo fa, gli studiosi iniziarono a indagare il fenomeno della standardizzazione (o normazione), una caratteristica che ha contraddistinto le civilizzazioni sin dall'antichità. Nel corso della storia, individui e organizzazioni hanno spesso avuto la necessità di sviluppare riferimenti tecnici comuni e di usarli in svariati contesti, ripetutamente, per coordinarsi fra di loro. Esempi antichi di standard includono le unità di misura e le valute di scambio. La loro diffusione crebbe in modo esponenziale con la standardizzazione delle catene di montaggio durante la prima rivoluzione industriale, e oggi gli standard permeano la nostra vita quotidiana, dai formati di fogli di carta ai container merci standard, dai metodi di testing per la sicurezza dei prodotti alle interfacce fisiche e digitali dei nostri computer.

Lo sviluppo della ricerca sulla standardizzazione ha attraversato tre principali fasi. Inizialmente, essa si è costituita come disciplina accademica autonoma, principalmente legata al management e all'ingegneria. Successivamente, si è evoluta in un campo scientifico multidisciplinare, specialmente con l'aumento degli studi ambientali, sociologici e giuridici sugli standard. Oggi, la standardizzazione può essere considerata a tutti gli effetti un campo scientifico interdisciplinare. L'adozione progressiva di approcci interdisciplinari (ossia che combinano elementi di due o più discipline in uno stesso studio) sta facendo emergere un insieme di teorie comuni (che il filosofo della scienza Imre Lakatos definiva "cinture protettive") sul processo di standardizzazione, dalla fase di sviluppo degli standard fino alla loro adozione e impatto.

Tuttavia, tale processo non è lineare: la divergenza negli approcci e nelle terminologie impiegate dalle diverse comunità di ricerca sta minando la coerenza di questo campo scientifico. Questa tesi si propone di portare ordine in questa fase "interdisciplinare" del processo, attraverso un duplice obiettivo: da un lato, esplorare il grado di interdisciplinarità della ricerca sulla standardizzazione; dall'altro, individuare nuove direzioni possibili per la ricerca interdisciplinare. A tal fine, la tesi adotta un approccio multi-metodo, che spazia dalla ricerca bibliografica (sia bibliometrica che concettuale) alla ricerca quantitativa e qualitativa. La tesi è strutturata in una rassegna interdisciplinare della letteratura (Capitolo 2) e tre studi interdisciplinari esemplificativi (Capitoli 3-4-5).

Dopo un'Introduzione (Capitolo 1) che descrive lo stato della standardizzazione come campo scientifico e la sua interdisciplinarità, il Capitolo 2 presenta una

rassegna completa della letteratura sulla standardizzazione. Il capitolo analizza il panorama della letteratura e ne mappa l'ampiezza disciplinare nel decennio 2012–2021, includendo un'analisi bibliometrica e cosiddetta "di rete" delle principali discipline e tematiche. I risultati offrono diversi spunti sui trend più rilevanti della ricerca e mettono in luce il ruolo centrale dell'economia e del management, le due discipline più orientate alla teoria, come elementi di connessione tra le altre discipline e garanti della coerenza teorica del campo.

Il primo dei tre studi interdisciplinari è contenuto nel Capitolo 3. Esso integra elementi di economia/management e sociologia, proponendo un framework per misurare l'adozione di standard e piattaforme digitali in presenza di effetti di rete. Il framework fonde le teorie economico-manageriali sull'adozione tecnologica con la teoria dei social network, per ripensare il modo in cui gli standard e le piattaforme acquisiscono valore man mano che aumentano gli utenti. Il modello utilizza anche concetti matematici e di calcolo combinatorio per considerare come la struttura delle reti (es. densità o numero di gruppi) incida sul loro valore più della mera dimensione. Oltre a colmare un gap teorico sulla comprensione parziale della struttura delle reti in questo contesto, il capitolo affronta anche un problema pratico legato alla dominanza di tecnologie basate su standard e piattaforme.

Il secondo studio, nel Capitolo 4, è un caso studio quantitativo sugli effetti economici della standardizzazione. L'analisi esamina la partecipazione delle imprese allo sviluppo degli standard nel settore delle tecnologie dell'informazione e della comunicazione (ICT). Utilizzando un dataset relativo alla partecipazione delle imprese agli enti di standardizzazione tecnica (SSO) dal 1996 al 2014, il capitolo testa come diversi fattori – la partecipazione a uno o più SSO, il livello di competizione all'interno di tali SSO e la loro dimensione – influenzino le performance economiche in termini di produttività. Lo studio si concentra in particolare sui cosiddetti *Focused Standardization Players* (FSP), ovvero imprese che partecipano a un solo SSO in un dato anno, e svela dinamiche controintuitive su come queste imprese possano trarre vantaggio in un contesto solitamente dominato da grandi imprese con un vasto portfolio di tecnologie.

Il terzo e ultimo studio, nel Capitolo 5, è un'esplorazione qualitativa del ruolo della standardizzazione nell'adattamento all'innalzamento del livello del mare (SLR). Basato sulle teorie della geografia economica e dell'adattamento climatico, lo studio affronta un dibattito centrale: la capacità degli standard di rispondere alla specificità dei luoghi e agli scenari in evoluzione, concetto coniato nel capitolo come "standardizzazione flessibile". L'analisi si basa su tre fonti principali di dati: una revisione sistematica delle misure di adattamento al SLR e dei relativi standard esistenti, interviste semi-strutturate ad esperti del settore, e un sondaggio basato sul metodo "Q" per analizzare il consenso tra gruppi di esperti. La revisione sistematica ha messo in luce un chiaro divario tra ciò che è standardizzabile e ciò che è già standardizzato. Basandosi sulle opinioni degli esperti, lo studio propone un framework di standardizzazione flessibile che, tenendo conto di fattori come le caratteristiche morfologiche del territorio e il grado di maturità tecnologica delle misure di adattamento, possa adattarsi ai diversi contesti spaziali e temporali.

Attraverso questi studi, la tesi conclude che la standardizzazione può essere considerata un campo scientifico interdisciplinare, e che l'interdisciplinarità contribuisce alla coerenza teorica più della monodisciplinarità. Oltre a mostrare lo stato attuale di questa crescente interdisciplinarità, la tesi discute come tali approcci facilitino l'emergere di teorie comuni tra le discipline, le quali – insieme a una solida comunità di ricerca – costituiscono la base di un campo scientifico unificato e coerente. Nelle Conclusioni (Capitolo 6), la tesi compie un primo tentativo di definizione di alcune di queste teorie comuni, o "cinture protettive", tra cui: i diversi livelli di analisi (micro, meso e macro, rispettivamente trattati nei Capitoli 3-4-5), la funzione della standardizzazione come meccanismo di coordinamento (tra individui, imprese ed enti politici), i diversi tipi di valore che essa può generare (valore di rete, economico, ambientale), e i paradossi intrinseci alla standardizzazione (es. ritorni non lineari degli effetti di rete, dualità tra imprese "focalizzate" e multi-tecnologiche, tensione tra rigidità e flessibilità del processo).

Lo scopo della tesi non è solo evidenziare l'importanza e la pervasività degli standard, ma anche sottolineare quanto sia cruciale studiare il processo alla base della loro creazione e diffusione con una prospettiva olistica, che consideri sì gli aspetti tecnici, ma anche quelli economici, giuridici, etici, sociologici e ambientali. Una maggiore contaminazione tra comunità di ricerca attualmente isolate rappresenta un passo fondamentale per il progresso del campo e per una comprensione più completa degli standard. Tale comprensione, data l'ubiquità e l'impatto diffuso degli standard, porterà benefici a tutta la società.

Samenvatting

Ongeveer een eeuw geleden begonnen wetenschappers normalisatie (vaak aangeduid met het anglicisme standaardisatie) te onderzoeken. Dit fenomeen bestaat overigens al sinds de oudheid. Door de geschiedenis heen moesten individuen en organisaties vaak gemeenschappelijke technische specificaties ontwikkelen en deze herhaaldelijk gebruiken om coördinatie in uiteenlopende contexten te bereiken. Vroege voorbeelden van normen zijn onder andere gemeenschappelijke maateenheden en de specificatie van ruilmunten. De reikwijdte van standaarden groeide aanzienlijk met de standaardisatie van lopende banden tijdens de eerste industriële revolutie. Vandaag de dag zijn standaarden overal aanwezig: van gestandaardiseerde papierformaten tot vrachtcontainers, van testmethoden voor productveiligheid tot fysieke en digitale gestandaardiseerde interfaces voor onze computers.

De ontwikkeling van onderzoek naar standaardisatie verliep in drie hoofdfasen. In de eerste fase ontstond standaardisatieonderzoek als een zelfstandige academische discipline, voornamelijk verbonden aan management en techniek. Later evolueerde het tot een multidisciplinair wetenschapsgebied, vooral dankzij de opkomst van milieu-, sociologisch en juridisch onderzoek naar standaarden. Tegenwoordig wordt standaardisatie beschouwd als een volwaardig interdisciplinair wetenschapsgebied. Het toenemende gebruik van interdisciplinaire benaderingen (waarbij elementen uit meerdere disciplines in één onderzoek worden gecombineerd) heeft geleid tot een reeks gemeenschappelijke theorieën (door de wetenschapsfilosoof Imre Lakatos "beschermende gordels" genoemd) over het standaardisatieproces, van normontwikkeling tot adoptie en impact.

Het proces is echter niet lineair, omdat de uiteenlopende benaderingen en terminologieën van verschillende onderzoeksgemeenschappen de consistentie binnen het vakgebied ondermijnen. Dit proefschrift heeft als doel orde te scheppen in deze "interdisciplinaire" fase. Dit gebeurt via een tweeledig onderzoeksdoel: ten eerste de mate van interdisciplinariteit in standaardisatieonderzoek verkennen, en ten tweede mogelijke nieuwe richtingen voor interdisciplinair onderzoek identificeren. Hiervoor hanteert het proefschrift een multi-methodologische aanpak, variërend van literatuuronderzoek (zowel bibliometrisch als conceptueel) tot kwantitatief en kwalitatief onderzoek. De opbouw bestaat uit een interdisciplinaire literatuurstudie (hoofdstuk 2) en drie illustratieve interdisciplinaire studies (hoofdstukken 3-4-5).

Na de Inleiding (hoofdstuk 1), waarin de status van standaardisatie als wetenschapsgebied en haar interdisciplinariteit wordt besproken, bevat hoofdstuk 2 een uitgebreide literatuurstudie over standaardisatie. Het hoofdstuk analyseert het onderzoekslandschap en brengt de disciplinaire breedte in kaart, onder andere via een bibliometrische en netwerkanalyse van de belangrijkste academische disciplines en thema's in de periode van 2012 tot 2021. De resultaten laten enkele belangrijke trends zien en onderstrepen de centrale rol van economie en management. Deze theoriegedreven disciplines verbinden alle andere disciplines met elkaar en dragen bij aan de theoretische samenhang van het vakgebied.

Het eerste van de drie illustratieve onderzoeken, in hoofdstuk 3, combineert economie/management en sociologie door een raamwerk te ontwikkelen om de adoptie van standaarden en platformen bij netwerkeffecten te meten. Dit raamwerk integreert theorieën over technologieadoptie met theorie over sociale netwerken om te heroverwegen hoe standaarden en platformtechnologieën aan waarde winnen naarmate meer gebruikers ze toepassen. Hiervoor zijn ook wiskundige en combinatorische begrippen gebruikt om te laten zien hoe netwerkstructuur (zoals dichtheid en aantal zijden) de waarde beïnvloedt, meer dan alleen de omvang. Naast een theoretische bijdrage over het onvolledige begrip van netwerkstructuren bij standaarden en platformen, behandelt dit hoofdstuk ook een praktisch probleem omtrent dominantie van op standaarden of platformen gebaseerde technologieën.

Het tweede onderzoek, in hoofdstuk 4, is een kwantitatieve casestudy over de economische effecten van standaardisatie. Het onderzoekt hoe deelname van bedrijven aan de ontwikkeling van standaarden in de ICT-sector hun productiviteit beïnvloedt. Gebruikmakend van een dataset over lidmaatschappen van bedrijven in technische standaardisatieorganisaties (SSO's) van 1996 tot 2014, wordt geanalyseerd hoe factoren zoals deelname aan een SSO, de mate van concurrentie binnen SSO's en bedrijfsgrootte van invloed zijn op economische prestaties. De focus ligt op zogeheten *Focused Standardization Players* (FSP's), oftewel bedrijven die in een bepaald jaar slechts aan één SSO deelnemen. Opvallend is dat deze veelal kleinere bedrijven toch baat kunnen hebben bij deelname in een veld dat normaal gesproken wordt gedomineerd door grote, multi-technologische ondernemingen.

Het derde en laatste onderzoek, in hoofdstuk 5, is een kwalitatieve verkenning van de rol van standaardisatie bij plaats- of tijdgebonden aanpassingen, aan de hand van een case over aanpassingen aan de zeespiegelstijging (SLR). Op basis van theorieën uit de economische geografie en klimaatadaptatie belicht het hoofdstuk een belangrijk debat: in hoeverre kunnen standaarden worden aangepast aan plaatsgebonden omstandigheden en veranderende situaties – een concept dat hier "flexibele standaardisatie" wordt genoemd. De analyse combineert drie soorten gegevens: een systematisch overzicht van bestaande SLR-maatregelen en de bijbehorende standaarden, semigestructureerde interviews met experts, en een Q-methodologie-onderzoek waarmee consensus tussen expertgroepen kan worden gemeten. De studie laat een duidelijke kloof zien tussen wat er gestandaardiseerd *kan* worden en wat er daadwerkelijk gestandaardiseerd *is*. Op basis van expertinzichten wordt een raamwerk voor flexibele standaardisatie voorgesteld, waarmee standaarden kunnen worden aangepast aan verschillende contexten en tijdsschalen, om recht te doen aan factoren zoals morfologie en technologische volwassenheid.

Mede op basis van deze drie onderzoeken concludeert het proefschrift dat standaardisatie gezien kan worden als een interdisciplinair wetenschapsgebied, en dat interdisciplinariteit de theoretische samenhang beter bevordert dan monodisciplinariteit. Naast het aantonen van de toenemende interdisciplinariteit, bespreekt het proefschrift hoe dergelijke benaderingen de opkomst van gemeenschappelijke theorieën over disciplines heen vergemakkelijken. Samen met een sterke onderzoeksgemeenschap vormen deze theorieën de basis van een consistent en verenigd wetenschapsgebied. In de Conclusie (hoofdstuk 6) wordt een eerste poging gedaan om enkele van deze theorieën, of "beschermende gordels", te formuleren. Deze omvatten de verschillende analyseniveaus (micro, meso en macro, respectievelijk toegepast in hoofdstuk 3, 4 en 5), de functie van standaardisatie als coördinatiemechanisme (voor individuen, bedrijven en beleidsmakers), de diverse vormen van waarde-creatie (netwerkwaarde, economische waarde en ecologische waarde), en de paradoxen die inherent zijn aan standaardisatie (bijv. niet-lineaire opbrengsten van netwerkeffecten, de dualiteit tussen gespecialiseerde en multi-technologische bedrijven, en de spanning tussen starheid en flexibiliteit).

Het doel van dit proefschrift is niet alleen om het belang en de alomtegenwoordigheid van standaarden aan te tonen, maar ook om het belang te onderstrepen van een brede studie van het standaardisatieproces – met aandacht voor technische, economische, juridische, ethische, sociologische en ecologische dimensies. Meer kruisbestuiving tussen momenteel geïsoleerde onderzoeksvelden is essentieel voor de vooruitgang van het vakgebied en voor een beter begrip van standaarden. Dit laatste is vooral belangrijk omdat standaarden, door hun alomtegenwoordige en verstrekkende impact, iedereen in de samenleving ten goede komen.

1. Introduction

The global challenges that our society is facing to date are associated with coordination failures between actors, such as public institutions, private organizations, or individuals. For instance, global warming persists due to the difficulty of aligning national policies, corporate interests, and individual behaviors to reduce emissions effectively. Trade wars arise when countries prioritize short-term national gains over international trade stability, disrupting global supply chains. Cybersecurity threats escalate as governments, businesses and individuals struggle to enforce and adopt cohesive security measures, leaving vulnerabilities that cybercriminals can exploit.

To avoid these coordination failures, actors need coordination mechanisms, namely tools that incentivize these actors to act for a common specific mission or interest (Mintzberg, 1980). "Authority" and "faith" are two examples of coordination mechanisms: actors can perform a task because of rules imposed hierarchically (authority) or because that is expected by the doctrines of their religion (faith) (Bulbulia, 2012; Martinez & Jarillo, 1989). When actors lack a coordination mechanism and the cited societal challenges exacerbate, so-called transaction costs increase (Coase, 1937; Gulati & Singh, 1998). These costs can be of financial nature, or involve – for example – burdensome compliance with different regulatory regimes, irreversible environmental costs, and corresponding opportunity costs.

This doctoral thesis explores standardization, a unique and compelling coordination mechanism (Martinez & Jarillo, 1989; Mintzberg, 1980; Thompson et al., 1967). As will be discussed in the second chapter of this thesis, research about standardization covers multiple disciplinary fields, also reflecting the presence of standards in numerous fields and industries. This chapter contains a systematically derived definition for standardization, which describes its intrinsic function of coordination mechanism. That is 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". The resulting set of solutions, often expressed in the form of a written document, is the "standard".

The standardization literature permeates multiple academic disciplines and has been growing in recent years. Besides this multidisciplinarity, three characteristics distinguish standardization from other coordination mechanisms. First, the actors involved can democratically decide "how" to coordinate: formal standards normally require the consensus of the same actors (or a representative sample) that, to a large extent, will later adopt the standards (Bekkers & Lazaj, 2025; Melnitsky, 1953), while informal standards become dominant often due to the broad support they receive in the market (van de Kaa et al., 2011). Second, because the adoption of standards is initially voluntary (Baynard, 1982), and may become obligatory de-jure when mandated by law or de-facto if they achieve market dominance or because customers prescribe them in contracts. Third, because adopting standards helps reach efficiency and economies of scale, thus inherently reducing the cited transaction costs (Katz & Shapiro, 1985).

It is thus not surprising that standardization is widely discussed as a fundamental multi-stakeholder approach to face such a variety of societal challenges. The three cited examples of societal challenges can witness this importance: global warming is addressed, among many others, by the ISO 14000 series of standards (Boiral, 2007; Boiral et al., 2018); standards contained in the WTO agreements on the technical barriers to trade help establish efficient and reliable global supply chains (World Trade Organization, 2021); the European General Data Protection Regulation (GDPR) refers to standardized practices that reduce the risk of data breaches (European Parliament & European Council, 2016).

The pervasiveness of standards is reflected in the many disciplines studying standardization (e.g., economics, management, computer science, engineering, law, sociology, sustainability, and ethics). This *multidisciplinary* nature poses several opportunities for the field of standardization, but also an important tension. The study of standards in different academic disciplines may result in sparse approaches, terminologies, definitions, research methods, and a general isolation between research communities. However, the field of standardization research is also increasingly *interdisciplinary*. Interdisciplinarity occurs when two or more disciplines involved in standardization research are combined in the same study, and not separated as in multidisciplinary ones (Aboelela et al., 2007; Choi & Pak, 2006). In this context, pursuing interdisciplinarity helps establish common theories and a common language that transversely apply to standards in different fields and industries, thus strengthening the theoretical consistency of the field more than multidisciplinarity.

Here lies the fulcrum of this dissertation. Standards are often reflective of the state-of-the-art technologies, thus pushing for theoretical development about standards and standardization is important to both researchers and practitioners. This dissertation addresses the need for further interdisciplinary research for such a purpose. A review of the standardization literature (Chapter 2) shows, through a bibliometric network analysis, that "economics and management" is the central discipline that stimulates the theoretical advancement of the field. Later, the dissertation continues with three illustrative interdisciplinary articles studying, jointly, economics and management and one other academic discipline: sociology in Chapter 3, IT and engineering in Chapter 4, and ethics and sustainability in Chapter 5.

Altogether, while Chapter 2 provides a detailed overview of how the disciplines are connected through interdisciplinary studies, the three illustrative articles presented in Chapters 3 to 5 witness how using an interdisciplinary approach helps address theoretical and practical challenges of standardization, and stimulates the establishment of an interdisciplinary scientific field. Furthermore, the four chapters employ different methodologies (literature review, conceptual, quantitative, qualitative), showing the breadth of approaches that standardization research can adopt. The next two sections explain the premises for standardization to be considered an interdisciplinary scientific field. Later, the research objective and the outline of this dissertation are presented, together with the positioning of the four chapters in the standardization literature.

1.1 Standardization as a scientific field

The title of this dissertation contains two important concepts worth further clarification: "scientific field" and "interdisciplinarity". This paragraph elaborates on the former aspect. Scholars of *science of science* and *philosophy of science* have long studied the emergence and evolution of scientific fields, and the increasing availability of empirical and academic data facilitates this task (Fortunato et al., 2018).

Verman (1973) was the first to refer to standardization as a discipline, with a strong connection to engineering and metrology. In 2001, however, de Vries argued that it could not be defined as an academic discipline due to the lack of "own" scientific approaches besides some in the field of "business science". Research on standardization, however, has evolved ever since, and novel approaches outside of business science and engineering are being debated now, for example on the inclusion of ethical acceptance as a stage of the standardization process (Gordon &

Fomin, 2019), or the legal status of international standards referred to in law (Eliantonio & Medzmariashvili, 2017).

This thesis advocates that it is more appropriate to label standardization as a scientific field than an academic discipline. Although the two concepts are similar in defining "areas of knowledge", what distinguishes scientific fields is the presence of an underlying scientific method and reproducibility. Academic disciplines may be based on a scientific method as well, but for scientific fields this is a sine qua non condition. That is why there are some disciplines that are generally not considered scientific fields. This may be because they have a descriptive, rather than scientific, character (think of art and literature) or because they are what Karl Popper (1934) defines "metaphysical", namely that cannot be proven wrong because they only rely on inductive reasoning (e.g., inductive logic). The capacity of being proven wrong, which Popper calls "falsifiability", is thus a requirement for a scientific field to be qualified as such.

Formerly, a scientific field was seen as a set of theories emerging from proven knowledge (inductive reasoning). Starting from the 1930s, philosophers such as Karl Popper, Thomas Kuhn and Imre Lakatos observed how both deductive and inductive logics, and a combination of these, could generate a set of theoretical and methodological patterns, which Kuhn calls "paradigms" (Kuhn, 1962). According to them, a scientific field is typically formed when a scientific community acknowledges these paradigms for a period of time and investigates their consequences in practice (Kuhn, 1962; Lakatos & Musgrave, 1970). Furthermore, scientific fields are often broader than a single academic discipline and embrace multiple ones (Lakatos & Musgrave, 1970).

Standardization complies with all four cited characteristics of a scientific field: a combination of inductive and deductive logic, falsifiability, the establishment of a research community, and a connection to multiple disciplines. The emergence of this field started around one century ago, when the first sources on industrial standardization research could be retrieved (Brady, 1929; Condit, 1928; Gaillard, 1934). Brady (1929) stated that "there are questions about the effects of standardization which cannot be answered, even tentatively, by an appeal to evidence". Throughout the decades, however, theoretical notions on standards common to multiple fields were established "inductively" based on observing the consequences of standardizing, for example their impact at the societal, economic, and environmental level (Blind et al., 2017; de Vries & El Osrouti, 2019; Manders, 2015). Likewise, some theories drawn from other research streams "deductively" led to hypotheses that could be tested in standardization contexts, such as the laws and factors driving their dominance (van de Kaa & de Vries, 2015), or the stages behind the different modes of standardization (Farrell & Saloner, 1988; Wiegmann et al., 2017).

Some dogmas about standardization are also falsifiable, resulting in paradoxes that, according to Popper's principle of falsifiability, characterize standardization as a scientific field and not as a universal (or metaphysical) law (e.g., Kim, 2024; van den Ende et al., 2012). Examples of paradoxes, such as the value creation driven by network effects that lead to one dominant standard, or the fact that standards block innovation by creating technical lock-ins, are disproved in this thesis. These and numerous other paradoxes stimulated the creation of a well-built research community, with dedicated research institutions[1], journals[2], and academic conferences[3], that acknowledge commonalities and differences across disciplines and industries (e.g., the process approach, the types of standards, market dynamics and battles, adoption and network effects, their functions and goals, and their impacts).

Lastly, standardization research can be defined as a scientific field because it engages with multiple disciplines. The second chapter of this thesis provides a holistic and quantitative description of this aspect, thus requiring no further attention at this stage.

1.2 Interdisciplinarity in standardization research

The multiplicity of disciplines leads us to the second and most important element of this thesis' title: the interdisciplinary approach to study standardization. Scholarly communities in fields such as engineering, sustainability or sociology, have shown a different understanding of the common features of standards, studied them for disparate purposes, and employed a scattered terminology in doing so. In the second chapter of this thesis, I argue that this divergence between disciplines hampers the theoretical consistency of the scientific field of standardization, and that an

---

[1] For example, the European Academy for Standardisation (EURAS), the (Korean) Society for Standards and Standardisation, and the ISO Research and Innovation (R&I) Department.
[2] For example, the Journal of Standardisation, Computer Standards and Interfaces, and the International Journal of Services and Standards.
[3] For example, the Standardization and Innovation in Information Technology (SIIT) conferences and the Annual Empirical Research Conference on Standardization at Northwestern University, Chicago.

interdisciplinary approach is needed for this purpose. This need is confirmed by recent advancements in science of science arguing that scholars are increasingly risk averse, tending to remain within their research field rather than investigate new ones, and limiting the creation of novel knowledge (Fortunato et al., 2018).

A call for an interdisciplinary science to standardization is thereby timely, but it is also long-held. Standards appeared to be more than just engineering artifacts when they started to emerge in "product design, production management, packaging and shipping, purchasing, inventory and storeskeeping" (Melnitsky, 1953). The first explicit mention of the "interdisciplinarity" of standardization research dates back to 1997, when Wilfried Hesser held a workshop on this topic in Sweden (Hesser, 1997). The takeaways of this workshop proved that standardization was not just a multidisciplinary phenomenon, but that it needed interdisciplinary cross-fertilization to respond to the paradoxes of the field.

Years later, the book "Standardisation in Companies and Markets" (Hesser et al., 2010) provided the first integrative view on standardization, discussing, among others, the role of standardization in law, business strategy, product design, and environmental policy, also drawing theoretical notions across use-cases on, e.g., conformity assessment and the relationship between standardization and innovation. After 15 years, the world of standards' development is facing new challenges in relation to, among others, the sprawl of digital platforms, the geopolitical tensions in standard setting, and new problems associated with climate change, thus requiring a novel, updated view on the field and an interdisciplinary response to some of the persisting paradoxes.

1.3 Research objective, thesis outline, and theoretical positioning

The proposal described in the previous sections leads to our research objective. The tension between the long-held multidisciplinarity and the increasing interdisciplinarity of standardization research poses a threat to the future of the standardization community. Issues related to multidisciplinarity in standardization research were already raised by Verman in 1973:

"Even when a number of fairly clear-cut discipline-wise divisions has been created within a standards organization, questions arise as to which division could a given subject be allotted. For example, should household refrigerators go to the engineering division or to the electrical, or perhaps to the consumer products?".

Besides the clear emphasis on "engineering" standardization, the refrigerator example of Verman shows how the isolation of these disciplines already appeared as problematic in practice. Interdisciplinary studies have been proven to help scientific fields achieve theoretical consistency and grow further (Fortunato et al., 2018; Larivière et al., 2015). For this purpose, this thesis' objective is twofold: first, it aims to explore the extent to which research on standardization is interdisciplinary; second, it aims to illustrate further possible avenues for interdisciplinary research.

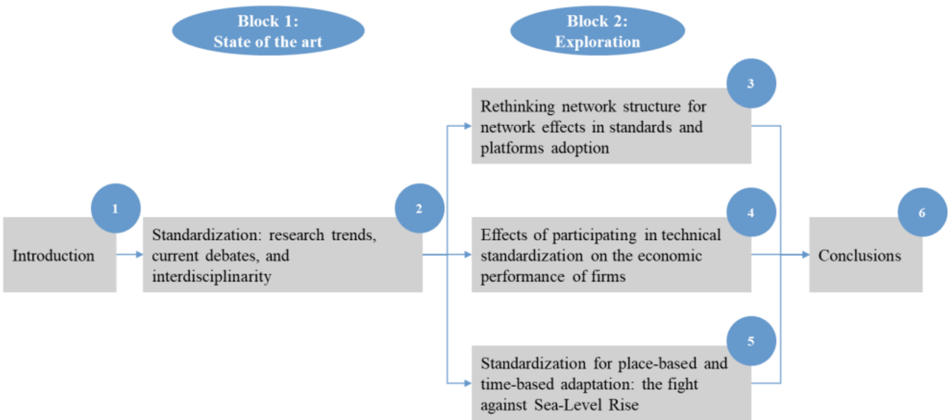


Figure 1-1 – Outline of the thesis

To address this objective, this thesis is divided into two main building blocks (Figure 1-1). The first block (Chapter 2) is a review of the standardization literature between 2012 and 2021, where definitions, foundational research, and research topics for each academic discipline are discussed. Here, the connections between academic disciplines and between research topics are described through a network analysis of 1,313 high-impact articles. This analysis highlights, among other findings, that "economics and management" is the discipline with the highest number of connections to all other disciplines, and provides more "horizontal" knowledge, namely the theoretical knowledge that applies transversely to all disciplines studying standardization.

The second block contains three interdisciplinary studies that exemplify how blending two or more disciplines into one investigation can contribute to the progress of a scientific field. The studies were purposively selected to address three timely theoretical gaps related to standardization. Each study intersects economics and management with another discipline, and fills a theoretical gap, each using a different method (conceptual, quantitative and qualitative) and a different level of analysis (micro - individuals, meso – firms, and macro – governments and standard bodies). Altogether, the four chapters represent four diverse contributions to the field of standardization, with both theoretical and practical implications. The four problems addressed and information concerning their research questions, methods, and their positioning in the related literature are summarized in Table 1-1 and elaborated in the next sub-sections.

Chapter	Problem	Method	Disciplines	Research streams
2	Need for interdisciplinary research	Literature review	All disciplines	Philosophy of science, management science
3	Adoption through network effects	Conceptual	Economics and management; sociology	Technology adoption, social network theory
4	Competing interests in technical standardization	Quantitative	Economics and management; IT & engineering	Economics of technology, technical standardization
5	Lock-in for climate adaptation challenges	Qualitative	Economics and management; ethics and sustainability	Economics of geography, climate adaptation

Table 1-1 – Summary of the chapters

1.3.1 Chapter 2: the need for interdisciplinary research

Chapter 2 is entitled "Standardization: research trends, current debates, and interdisciplinarity". It responds to the following research question: "What is the state of the art of the interdisciplinary literature on standardization?". This chapter consists of a bibliometric review of ten years of standardization literature (2012-2021). Starting from 6,900 sources, 1,313 high-impact articles were extracted. Each of these articles was categorized with one or two academic disciplines and one or two topics. After a thorough and collective thematic analysis, we mapped the academic disciplines involved in the standardization literature according to their co-occurrence in articles. The resulting network of academic disciplines is displayed in Figure 1-2. Here, the size of the disciplines represents the number of high-impact articles (IT/Engineering being the largest discipline with 406 articles). The size of the links between disciplines represents the number of interdisciplinary articles building on both connected disciplines (Economics/management being the most connected discipline with 167 interdisciplinary articles).

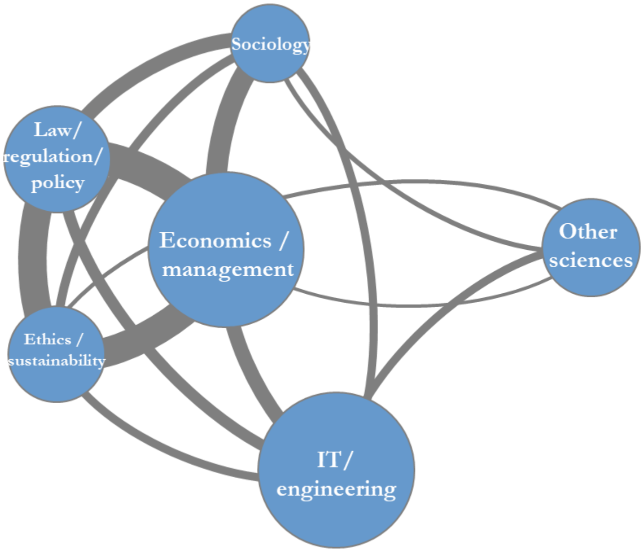


Figure 1-2 – The academic disciplines of standardization

The chapter provides a full-stack review of the literature. It includes detailed statistics on the articles' disciplines and topics, their connections, their trend over the ten years and the most recurring journals. It also provides a systematic collection of definitions of standardization across disciplines and a description of the most impactful articles per discipline. Most importantly, it clusters the literature into four research perspectives, and for each perspective, it discusses its "horizontal" orientation, which is the percentage of articles describing standardization theory, as opposed to the "vertical" orientation, which defines articles focused on the content or application of individual standards. Building on Imre Lakatos's theory about scientific programs (Lakatos, 1970), the article describes interdisciplinarity as a way to achieve theoretical consistency in the field of standardization.

1.3.2 Chapter 3: the problem of adoption through network effects

Chapter 3 is entitled "Rethinking network structure for network effects in standards and platforms adoption". It responds to the following research question: "How can the value of standards and platforms be measured through network effects?". The chapter, as shown in Figure 1-3, combines insights from economics/management and sociology. More specifically, it questions the general assumption, in the technology adoption literature, that the adoption of standards and platforms generates positive quadratic returns due to network effects. Likewise, it contributes to the field of social network theory, where the density of social networks is usually computed using the same assumption.

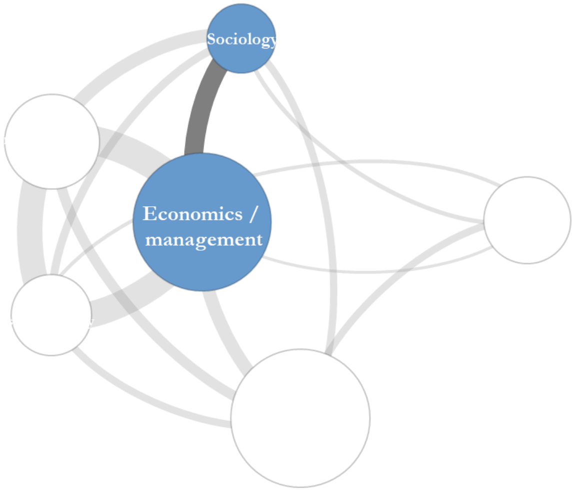


Figure 1-3 – The disciplinary nexus explored in Chapter 3

To solve these wrong assumptions, the paper combines formulas and concepts from the technology adoption literature and social network theory (e.g., negative network effects, competition between adopters, tie multiplexity, and multisidedness) into a framework to measure network value, considering the structure of a network of standards/platforms' adopters. Besides its theoretical relevance, the article has a fundamental implication in practice. Standards, as part of larger technological platforms, may achieve market dominance because of network effects, ruling out potential competitors and forcing users to adopt sub-optimal technologies. The diffusion of social media platforms and the increased globalization of the last 15 years exacerbated this problem, facilitating the feedback loops that induce users to adopt standards. This raised a fervent debate about their regulation, and estimating the value that the sponsors of standards appropriate from their users' networks is of utter importance for regulators.

1.3.3 Chapter 4: competing interests in technical standardization

Chapter 4 is entitled "Effects of participating in technical standardization on the economic performance of firms". It responds to the following research question: "What is the relationship between firms' participation in technical standard-setting organizations (SSOs), competition between member firms and the size of the SSO, and firms' economic performance?". This chapter is an investigation of the economic returns from technical standardization, using a conventional method in economics (the ordinary least squares), and the information and communication technology (ICT) industry as an empirical setting. The factors mentioned in the research question (participation, competition, and size) are widely discussed in the standardization literature, but large-scale evidence of their effects on firms' economic performance is still lacking. This chapter addresses this issue.

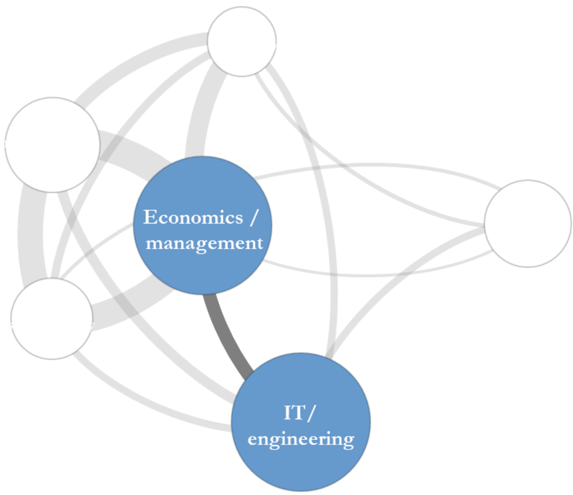


Figure 1-4 – The disciplinary nexus explored in Chapter 4

The second and main issue addressed is the competing interests of firms active in standards development in the ICT industry. SSOs in this industry often involve firms belonging to a varying number of sectors: the lower the number of sectors represented, the higher the percentage of market competitors a firm may expect in an SSO. This level of competition within SSOs is affected, among others, by the membership policy of each SSO and the breadth of stakeholders interested in the standard. The pool of participating firms often includes large multi-product firms active in several SSOs, where most of the empirical scholarship poses its attention, and smaller firms that participate in only one SSO, which receive less consideration. Analyzing the economic returns for the latter, we find that these smaller, focused players benefit from higher levels of competition, and that returns are higher in SSO with a lower number of participating firms. This has important implications for the ongoing debate about incentivizing smaller players to engage in technical standardization and stifle the dominance of "big tech" firms.

1.3.4 Chapter 5: the risk of lock-in for climate adaptation challenges

Chapter 5 is entitled "Standardization for place-based and time-based adaptation: the fight against Sea-Level Rise". It responds to the following research question: "How can standardization address sea-level rise (SLR) adaptation, given place and time-based specificities?". This chapter explores the case of SLR as an illustrative example of a societal challenge for which standards can have both a practical and theoretical contribution. Addressing a gap between (much) academic research on SLR adaptation and (few) standards developed in this field, the chapter triangulates this state-of-the-art analysis with two qualitative methods (experts' interviews and the Q-method) to propose a multi-stakeholder approach to develop flexible standards that can respond to varying local needs, also considering the evolving nature of SLR over time.

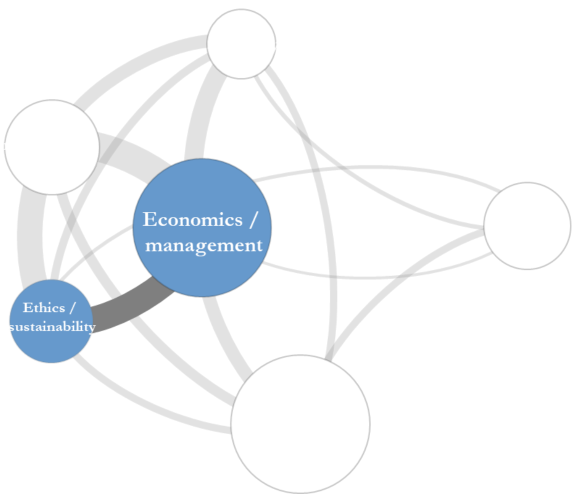


Figure 1-5 – The disciplinary nexus explored in Chapter 5

The chapter uses notions from economics of geography (e.g., place-based adaptation, regional path dependence, adaptive policy-making) to show how standardization can avoid a lock-in and block incremental innovation while addressing a climate adaptation challenge. In doing so, it conceptualizes a matrix that helps practitioners and academics to prioritize the standardization of adaptive measures based on, among others, their level of technological maturity and their place-based specificity. The chapter was developed in response to the call for papers by the International Organization for Standardization (ISO Research Grant 2022) that raised the attention over the practical problem of standards for climate adaptation, emphasizing their timely practical relevance.

2. Standardization: research trends, current debates, and interdisciplinarity [1]

Standards are ubiquitous in contemporary society and play a clear role in technological development, organizational functioning, and business success. Standards are very diverse and often boundary crossing in terms of stakeholders and impact, but are such diversity and range reflected by academic studies? We take stock of standardization research over the past decade, considering the full interdisciplinary breadth of this growing field. We use bibliometrics and network analysis to map emergent trends, and conduct an in-depth review of the literature. In doing so, we find that management science, along with economics, is at the core of work on standardization, bridging academic disciplines, and leading theoretical development. Technical disciplines, such as engineering and computer science, supply the largest body of literature, but rarely cross disciplinary boundaries and remain rather isolated. Building on our review, we discuss current debates and controversies and distill four interpretative perspectives on the recent and current developments of standardization research. Finally, we propose a research agenda for standardization research and practice for the years to come.

2.1 Introduction

Standards and standardization are ubiquitous and long-held features of our society (Brunsson, Rasche, & Seidl, 2012; Chavinskaia & Loconto, 2020; Timmermans & Epstein, 2010). Almost any firm uses standards, for its products or services, processes or management systems, and many firms are involved in setting and

---

[1] This chapter is published as: "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*, *July*, 788–830. https://doi.org/10.5465/annals.2023.0072". The data used for this chapter are available at https://journals.aom.org/doi/suppl/10.5465/annals.2023.0072. A digital version of the chapter is available on open access at the research portal of TU Delft.

developing these standards. Standards have been widely recognized by firms, policy-makers and academics alike as playing a pivotal role in key fields of economic, social and technological development (e.g., Büthe & Mattli, 2011; Geels, 2004; Timmermans & Epstein, 2010), such as the energy transition (European Commission, 2022), the development of artificial intelligence (European Commission, 2021; NIST, 2019) and the emergence of the platform economy (Jacobides, Cennamo, & Gawer, 2024; Shipilov & Gawer, 2020).

The ubiquity of standards in contemporary business and society is reflected by their relevance across organizational and governance settings. Managerial choices concerning standardization can affect a firm's competitive position and its overall success in the business environment (e.g., Bresnahan & Greenstein, 1999; Ranganathan, Ghosh, & Rosenkopf, 2018; Shapiro & Varian, 1999; Teece, 2018; Weitzel, Beimborn, & König, 2006). Success in the race for competitive advantage often depends on industry-level adoption of standards that are aligned with firm-level technological development and product innovation (e.g., Bekkers, Duysters, & Verspagen, 2002; Utterback & Abernathy, 1975; Wiegmann, 2019). Within a firm, implementing standards is subject to organizational dynamics that can markedly affect work practices and employees' tasks and coordination (e.g., Boiral, 2007; Brunsson et al., 2012; Sandholtz, 2012). Beyond business, standards have far-reaching implications for corporate governance and policymaking that can, in turn, affect patterns of strategic decision-making and organizational functioning. Standardization is likewise a core topic on the business and political agendas of many governments and international institutions, which define, in turn, coercive rules for businesses, stakeholders, and society[2].

Thus, it is not surprising that the importance of standards and standardization is recognized in the widespread attention that they have been getting in research across academic disciplines, such as economics and management (e.g., Leiponen, 2008; Ranganathan et al., 2018; Teece, 2018), law, regulation and policy (e.g., Büthe & Mattli, 2011; Delimatsis, 2015; Kanevskaia, 2023; Lemley, 2002), ethics and sustainability (e.g., Dyck & Silvestre, 2019; Henriksen, 2015; Narula et al., 2021),

---

[2] Policy documents on standardization and standards are issued, for example, by the U.S. administration (The White House, 2023), the European Commission (European Commission, 2022), the governments of China (The State Council of the People's Republic of China, 2021), and India (Government of India, 2018).

sociology (e.g., Slager, Gond, & Moon, 2012; Tamm Hallström & Boström, 2010; Timmermans & Epstein, 2010), and IT and engineering (e.g., Lu, Wang, Niyato, Kim, & Han, 2016; Shafi, Haustein, Tufvesson, & Wunder, 2017; Sheng, Yang, Yu, Vasilakos, McCann, & Leung, 2013). Attention across academic disciplines provides a strong impetus for the development of standardization as a burgeoning research field across diversified yet interconnected topics. Simultaneously, this interdisciplinary breadth may hamper consistency because standards are often defined and studied differently by different disciplines.

However, despite the longstanding acknowledgment that standards drive organizational functioning and advantage (see the discussion on integration and differentiation in March & Simons, 1958; on the connections between social and economic organization in Weber, 1964; and on the stages of development of the innovative production process in Utterback & Abernathy, 1975), a thorough systematization of standards for management theory and beyond is still missing and largely needed. Previous reviews (e.g., Choi, Lee, & Sung, 2011; David & Greenstein, 1990; Narayanan & Chen, 2012; Shin, Kim, Hwang, 2015; Timmermans & Epstein, 2010) showcase how research on standardization permeates multiple academic disciplines, but explore the different domains in a rather isolated fashion. In this paper, we ask: What is the state of the art of this interdisciplinary literature on standardization? In answering this question, our review shows that technical disciplines, such as IT and engineering, produce the largest share of standardization literature, but tend to be more isolated from other academic disciplines. On the contrary, social science disciplines, such as economics and management, tend to fuel interdisciplinarity and play a key role in orchestrating the theoretical integration and advancement of the field[3].

Overall, we found in the literature a tension between ‘centripetal’ dynamics, pushed mainly by management scholarship, which call for shared definitions and topics, and ‘centrifugal’ dynamics, mainly pulled by technical disciplines, which lead to increasing differentiation between academic languages and disciplines on the topic (e.g., Lakatos, 1978). Specifically, our review summarizes and discusses two key trends emerging from the literature: (i) standardization research is scattered across disciplines and topics, but (ii) it also represents an emerging area of research calling

[3] In particular, we find that around 70% of the reviewed literature focuses on the content of the standards, with findings that are often industry-specific. Only 30% of the reviewed literature examines standardization from a theoretical and conceptual standpoint.

for further theoretical consistency and integration. In our work, we add to this effort by bringing shared definitions, conceptual clarity, discussion of key trends connecting topics and academic disciplines, and a broader research agenda for the years to come.

We offer three contributions to theory and research on standardization. First, we systematize the scattered conceptual foundations of the academic disciplines' views on standards and derive discipline-specific definitions that can underlie future interdisciplinary research. Building on this, we propose an overarching definition of '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* (combining, among others, de Vries, 1997; Memon, Wagner, Fischer Pedersen, Aysha Beevi, & Hansen, 2014; Slager et al., 2012; Teece, 2018). Second, our overview of existing intersections between academic disciplines and topics in research shows the broad variety of aspects that have been covered. This includes standards at the intersection between corporate strategy and intellectual property, their role in facilitating renewable energy transitions, ethical dimensions of standards – e.g., in agricultural value chains and healthcare – and how they underlie technological development in areas like telecommunications, automation and privacy/cybersecurity. Through further bibliometrics and network analysis, we identify four theory-driven perspectives to reveal key emerging trends in the field (see the "Interpretative perspectives on standardization research" section of the paper). Third, the tension between interdisciplinary malleability and cross-topic fertility, on the one hand, and the need for overarching theoretical consistency, on the other hand, make the standardization research field appealing to scholars across management subfields and call for future research that bridges theoretical development and practical relevance. We derive an agenda for future research, with a focus on how management scholars can contribute to achieving this goal.

2.2 Methods for review and analysis of the literature

This paper's underpinnings are based on a systematic review of the standardization literature in management and across adjacent disciplines. To understand how research on standardization has evolved in the last ten years, we use bibliometric (Diodato, 1994; Pritchard, 1969) and network visualization methods (Jacomy, Venturini, Heymann, & Bastian, 2014) to analyze a dataset of research papers related to standards and standardization from 2012 to 2021. We deem this ten-year timespan suitable to give a comprehensive picture of the recent developments in the field and provide enough novelty from similar previous reviews (including Narayanan & Chen, 2012; Timmermans & Epstein, 2010)[4]. The diverse nature of standardization research does not cater well to a journal-based or classification-based type of search. Instead, we used a keyword search approach across the whole body of academic publications. In this section, we provide details on the three-step method (Chen, Mehra, Tasselli, & Borgatti, 2022) that we followed to select the relevant literature. In the spirit of open science, we provide information about the coding of papers (Appendix A) and detailed statistics (Appendix F and G). We also make the full dataset publicly available.

Step 1: Collecting and pooling the set of papers. We created the dataset that guides our review of the literature by merging the results of six keyword strings (one per academic discipline) from two of the most popular academic search engines, ISI Web of Knowledge and Scopus, with the forward citations of seven literature reviews in the field of standardization (Choi et al., 2011; David & Greenstein, 1990; Murmann & Frenken, 2006; Narayanan & Chen, 2012; Shin et al., 2015; Timmermans & Epstein, 2010; Wiegmann, de Vries, & Blind, 2017). The seven literature reviews were used as a starting point to define the keywords. Following this broad and preliminary screening procedure, 6,900 academic sources were gathered. An ex-ante skimming excluded search-engine categories such as *medical research*, *veterinary*, *linguistics* and *statistics*. Medical research was excluded because of the huge volume of publications using the terms "standard" and "standardization" for a different purpose (the term often refers to "standard" treatments and procedures). Similarly, statistical research was excluded because unrelated constructs such as "standard deviation" and "standard error" still resulted as an output of the search. Other areas that were considered out of scope include, e.g., "standard of review", "standard of objectivity", or "standard of civilization." The research team conducted careful checks to ensure that only papers unrelated to standardization were excluded from this step of the literature selection. Consistent with the time span of our study

[4] This is not the first study reviewing the standardization literature (e.g., David & Greenstein, 1990; Timmermans & Epstein, 2010; Shin et al., 2015; Wiegmann et al., 2017), but to the best of our knowledge this is the first systematic attempt to summarize and interpret the interdisciplinary richness of this literature. Among previous work of review, for example, Choi et al. (2011) only focused on the relation between standardization and innovation; Narayanan and Chen (2012) mapped research in the field of standardization but limited their scope mostly to the management literature; and de Vries (2015) mapped the scientific disciplines to study standardization but mentioned only a few exemplificative topics.

design, both components (keyword strings and forward citations) included papers that were published in the period 2012 – 2021.

Step 2: Definition of academic disciplines and topics. We used a set of 100 standardization papers that were randomly selected from our full dataset as a trial, and had three independent coders (each looking at all 100 papers) identify the main categories, where relevant across multiple dimensions. Based on the outcomes of this trial, as a research team, we collectively decided on a twofold coding (based on (i) academic disciplines and (ii) topics, see further below), with a maximum of two academic disciplines and two topics for each paper. After comparing the three trials, we agreed on six broad and comprehensive academic disciplines (IT/engineering; Law/regulation/policy; Economics/management; Sociology; Ethics/sustainability; Other sciences) and a preliminary list of 40 topics. While coding the full dataset, the number of topics grew to 56, both by adding and grouping some of them.

Step 3: Selection and categorization of papers. To make an in-depth topic analysis of papers feasible with our given set of resources, we narrowed the initial set of 6,900 sources down to 1,313 papers. We first filtered the sources by journal articles, data papers and reviews (thus excluding books, papers from conference proceedings, grey literature, and other unrelated items), resulting in a first full dataset of 4,145 articles. Secondly, because this number of papers was still unmanageable to provide a theory-driven review of the current literature, we selected the most impactful papers by setting citation thresholds, which allowed us to identify approximately the top 150 most impactful papers per year. To avoid citation biases in setting these thresholds, we accounted for the fact that more recent papers had fewer opportunities to receive citations (see Table 2-1).

Year	Citation threshold	N. of selected papers
2012	≥ 9	142
2013	≥ 11	143
2014	≥ 11	141
2015	≥ 8	152
2016	≥ 9	147
2017	≥ 7	146
2018	≥ 6	162
2019	≥ 5	145
2020	≥ 1	156
2021	≥ 0	221
Total categorized set		**1555**
Excluding duplicates and out-of-scope		**1313**

Table 2-1 – Summary of the dataset composition for high-impact papers

To guarantee intercoder reliability, three authors separately coded the set. Using the adopted categorization scheme, we coded all 1,313 papers that represent the final dataset. To categorize the dataset, we referred to specific items of each paper that were provided by the search engines. We summarized the information coming from these items into the academic disciplines and the topics (see Figure 2-1) via open coding (Corbin & Strauss, 1990). In essence, we initially labeled papers with topics according to (search engine and authors) keywords; then, based on the analysis of the papers' abstracts, we grouped them based on the presence of conceptual and linguistic overlaps between topics (e.g., policies on "greenhouse gases" and "CO2 emissions" were both labeled as "Energy policy").

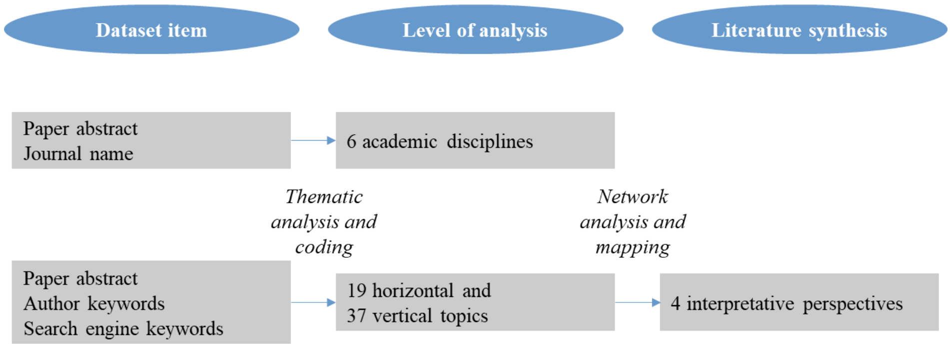


Figure 2-1 – Process of coding and analysis of the dataset

The result of this final coding allowed us to categorize the paper based on two key dimensions: *academic disciplines* (e.g., *sociology* or *economics/management*) for a higher-level overview, and *topics* (e.g., *standards competition* or *impact assessment*) for deeper content. As mentioned above, we distinguished a total of six relevant academic disciplines and 56 topics. To simplify this coding effort, each paper was coded with up to two academic disciplines and up to two topics, allowing us to study the co-occurrence between disciplines and between topics using bibliometric network analysis techniques for visualization (e.g., Pritchard, 1969; Wasserman & Faust, 1994). The resulting network diagrams followed a network algorithm - ForceAtlas2 - that arranges nodes (in our case, academic disciplines or topics) based on the strength of their ties (number of co-occurrences in papers). The larger the size of a node, the more papers form the corresponding discipline/topic. The closer the two nodes are, the more papers are coded with the two connected disciplines/topics, and the thicker the corresponding network tie is plotted in the graphs (Jacomy et al., 2014). More details on our dataset creation and the selection criteria can be found in Appendix A, where we describe our review method using the PRISMA protocol and measure its quality in terms of precision and recall, for which we respectively reach a level of 87% and 85%. Appendix B provides further details on the software and algorithm we used for the network analysis. We also recognize our dataset's limitations in Appendix C.

2.3 Foundations across academic disciplines

Standardization is an increasingly complex and intertwined field of research, as suggested by the wide array of disciplines and topics involved. One complexity stands in the varying interpretations that different academic disciplines may have, starting from the basic definitions of the terms "standard" and "standardization." To set a common background for the review of the literature, we delve into foundational and highly cited research articles from each discipline to describe the different knowledge domains and definitions. In Table 2-2, more precisely, we refer to assumptions as the overarching issues that each discipline covers for standardization, knowledge created as the main (theoretical) contributions of the cited papers, and portability as the extent to which firms and practitioners can benefit from such knowledge. We gathered an extensive array of definitions present in the literature to formulate a complete definition of standardization for management research. The full definitions for each academic discipline and the processes behind their formulation are explained in Appendix D.

2.3.1 Economics/management

Building on early foundations in organizational research that see standards as the process of homogenization of economic activities in a given industry (e.g., (March & Simons, 1958) standards are currently defined as interface specifications and corporate practices that function as governance mechanisms within innovation ecosystems (e.g., Brunsson et al., 2012; Gao, Yu, & Lyytinen, 2014; Haack, Schoeneborn, & Wickert, 2012; Hinings, Gegenhuber, & Greenwood, 2018; Teece, 2018). Thus it is no surprise that the role of standards as key components of (larger) cross-industry technological architectures is broadly emphasized both in economics (Fontagné, Orefice, Piermartini, & Rocha, 2015; Simcoe, 2012) and management (Cusumano, Kahl, & Suarez, 2014; Dattée, Alexy, & Autio, 2018) scholarship. Examples of these architectures include platforms (Gawer & Cusumano, 2014) and dominant designs (Suarez, Grodal, & Gotsopoulos, 2015), where standards are considered fundamental boundary resources (Fontagné et al., 2015). This research emphasizes both the positive economic effects of standards, for example in terms of enabling and coordination mechanisms and drivers of economies of scale (Blind, 2004; Gallagher, 2012; Ranganathan et al., 2018; Swann, 2010), and their possible downsides, ranging from path dependence to risk of lock-in (David, 2001; Dosi & Nelson, 2013; Puffert, 2000), which may lead to both a lower availability of technologies and to asymmetric industry structures and monopolies (Blind, 2004; Heinrich, 2014; Swann, 2010) . Economic research is particularly interested in the macro-level consequence of these effects, looking at the relationships between standardization and society-level outcomes such as innovation (Baron, Ménière, & Pohlmann, 2014), economic growth (Blind & Jungmittag, 2008; Zoo, de Vries, & Lee, 2017), labor productivity (Acemoglu, Gancia, & Zilibotti, 2012), technological life-cycles (Blind & Gauch, 2009) and global trade (Fontagné et al., 2015; WTO, 2023).

2.3.2 Law/regulation/policy

In the legal field, standards are seen as rules developed by governments and private actors to reduce information asymmetry in transactions, and give normative certainty to business and civil society. As opposed to the early blurred understanding of them as soft laws (Busch, 2011; Kerwer, 2005; Kirton & Trebilcock, 2004) and self-regulatory tools (Meyer, 2012), standards are increasingly mentioned as documents, approved by an official body, that support legislations and can be seen as co-regulation tools. This applies, for example, to data privacy standards (Greenleaf, 2012; Kamara, 2017), and to international standards adopted in the EU for customer safety and market transparency (Eliantonio & Cauffman, 2020; Kanevskaia, 2023). Recent juridical sources explore the debate comparing feed-in tariffs to renewable portfolio standards (Alizada, 2018; Dong, 2012; Sun & Nie, 2015). Foundational to this discipline is also the study of the governance of standards in their function as providing criteria and test methods, signaling quality and performance. Examples of this include the electric vehicles industry (Das, Rahman, Li, & Tan, 2020; Li, Zhan, de Jong, & Lukszo, 2016) the certification of bio-based products (Ladu & Blind, 2017; Wang et al., 2020), and energy labels (de Vries, 2015; Schleich, Durand, & Brugger, 2021).

2.3.3 Ethics/sustainability

The foundations of standardization research in this group of disciplines trace back to seminal work on the behavioral and environmental underpinnings of standards (Baumol & Oates, 1971; Hoffman, 1999; Unruh, 2000), and consider standards as documents providing the basis for certification schemes to assess the quality of a firm's performance and behavior (e.g., Gilbert, Rasche, & Waddock, 2011; Higgins & Richards, 2019) and help institutions achieve sustainable, long-term goals (Wijen, 2014). The most impactful recent research in these disciplines defines standards as norms and coordination mechanisms for multiple stakeholders (Ponte & Cheyns, 2013). Debates revolve around their mandatory (Davies & Vadlamannati, 2013; Elton-Chalcraft, Lander, Revell, Warner, & Whitworth, 2017) or voluntary (Christensen, Morsing, & Thyssen, 2017; Von Geibler, 2013) enforcement. In this context, emphasis is given to the ethical goals behind standards' adoption, including the extent to which firms legitimately believe in the ethics' requirements and implications of the standards they adopt, or instead follow the path of decoupling (Mercado, Hjortsø, & Honig, 2018; Wijen, 2014). In terms of business settings, this research mainly discusses standardization controversies around certification schemes in international trade (Boström, Jönsson, Lockie, Mol, & Oosterveer, 2015) and agricultural commodities in global value chains (Bitzer & Bijman, 2014; Bitzer & Glasbergen, 2015; Oya, Schaefer, & Skalidou, 2018).

2.3.4 Sociology

Building on the idea that standards are "a source of authority and a level of achievement" (Timmermans & Epstein, 2010: 70), sociologists define standards as measurements or technical rules built by individuals, groups and institutions that reproduce values, beliefs, and assumptions affirmed in a society (e.g., Ritzer, 2000; Williams, 1985) In sociology, the discussion around standards builds on the assumption that shared behaviors are institutionalized in society through the structuration process by which they are first adopted and later certified as normative phenomena (e.g., Berends, van Burg, & van Raaij, 2011; Giddens, 1984). Key issues for sociology scholars include the underrepresentation of stakeholders in the process of standards' development (Bennett & College, 2017; Carse & Lewis, 2017; Schweber, 2013), and acknowledging social inequalities connected to the representation – in the dominant standards – only of the most influential social groups (Lamont, Beljean, & Clair, 2014; Panofsky & Bliss, 2017). In this discipline, the view of standardization oscillates between research that sees it as a tool for

Academic discipline	Assumptions	Knowledge created	Portability
Economics/ management	Standards are indispensable for industrial transformation and the establishment of new (platform) ecosystems.	In the stage of uncertainty before the establishment of a technology, the standardization process determines how (rapidly) society develops, selects, and adopts them, and industries evolve.	SDOs and firms play the "ecosystem" game to prioritize their interests, sometimes at the cost of slower technological progress or unintended societal consequences.
Law/ regulation/ policy	Standards are fundamental to quantify the impact of policies (governmental and institutional). Especially in climate-related issues (renewable energies and flood-risk management), cybersecurity, and education.	The inclusion of standardization in policies is mostly country specific. In this regard, the harmonization of governmental policies may be more suitable than establishing global standards (e.g., the European New Approach).	Collaboration between governments as well as with academia, to quantify and legitimate the expected impact of standards.
Ethics/ sustainability	Agri-food sustainability certifications, labor standards, and living standards all aim at societal benefits but may have unintended consequences.	Standards' pervasiveness may hinder competition and authenticity instead of fostering them. This may incentivize ceremonial compliance rather than 'real' implementation.	"Informal" stimuli for standards are more fruitful than obligations to implement. Standard-developing organizations (SDOs) should involve multiple stakeholders, and governments should balance voluntary and mandatory practices.
Sociology	Weak stakeholders are underrepresented in standardization processes. This enhances social inequalities instead of reducing them. This can be observed in very diverse fields, such as accounting, genetics, port management, and journalism.	Standards are sociotechnical solutions. Even technical-intensive solutions require diverse perspectives and representation. Root causes of inequalities include wrong cultural processes, excessive governmental intervention driven by political interest, and ignorance of local and country-specific characteristics.	Governments should stimulate transparent and inclusive standardization processes.
IT/ engineering	New generations of telecommunications, smart-grids and other technical intensive sectors benefit from a lot of standardization activities by private firms.	Technical standardization is driven by market in earlier stages (development, competition), institutions and formal SDOs intervene at later stages.	Private and public actors should collaborate in standardization even in early stages, starting from the ideation and development of technologies.
Other sciences	This diverse set of papers have in common that conformity assessment (particularly measurement) is part of them.	Standards in fundamental sciences such as biology, physics and chemistry are essential part of the standardization process of global (interdisciplinary) challenges, such as the energy transition and world hunger.	These pre-normative findings are relevant for technical research communities and scientists. Their portability should be extended to other complementary communities through normative and "horizontal" research.

Table 2-2 – Summary of assumptions, knowledge created, and portability of the ten most impactful papers per academic discipline

empowerment (e.g., Dietz, Grabs, & Chong, 2021; Fine, 2017), and research that sees it as a mechanism leading to market inequalities (e.g., Raynolds, 2002; Reinecke, Manning, & von Hagen, 2012), dehumanization, and even racial inequalities (Hirschman & Bosk, 2020; Timmermans & Epstein, 2010). Altogether, sociologists look at standards as norms and policies that influence the cultural processes and classifications of society (e.g., Carse & Lewis, 2017; Fenech, Giugni, & Bown, 2012; ; Lamont et al., 2014; Schweber, 2013).

2.3.5 IT/engineering

From an IT perspective, standards ensure interoperability, cybersecurity and performance measurement of technological solutions (combining Festag, 2015; Huovil, Bosch, & Airaksinen, 2019; Keoh, Kumar, & Tschofenig, 2014; Trappey, Trappey, Govindarajan, Chuang, & Sun, 2017; Trappey, Trappey, Govindarajan, Sun, & Chuang, 2016). The foundations of the engineering literature consist of two main types of publications. The first entails high-level reviews and surveys of the technical architectures underlying new disruptive technologies, describing the main protocols, requirements, and fields of application. Case examples include 5G (Shafi et al., 2017), the Internet of Things (Keoh et al., 2014; Gazis, 2017; Sheng et al., 2013), Unmanned Aerials Vehicles (Fotouhi et al., 2019), Wireless Charging Technologies (Lu et al., 2016), and Direct Current microgrids (Kumar, Zare, & Ghosh, 2017). The second type includes low-level case-studies defining specifications of particular types of standards. Examples include the high-efficiency video coding standard (Pourazad, Doutre, Azimi, & Nasiopoulos, 2012), optical communications standards (Cailean & Dimian, 2017; Nguyen, Islam, Yamazato, & Jang, 2018), and standards on cement composition (Lee & Choi, 2018; Sanjuán & Argiz, 2012). Most of these technical standards are developed in the private sector, either through private companies (e.g., Chien, Hsu, & Chang, 2013; Kim et al., 2016), or private standard-setting organizations (e.g., ETSI, the European Telecommunication Standards Institute) (Abdelkafi, Bekkers, Bolla, Ascaso, & Wetterwald, 2021). Our review shows how this specific discipline has undergone a surge of publications from 2016 onwards, concurrent with the start of bulky research on 5G and IoT standardization, making it today the largest discipline in terms of sources and citations.

2.3.6 Other Sciences

Following the inclusion criteria listed in the previous section, this residual category groups the literature related to exact disciplines such as *Healthcare*, *Physics*, *Chemistry*, and *Biology* (these four being the most recurring in our dataset), but also from *Education*, *Sports science*, and *Psychology*. Similarly to the discipline of *IT/engineering*, standards are mainly defined as communication protocols, data models, and technical specifications that improve scalability, safety, quality assurance, and interoperability (e.g., de Lorenzo & Schmidt, 2018; Erlinghagen, Lichtensteiger, & Markard, 2015; Memon et al., 2014; Müller & Arndt, 2012; Naumann, Bilchev, Voropai, & Styczynski, 2014). The scientific community emphasizes the aspect of scalability of these standards, because they enable the diffusion of the state of the art of these sciences (Erlinghagen et al., 2015; Fearnley, McGuire, Davies, & Twigg, 2012; Mainetti, Patrono, Stefanizzi, & Vergallo, 2013; Memon et al., 2014). Scalable practices are important, for instance, for the use of standardized materials (Atinafu, Jin Chang, Kim, & Kim, 2020; Kim & Kim, 2012), the calibration of instruments (Papp, Kozma, Lindfors, & Gyurcsányi, 2020; Phala, Kumar, & Hancke, 2016), and shared methods for performance benchmarking and quality assessment, with notable examples from genetics (Hwang, Kim, Lee, & Marcotte, 2015), chemistry (Nam et al., 2020; Stepman et al., 2014) and agricultural sciences (Mainetti et al., 2013; Tinarelli et al., 2021).

2.3.7 A Shared Definition of Standardization for Management Research

Our review shows an extensive inspection of the field of standardization from many topical angles (e.g., academic standards, nutritional standards, ICT standards), based on different contextual factors (e.g., interoperability, common criteria, norms, procedures). While this enriches the field with multiple characterizations and industrial applications, scholars tend to characterize the concept for their own field, and the resulting definitions largely diverge. The theoretical consistency and progress of a field, being one of our review's main objectives, calls for an integrative definition of standards and standardization. Therefore, we propose a contextualized definition for management research. Appendix E discusses the elements of this definition in more detail.

We look at 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 (combining, among others, de Vries, 1997; ISO/IEC, 2004, p. 4; Memon et al., 2014; Slager et al., 2012; Teece, 2018). The resulting set of solutions, often expressed in the form of a written document, is the standard. A systematic review of 30 definitions (five per discipline, see Appendix D) provides us with many characterizations of standards, such as norms, procedures or methods, technical rules, regulations, interface specifications, corporate practices, documents or communication protocols, and data models. These categorizations show the wide array of forms a standard can assume and the multiple ways it can be interpreted. Given the emphasis in management scholarship on the role of standards and standardization for outcomes, specifically, we suggest that standards are *sets of solutions* (de Vries, 1997) that help address so-called *coordination problems* (Carse & Lewis, 2017; Schweber, 2013; Slager et al., 2012; Van Den Hurk & Verhoest, 2016). Of note, we remark the appellation of standards not as ideas, thoughts or proposals, but as being often expressed as 'documents' (ISO/IEC, 2004, p. 4; Trappey et al., 2016), which helps distinguish a formally written standard from a tacitly agreed social norm (Blind & Fenton, 2021; Brunsson et al., 2012).

Along with a shared definition of standardization, we also aim to provide terminological clarity to two key elements of the academic definitions that we gathered: (i) the *functions* of standards, and the (ii) different ways through which they can *emerge*. Taken together, these elements represent the foundations of how standardization works when multiple organizations are involved and are of interest when studying the topic.

(i) Our systematic review of 30 definitions (see Appendix D) showcases that each academic discipline describes standards as covering different *functions*, often aligned with the most recurring type of standards studied in such disciplines. These functions include assessing social and environmental performance (Ponte & Cheyns, 2013; Reinecke et al., 2012); facilitating control and compliance (Balzarova & Castka, 2012; Slager et al., 2012); being a coordination mechanism within innovation ecosystems (Gao et al., 2014; Teece, 2018); ensuring interoperability, cybersecurity and performance measurement of technological solutions (Festag, 2015; Trappey et al., 2017); improving scalability, safety, quality assurance, and interoperability (Erlinghagen et al., 2015; Müller & Arndt, 2012).

(ii) A second important feature complementing the definition of standards is their pattern of *emergence*. Building on David & Greenstein's (1990) seminal work, we argue that a standard may emerge in three ways: through a process of selection by the market; through the development and the following publication of a voluntary standard by a standard developing organization (SDO), or through the official promulgation of a standard by a governmental agency. As opposed to "informal" standardization, the second and third modes are often referred to as "formal" standardization, and require the presence of a neutral, non-partisan actor that coordinates the standardization process, whether it is a formal SDO or a governmental agency (Delcamp & Leiponen, 2014; Farrell, 1989). These modes of standardization relate to three ways of achieving coordination between multiple stakeholders: via markets/price, via community/trust, or through hierarchy/authority (Adler, 2001). Until recently, some studies have described the co-participation of private companies and committees in the standardization process (e.g., Farrell & Saloner, 1988; Stango, 2004), but most theories about standardization had largely treated these three coordination mechanisms as isolated phenomena (cf. Büthe & Mattli, 2010; Botzem & Dobusch, 2012; David & Greenstein, 1990). This co-participation can be observed empirically in many standards battles from the literature (e.g., Cusumano, Mylonadis, Rosenbloom, 1992; Johansson, Kärreman, & Foukaki, 2019; van de Kaa & de Vries, 2015; van den Ende, van de Kaa, den Uijl, & de Vries, 2012). More recent research has developed theories about 'multi-mode standardization', where the three coordination mechanisms occur concurrently with each other (Wiegmann et al., 2017).

2.4 An interdisciplinary survey of standardization research

In the previous section, we delved into the foundations and wrapped the bases of standardization literature defining the theoretical pillars of standalone disciplines. By discussing basic knowledge insights for each of these disciplines, we found that definitions range from the idea that standards are sets of specifications (David & Greenstein, 1990; Gao et al., 2014; Schweber, 2013), to published documents (ISO/IEC, 2004; Trappey et al., 2016), or behavioral rules and norms established in a society (Lamont et al., 2014; Timmermans & Epstein, 2010). Building on this interdisciplinary variety and following the shared definition of standardization that we introduced, in the next section ('Key Insights Across Disciplines') we describe the key themes and explore the co-occurrence of disciplines and topics that emerge from the multiple sources of our dataset. Studying co-occurrence patterns, we observe the most and the least frequent, i.e., the strongest and the weakest links between topics and disciplines, drawing conclusions on which of them are more central (and represented in the literature) and which are more isolated (and therefore less relevant). To accomplish this survey of the literature, for ease of interpretation, we divided the full list of 56 topics into 19 horizontal and 37 vertical topics. The former includes topics that focus on conceptual and theoretical aspects of standards/standardization, and that could be applied in other standardization contexts (e.g., *Legitimacy* or *intellectual property rights [IPR]*); the latter describes the actual content or context of the standards (e.g., *Automation* or *Healthcare*). A complete list of topics and their description are illustrated in Appendix F. Finally, we interpret the literature in terms of four interpretative perspectives that summarize key trends for interdisciplinary research in the standardization research program and open to new avenues for future research. The network algorithm generated the diagrams illustrated later in Figure 2-2, 2-3 and 2-4. In Figure 2-4, we define the perspectives by purposely grouping topics based on the function they cover for the evolving standardization research program. To identify the perspectives' orientation to describe standardization through its theoretical lens, rather than through the content of single standards, we calculated the percentage of horizontal topics contained in the different perspectives. This exercise allows us to see whether the interpretative perspectives are more theory- or content-oriented and discuss what this means for standardization as an evolving and interdisciplinary research program.

2.5 Key insights across disciplines

As already shown in the foundations, research about standardization is widely dispersed across academic disciplines and topics (see Appendix F and G for more information on how the reviewed papers are distributed). Our analysis shows clear differences between how papers reflect this variety in the field. First, many reviewed papers draw on knowledge from only one academic discipline and address only one topic. In our dataset, we find an abundance of such focused and often phenomenon-driven research. Examples include high-profile work from the *economics/management* discipline (Gawer & Cusumano, 2014; Ranganathan et al., 2018; Suarez et al., 2015) and all other academic disciplines (Kafle, Fukushima, & Harai, 2016; Lamont et al., 2014; Van Den Hurk & Verhoest, 2016). This offers abundant evidence of fertility in the use of standardization across disciplines as a phenomenological object of analysis, but it also makes it difficult to accomplish theoretical integration across topics and disciplines.

However, our work also reveals that there is a substantial number of papers that create connections across the field, giving the opportunity for theoretical integration. Our review shows two common ways in which these connections are made: by drawing on knowledge from multiple academic disciplines and integrating topics across disciplines, and/or by addressing multiple topics simultaneously, creating qualitatively rich and often implicit connections across such topics. Examples of the first way to achieve integration include work that builds on insights from *economics/management* and *sociology* (Arnold & Loconto, 2021; Dokko, Nigam, &

Rosenkopf, 2012) and research combining *economics/management* with *ethics/sustainability* (e.g., Reinecke et al., 2012). Examples of the second way to achieve integration include work that combines the topics of IPR in standards with corporate strategy questions (Bekkers & Martinelli, 2012; Teece, 2018) and questions related to technology development and adoption (Vakili 2016); and work that combines the topic of standards' legitimacy with questions related to agricultural value chains (Wijen, 2014).

In this section, we analyze these connections in detail. We first focus on papers that draw on more than one academic discipline to understand which types of knowledge are often combined. Subsequently, we zoom in on the content of the papers that bridge discourses by exploring which topics are frequently studied in combination with each other. Based on this analysis, we discuss the integration of the literature in four interpretative perspectives, of which we describe their theoretical and empirical setting, and discuss their role within standardization research. Although our definition of these perspectives builds on the review of a field that is in continuous evolution, and thus subject to natural development following the progression of standardization research, we believe that they represent an insightful starting point to realize theoretical integration across topics and disciplines.

2.5.1 Connections between academic disciplines

Analyzing the connections between academic disciplines is valuable because it shows the sources of knowledge that are combined in the standardization field. The results of these connections are visualized in Figure 2-2 as follows: the size of the nodes represents the overall number of papers that draw on knowledge from the respective discipline. The thickness of the ties between two disciplines shows how many papers combine both (also shown by the numbers next to the ties). The position of a discipline in the network shows how central its knowledge is for the overall interdisciplinary work in the field. Below, we discuss the content of the literature for the most important connections in the field. Table 2-3 provides an overview of the contents of all identified connections, including ones that are less central for the field's development.

The first remarkable finding is that *economics/management* is the most central discipline in connecting standardization research across disciplines, despite *IT/engineering* being most largely represented in the overall sample of papers (406 out of 1631 papers). A total of 167 papers combine *economics/management* with insights from other disciplines, compared with 151 papers that combine insights from all other disciplines except *economics/management*. Overall, most work that draws from at least two academic disciplines (i.e., interdisciplinary) involves the social science disciplines (out of 317 papers combining two academic disciplines, 226 are at the intersection of two social science disciplines and a further 80 papers link a social science discipline to technical and other sciences). Only relatively few interdisciplinary papers (i.e., 11) draw on knowledge from *IT/engineering* and *Other sciences*, suggesting these are being researched in a more isolated fashion.

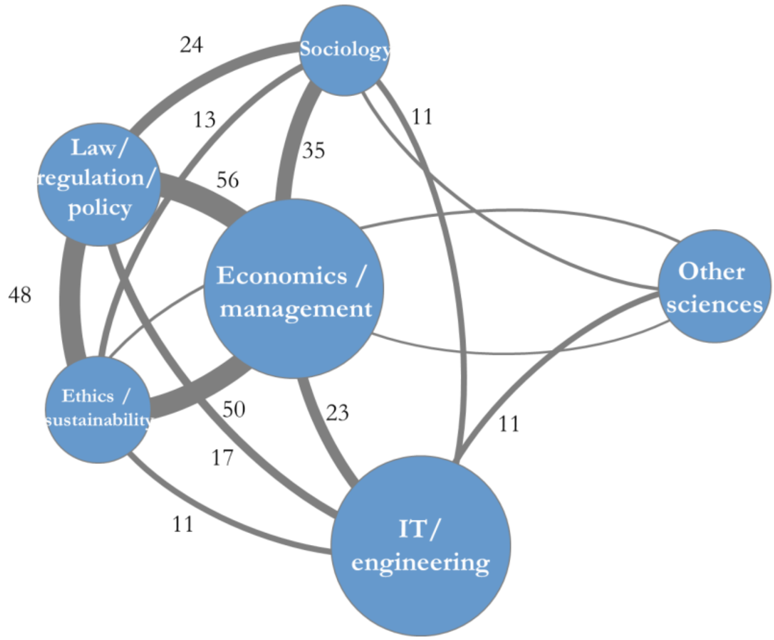


Figure 2-2 – Network visualization of the academic disciplines of standardization research (2012-2021)

NB: Numbers show the amount of co-occurrences in the dataset.

Three academic disciplines (*economics/management*, *law/regulation/policy*, *ethics/sustainability*) form the core of interdisciplinary research about standardization. As Figure 2-2 shows, indeed, this 'triangle' accounts for the largest share of connections among the reviewed papers (154 out of the 317 papers combining academic disciplines, i.e., almost half). In the following paragraphs, we look in more detail at the research underlying these connections.

	Sociology	Law/regulation/ policy	Economics/ management	IT/ engineering	Other sciences
Ethics/ sustainability	Standards used as private regulatory initiatives and private governance for sustainability and CSR.	The role of policymakers for the energy transition and SDGs; the legitimacy of their policies; the interplay between multi-stakeholder initiatives and geographical factors.	Organizational implications of multi-stakeholder initiatives in the sectors of agriculture and energy.	Safety and compatibility standards in technical-intensive contexts (e.g., construction, wind energy, automation).	Standards for healthcare in developing countries.
Sociology		The (unintended) consequences of standardization on fundamental human rights; the cultural norms affecting the adoption of standards in specific countries (e.g., the comparison between feed-in tariffs and Renewable Portfolio Standards (RPS).	The pervasiveness of global standards via network effects, versus the authenticity safeguarded by local standardization, in sectors such as agriculture, education, and healthcare.	Standards to fight human inequalities (racial justice, gender equality) arisen in digital technologies.	The intersection of healthcare, education, and human rights.
Law/ regulation/ policy			The impact assessment of policies, the pricing of RPS; the influence of IPR on innovation (e.g., through standard-essential patents).	The legal implication of cybersecurity, smart cities, and IoT automation.	The role of public institutions in the healthcare industry.
Economics/ management				Corporate strategy and market-based standardization in technical-intensive sectors (construction, telecommunications, energy).	Standards driving innovation in the healthcare industry.
IT/ engineering					The role of physics within telecommunications (e.g., wave propagation and optical communication).

Table 2-3 – Intersecting areas between disciplines

Economics/management and law/regulation/policy. The most recurring tie (56 high-impact papers) is the one between *economics/management* and *law/regulation/policy*. A large share of this work investigates the effects of standardization-related policy on the economy and/or individual firms. For example, several studies (Gao, 2015; Gao, Gao, & Liu, 2021; Gao & Liu, 2012; Kwak, Lee, & Chung, 2012) show how the Chinese government's standardization policy supported the catching up of Chinese firms in the mobile communications sector. On a more fundamental level, Farrell & Simcoe (2012) build on seminal work from economics and the legal discipline (Farrell & Saloner, 1988; Lemley, 2002; Lerner & Tirole, 2006)[5] to develop a game-theoretical analysis of rules for consensus standardization. They suggest that policies that de-emphasize vested interests in the standardization process (e.g., by strengthening the role of neutral parties) may contribute to more socially optimal standards. Also on a fundamental level, Blind, Petersen, & Riillo (2017) compare the effects of standards and regulation on firms' ability to innovate. More recent research investigates standards in the digital (Hinings et al., 2018; Mirtsch, Kinn, & Blind, 2021) and in the sustainability context (Bao, Zhao, Wang, & Tan, 2019; Stephan, Schmidt, Bening, & Hoffmann, 2017; Tan, Ding, Zheng, Dai, & Zhang, 2021; van der Loos, Negro, & Hekkert, 2020; Young & Bistline, 2018). This work on sustainability mainly revolves around the effectiveness of Renewable Portfolio Standards (RPS) as policy tools for promoting a sustainable economy (e.g., Bao et al., 2019; Tan et al., 2021; Young & Bistline, 2018)[6], and the role of standards and dominant designs in creating the innovations needed to reach sustainability targets (Stephan et al., 2017; van der Loos et al., 2020). Accounting standards are another vast area, that is frequently researched with a combination of *economics/management* and *law/regulation/policy* lenses (Dabbicco & Steccolini, 2019; Einwiller, Ruppel, & Schnauber, 2016; Houghton, Kend, & Hubb, 2013; Rojszczak, 2021). Our analysis also reveals that these research streams are evolving over time. The work on standards in the digital and sustainability contexts has only been emerging relatively recently in the second half of the period 2012-2021. During the entire period, there has been a steady stream of work on accounting standards. The work on the Chinese mobile telecommunications sector mainly stems from the earlier years covered by

[5] This work is not included in our review since it was published in a timeframe that has already been covered by earlier reviews (Timmermans & Epstein, 2010; Choi et al., 2011; Narayanan & Chen, 2012).
[6] See the discussion of this research in the section on connections between topics.

our review but tended to fade away in the second half of the reviewed period (2017-2021).

Economics/management and ethics/sustainability. Also, *ethics/sustainability* is strongly tied to *economics/management* (50 co-occurrences). While the subjects of this research overlap to some extent with those covered in the previous paragraph, we see that the perspectives from which they are studied often differ. Research that combines *ethics/sustainability* with *economics/management* often places values, such as fairness and human rights, at the core of its reasoning (e.g., Husted, Montiel, & Christmann, 2016; Meemken, 2020; Narula, 2019; Yanuardi, Vijge, & Biermann, 2021). In terms of subjects, this research mainly revolves around (i) standards in the context of renewable energy, and (ii) standards for sustainable farming and fair trade. The first stream focuses on 'vertical topics' (i.e., it studies standards in a specific application area, the energy sector in this case, rather than aiming to generalize to standards as a broader phenomenon). Most papers in this stream appeared in the first half of the period covered by our review. They mainly study Renewable Portfolio Standards (RPS) (e.g., Chen & Wang, 2013; Kwon, 2015; Novacheck & Johnson, 2015; Rouhani, Niemeier, Gao, & Bel, 2016; Tanaka & Chen, 2013) which we discuss in more detail in the next section.

The second stream (standards for sustainable farming and fair trade) is even more prominent among the research that draws on *economics/management* and *ethics/sustainability*. Papers related to this stream are represented throughout the entire period covered in our dataset, but the stream has particularly been gaining increasing prominence from 2017 onwards. The earlier work includes a highly cited paper by Reinecke et al. (2012), who studied the case of sustainability standards in the global coffee industry. Based on their research, they developed the notion of a 'standards market', where multiple standards with similar purposes exist in parallel. According to Reinecke et al. (2012), the dynamics in such a 'standards market' may give rise to 'meta-standardization', where standards converge at a high level of characteristics but compete by differentiating themselves regarding how these characteristics are implemented. Later work on standards for sustainable farming and fair trade includes (i) case-studies of standards in specific settings (e.g., Brako, Richard, & Alexandros, 2021; Campos, Álvarez, Oviedo, Mesa, Caparrós, & Ovando, 2020; Johnson, 2019; Yanuardi et al., 2021), as well as (ii) more general empirical and modeling approaches to the topic (Meemken, 2020; Mohan, 2019; Poret, 2019). For example, Yanuardi et al. (2021) show that governance standards in the Indonesian raw materials sector have helped improve the participation of civil society in the industry. However, they did not live up to their potential in improving transparency and accountability. To mention a few other relevant examples, Brako et al. (2021) study standards in the Ghanaian Cocoa industry to show mixed effects of sustainability standards and certification on the living conditions of farmers. Meemken's (2020) meta-analysis on the topic shows that sustainability standards contribute to improving the conditions in agricultural supply chains in poor countries. Other authors take a more critical stance on sustainability standards: Narula (2019) points towards their negative effects for actors in the informal economies of poor countries who lack the means to comply with the requirements. Silvestre, Viana, & Sousa Monteiro (2020) highlight the issue of supply-chain corruption which may lead to standards only being implemented in a symbolic manner without any real effect. They also develop a typology of corrupt practices in supply chains, which contribute to such outcomes. Christensen et al. (2017) respond to such critical views on sustainability standards by arguing in favor of "licenses to critique" in organizations. According to them, organizational practices that allow for inquiry and contestation need to be established in global value chains to offset tendencies towards closure in standards implementation. Overall, this work shows that standards have a strong effect on global supply chains, but do not under all conditions bring the intended improvements for farmers and other marginalized actors in the global south.

Law/regulation/policy and ethics/sustainability. The tie between *law/regulation/policy* and *ethics/sustainability* completes the 'triangle' at the core of interdisciplinary standardization research, as identified in Figure 2-2 (48 papers). The connection between these two disciplines is dominated by a discourse about the role of standards and other private instruments in (trans)national governance. Central to this discourse are questions related to the legitimacy of private sector-led standards as governance instruments (e.g., Boström & Tamm Hallström, 2013; de la Plaza Esteban, Visseren-Hamakers, de Jong, 2014; Flynn & Hacking, 2019; Von Geibler, 2013). Subjects discussed in relation to legitimacy include (i) stakeholder involvement, (ii) the extent to which standards reflect what is desirable from a societal point of view, (iii) how the co-existence of multiple standards affects their effectiveness as governance instruments, and (iv) how international standards relate to national legislation and the local context. The key contributions to this debate can be summarized by mentioning examples of research that looks at the multi-stakeholder nature of standardization and at the societal challenges that are associated with standardization. For instance, Boström & Tamm Hallström (2013) argue that the involvement of many stakeholders contributes to standards being a legitimate form of governance, but also causes them to be fragile because they rely on the involved stakeholders' continued support. Von Geibler (2013) follows this intuition, highlighting that societal challenges may to some extent be seen as market opportunities by enterprising standard-setters. According to this research, there is the risk of imbalance among the multiple and often diverse stakeholder groups that are involved in standardization. Based on a study of standards in the palm oil industry, this research questions whether the resulting standards meet needs for sustainability. In the context of the circular economy, Flynn & Hacking (2019) build on this conversation to conclude that standards may increase the quality of recycled materials and instill confidence in the market but are also likely to prioritize costs over quality. They link these findings to a call for standards to "challenge neoliberal market relations rather than simply follow them" (Flynn & Hacking, 2019, p. 1266).

A related still parallel discourse analyzes standards' effectiveness as a potential governance mechanism. Derkx & Glasbergen (2014) claim, for example, that the coexistence of competing standards can cause fragmented governance and therefore call for meta-governance to address this issue. Their findings provide lessons for the success of governance initiatives in the domain of standardization and call into question the notion that private sector-developed standards lack ambition. The coexistence of multiple standards in one field is also observed in Manning & Reinecke's (2016) study of sustainability standards for coffee. However, they do not interpret this insight as a fragmentation of governance, but as a modular approach that can help standard-setters collectively "manage to lower the ambiguity of the ongoing global sustainability discourse […] and facilitate coordination among multiple actors with potentially conflicting interests" (Manning & Reinecke, 2016, p. 628).

Inspired by such fundamental debates about the legitimacy and effectiveness of standards in stakeholders' governance, some authors also investigate how standards are implemented in local contexts and interact with national regulations. Examples of this stream are studies of sustainability standards and national regulation in the Indonesian and Brazilian palm oil and soy industries (Hospes, 2014; Macdonald, 2020), and in the Russian forestry sector (Malets, 2015). Beyond this, Renewable Portfolio Standards (discussed in detail below) and related policies are also a recurring topic in papers combining the *ethics/sustainability* and *law/regulation/policy* disciplines (e.g., Christensen & Hobbs, 2016; Dong, Shi, Ding, Li, & Shi, 2019; Schelly, 2014).

Sociology and other social science disciplines. Outside the 'triangle' that we identified as core to the interdisciplinary discourse, the link between *economics/management* and *sociology* is the strongest (35 papers). Furthermore, *sociology* is connected to *law/regulation/policy* (24 papers) and *ethics/sustainability* (13 papers). Our dataset shows that this connection is driven largely by research that draws on a variety of sociological approaches to study how actors in standardization address managerial and/or social issues. Sociological approaches used in this literature include topics ranging from negotiated order to actor-network theory, structuration theory, institutional work, and collective action. In terms of subjects, three themes stand out from this part of review: (i) implementation of standards in institutional and organizational contexts (Arnold & Loconto, 2021; Constantinides & Barrett, 2015; Nurunnabi, 2015; Sandholtz, 2012; Wilhelm, Bullinger, & Chromik, 2020); (ii) development of standards and dominant designs at the industry level (e.g., Dokko et al., 2012; Kester, Noel, Lin, Zarazua de Rubens, & Sovacool, 2019; Lee, Harindranath, Oh, & Kim, 2015; Slager et al., 2012; Sydow, Windeler, Schubert, & Möllering, 2012); and (iii) social dynamics in the adoption of sustainability standards in agricultural supply chains (e.g., Arnold & Loconto, 2021; Davey & Richards, 2013; Tennent & Lockie, 2012; Wijen & Chiroleu-Assouline, 2019).

Research on implementing standards in organizations identifies dynamics, which relate to the involved parties' framing and a standard's fit in existing norms and practices (Arnold & Loconto, 2021; Constantinides & Barrett, 2015; Sandholtz, 2012). To mention a relevant example, Sandholtz (2012) applied a decoupling approach to his case study of ISO 9001[7] implementation in two units of the same company. He observed that organizational factors can cause the same standard to have remarkably different outcomes: chaotic work practices and a culture of cynicism in one unit vs. effective practices that are enthusiastically followed in another one. Applying a collective action lens to the information-systems context, Constantinides & Barrett (2015) endorse implementing standards in bottom-up processes, as top-down approaches can lead to unintended outcomes. Arnold & Loconto (2021) mirror these insights by arguing that it is not sufficient to consider individual standards, because they are often implemented in combination. Using a case study of the Ghanaian pineapple industry, they develop the concept of 'nesting' to explain how actors negotiate their own way of fitting standards with each other.

[7] ISO 9001 is a standard for quality management systems, which is used in millions of organizations around the world.

The stream on standard development investigates how actors engage in collective action to create and maintain standards at the industry level (e.g., Dokko et al., 2012; Lee et al., 2015; Slager et al., 2012; Sydow et al., 2012). Within this stream, we observe a variety of theoretical approaches used to describe the development and success of specific standards. Theories are used by researchers in quite a malleable way to introduce case studies. In the case of the FTSE4Good Index[8], for example, Slager et al. (2012) apply an institutional perspective to find that institutional work revolves around three activities: calculative framing, engaging, and valorizing. Sydow et al. (2012) use structuration theory to study standards in the semiconductor tool manufacturing industry. They show how standards emerge through both path dependency and agency of the involved actors. Lee et al. (2015) use actor-network theory to investigate how members of alliances in the Korean mobile payment industry enlisted the support of other actors and technology to shape standards. While most of this literature focuses on new standards, Dokko et al. (2012) study periods between the emergence of new standards. Building on the concept of negotiated order (Strauss, 1978), they argue that standards do not perpetuate themselves during these periods. Instead, actors engage in negotiated-order processes to reinforce standards.

The final stream that connects sociology with other social science disciplines investigates social dynamics in the adoption of sustainability standards in agricultural value chains. For example, both Tennent & Lockie (2012) and Davey & Richards (2013) study how standards affect power relationships in food value chains. Both papers conclude that retailer-controlled food standards give supermarkets substantial power over farmers, because they are quasi-mandatory governance instruments to which food producers must comply to access the market. Tennent & Lockie (2012) investigate how organizing in cooperatives helps farmers deal with these standards, whereas Davey & Richards (2013) focus on the certification under these standards and study how standard owners' interference in the supposedly independent audit process further exacerbates the power imbalances created by these standards. Another example is the work by Wijen & Chiroleu-Assouline (2019), who frame the relationships among the stakeholders of standards in agricultural value chains in terms of controversy and argue that this controversy ultimately had a positive impact on sustainability transitions of these value chains.

[8] The FTSE4Good Index is a standard for socially responsible corporate behavior.

We also observe trends in how research develops over time in the connection between *sociology* and other social science disciplines. Throughout the entire period 2012-2021, there was a steady stream of work about standard implementation in organizations. The same applies to the sociological perspective on standards in agricultural supply chains. Work on standard development, which combines *sociology* with other academic disciplines, predominantly occurs in the first years of our review. While there is much work on standard development in later years (e.g., Toh & Miller, 2017; Ranganathan et al., 2018), it lacks the sociological perspective included in the earlier work.

Other connections between academic disciplines. In comparison to the connections discussed above, there are relatively few papers drawing on *IT/engineering* or *Other sciences* in connection with other disciplines. The work that does exist with these combinations is relatively scattered in terms of the researched subjects. Some examples include work on the energy transition, economic assessment and the legal compliance of new sustainable technologies, such as interconnected smart grids and additive manufacturing (Erlinghagen et al., 2015; Han, 2015; Ho & O'Sullivan, 2017). In these areas, research often takes a phenomenon-driven approach and aims at designing frameworks, roadmaps, and models.

2.5.2 Connections between topics

As explained earlier, we considered the core subjects in each paper and coded them accordingly with up to two topics per paper. This supports a more fine-grained analysis. Overall, we identified 56 topics across all papers in our review. Table 2-4 exhibits the seven most recurring topics within each academic discipline. For each discipline, we also calculated their rate of horizontal and vertical orientation, to understand the extent to which these are inclined towards the theoretical setting of standardization rather than the content or field of application of standards.

Within this level of coding, we found a substantial amount of work that creates connections across the field by combining two topics (e.g., IPR and corporate strategy). Overall, 36 topics are researched repeatedly in tandem with another topic. We do not analyze in detail the remaining 20 topics (e.g., forestry, genetics), which have no or only one connection with another topic. Indeed, these remaining 20 topics tend to be relatively isolated in the topological network mapping of the standardization literature.

Figure 2-3 maps the connections between topics in the 2012-2021 timeframe (i.e., the entire timespan in our dataset). This figure shows which topics are closely related to each other. In the subsequent paragraphs, we address some key insights that can be derived from this analysis. We focus on connections between topics that stand out in terms of their prominence in the field and/or are particularly relevant from a managerial perspective.

	Economics/management		**Ethics/sustainability**		**Law/regulation/ policy**	
Topics nature	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**
% Total coding	**58%**	**42%**	**39%**	**61%**	**36%**	**64%**
1)	Technology development and adoption			Agriculture		Energy policy
2)		Accounting and finance		Energy policy		Accounting and finance
3)	Corporate strategies		Multi Stakeholders Initiatives			Agriculture
4)	Standards' competition		Local context			Renewable portfolio standards
5)	Management of innovation			Human rights	Impact assessment	
6)		Energy policy	Legitimacy		Legitimacy	
7)	Impact assessment			Renewable portfolio standards		Healthcare

	Sociology		IT/engineering		Other sciences	
Topics nature	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**
% Total coding	**35%**	**65%**	**12%**	**88%**	**4%**	**96%**
1)		Education		Telecommuni-cations		Healthcare
2)		Human rights		Automation		Telecommuni-cations
3)		Healthcare		Privacy and cyber security		Physics
4)	Standards pervasiveness			Energy policy		Chemistry
5)		Accounting and finance		Energy engineering		Biology
6)		Agriculture		Civil engineering and transports		Metrology / instruments
7)	Legitimacy			Healthcare		Education

Table 2-4 – Top seven most recurring topics and horizontal vs vertical relevance of each discipline

Corporate strategy and IPR. Questions around strategic issues related to standards and intellectual property rights (IPR) in standardization are at the core of managerial research on the topic. This is also reflected in our coding, where a substantial number of papers are assigned to these two topics: 43 papers have been coded as addressing corporate strategy (e.g., Blind & Mangelsdorf, 2016; Jones, Leiponen, & Vasudeva, 2021; Ranganathan & Rosenkopf, 2014; Ranganathan et al., 2018; Suarez et al., 2015), many of which address topics that include cooperation, networks, and alliances in standardization. IPR issues, often related to standard-essential patents (SEPs), are at the core of 40 papers in our dataset (e.g., Baron, Pohlmann, & Blind, 2016; Bekkers, Iversen, & Blind, 2012; Kang & Bekkers, 2015; Kang & Motohashi, 2015; Lerner & Tirole, 2015; Vakili, 2016). Both topics occur together with several others (e.g., management of innovation, technology development and adoption), and have a strong link with each other.

A first insight from this connection is the value that standards can bring to the management of IPR. Thus, it is no surprise that the most highly cited and arguably most influential paper on the intersection of corporate strategy and IPR is the work by Teece (2018) on profiting from innovation in the digital economy. This paper argues that standards and SEPs are two inter-related key elements of strategies for monetizing innovation in the digital era. In a similar vein, Toh & Miller (2017) show how firms can maximize the value of their intellectual property by strategically deciding how much and which IPR to disclose in standardization, in light of tradeoffs between increasing their technology's value and risks of expropriation of this value by competitors.

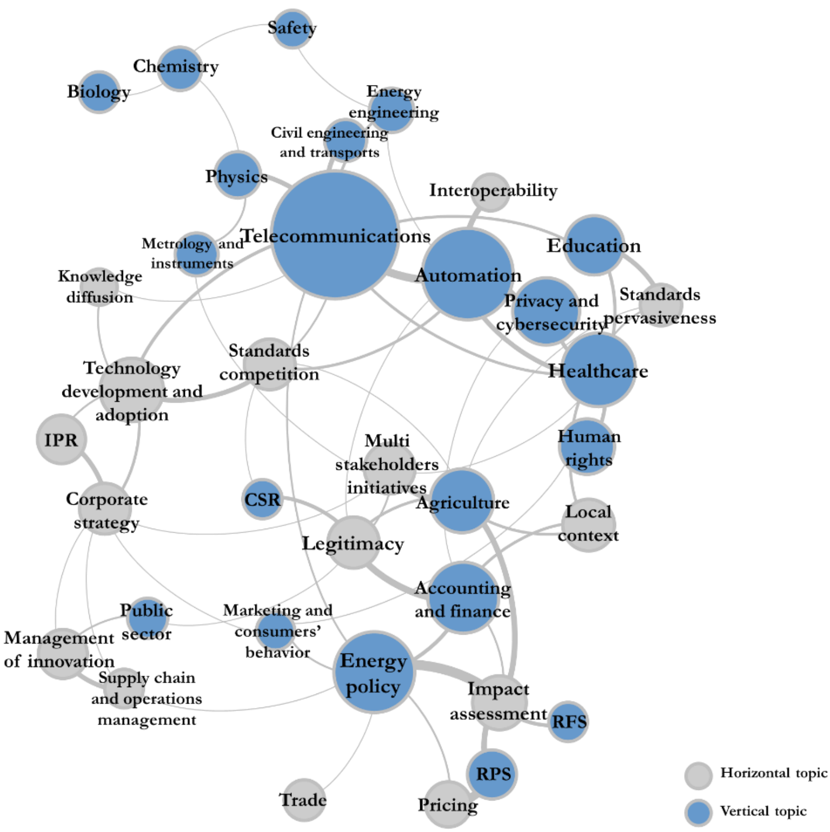


Figure 2-3 – Network visualization of the topics in standardization research (2012-2021)

A second topic at the intersection of IPR and corporate strategy in our dataset concerns alliances in standardization (Baron & Pohlmann, 2013; Lou, Yao, & Zhang, 2022). This work investigates how companies coordinate their standard-related R&D activities in alliances and consortia, and how they distribute the related IPR among each other. For example, Baron & Pohlmann (2013) compare standard development in consortia, such as the World Wide Web Consortium (W3C), with the work in formal standard bodies, such as the International Organization for Standardization (ISO). They find that consortia often include firms with complementary, rather than competing, IPR portfolios, and can be used to settle conflicts before standard development in formal standard bodies is initiated.

Technology development/adoption and standards competition. The combination of technology development/adoption and standards competition represents a second literature stream at the heart of strategy and innovation management scholars' interest. This is also evident from the frequency with which both topics appear in our dataset (see Appendix F): Technology development/adoption is indeed the most frequent horizontal topic (72 papers, e.g., Dokko et al., 2012; Gauch & Blind, 2015; Jain, 2012) with a high number of papers explaining how technologies co-evolve with standards. Standards competition is further discussed in 46 papers (e.g., Chen, Qian, & Narayanan, 2017; Gallagher, 2012; Reinecke et al., 2012) and usually occurs when de facto standards and/or dominant designs emerge in a market battle (Cusumano et al., 2014; Wiegmann et al., 2017).

Dominant designs are also a key issue of interest at the intersection between these two topics, as emerges from the following examples. Benner & Tripsas (2012), for instance, investigate how demand-side factors influence the role of technological factors in the emergence of dominant designs. In a similar vein, Eisenman (2013) argues that standards competition and dominant designs are influenced by a variety of contextual, non-technological factors related to sociology, marketing, and psychology. Gustafsson, Jääskeläinen, Maula, & Uotila's (2016) literature review of industry emergence highlights the key role of standards and dominant designs in the 'growth stage' of a new industry. Similarly, Raffaelli's (2019) case study of the Swiss mechanical watchmaking industry shows how incumbent firms can reinvent themselves in light of competing technologies supplanting the existing dominant design. In their variety, all these examples illustrate the breadth of aspects that have been studied in the context of dominant designs at the intersection between technology development/adoption and standards competition.

Accounting/finance and legitimacy. We already identified legitimacy to be a key concern in the research combining the *law/regulation/policy* and *ethics/sustainability* disciplines (see discussion above). The analysis of topics reveals a second area where the legitimacy of standards is a key concern: 15 papers in our dataset address this issue explicitly. They mainly ask whether the standardization process, in which international accounting standards are developed, considers all stakeholders fairly (e.g., Bamber & McMeeking, 2016; Jorissen, Lybaert, Orens, & van der Tas, 2013; Kok & Maroun, 2021; Sinclair & Bolt, 2013; Wingard, Bosman, & Amisi, 2016). Durocher, Fortin, Allini, & Zagaria (2019), for example, formulate this research question by studying the consequences of the potential imbalances associated with how the resulting accounting standards are perceived by financial analysts. Other work critically assesses the International Accounting Standards Board's (IASB) accountability in light of the 2008 financial crisis (Botzem, 2014).

Renewable Portfolio Standards (RPS). RPS are a frequently recurring vertical topic in the research captured by our dataset (more than 40 papers), making this a prominent subject in the standardization field. RPS are predominantly researched using *economics/management*, *law/regulation/policy*, and *ethics/sustainability* perspectives, and feature prominently in the work connecting these three academic disciplines. RPS are closely linked to regulation and define requirements for energy producers about the share of renewable energy sources that they must include in their production portfolios (e.g., Barbose, Bird, Heeter, Flores-Espino, & Wiser, 2015; Sun & Nie, 2015). Research on the topic addresses a variety of issues that range from the effects of RPS on prices and competition between firms in the energy market (Tanaka & Chen, 2013) to the interactions between RPS and other sustainability policies for energy production (Chen & Wang, 2013), the analysis of the comparisons of RPS with other policy designs for promoting clean energy production like feed-in tariffs (Kwon, 2015; Novacheck & Johnson, 2015; Yang et al., 2021) till the study of their overall costs and benefits for single actors and for the broader society (e.g., Barbose et al., 2015; Rouhani et al., 2016; Wiser et al., 2017).

In terms of connections between RPS and other topics, we observe considerable changes in the literature over the timeframe of our review (2012-2021). RPS research tends to be connected to pricing over the entire timeframe, often in the context of cost-benefit analyses (e.g., Barbose et al., 2015; Rouhani et al., 2016; Wiser et al., 2017). However, the connection with impact assessment emerged only in a later period, with the first paper making this connection being published only in 2018 (Bento, Garg, & Kaffine, 2018). This work decomposes the effects of RPS into multiple constituents (substitution effects, output-tax effects, output effects) and shows that increases in RPS requirements can lead to either large-scale investment in renewables or substantial reductions in emissions. Following this paper, in the period between 2018 and 2021, six other papers explored this connection.

Telecommunications, automation and privacy/cybersecurity. Given the strict link between standards and technology, technical topics represent a substantial share of our dataset, with telecommunications (209 papers, e.g., Lu et al., 2016; Nasrallah et al., 2019; Shafi et al., 2017) and automation (132 papers, e.g., Ayoub, Samhat, Nouvel, Mroue, & Prevotet, 2019; Chen et al., 2012; Sheng et al., 2013) being overall the two topics with the largest number of papers in our dataset (see Appendix F). We see strong connections between these topics: 46 papers link telecommunications, automation, and privacy/cybersecurity. Papers in this part of the network focus on the technical content of standards, often in the context of the Internet of Things (IoT). Key issues about these topics include (i) communication between IoT devices (e.g., Ali, Yigang, Shi, Sui, & Yuang, 2020; Burasa, Djerafi, & Wu, 2021; Han et al., 2020; Sharma, Kanaujia, & Kumar, 2021), (ii) IoT security and encryption (e.g., Keoh et al., 2014; Sciancalepore, Piro, Vogli, Boggia, Grieco, & Cavone, 2016; Radanliev et al., 2020), and (ii) vehicle-to-X communication (e.g., Abou-zeid, Pervez, Adinoyi, Aljlayl, & Yanikomeroglu, 2019; Harounabadi, Soleymani, Bhadauria, Leyh, & Roth-Mandutz, 2021; Wang, Mao, & Gong, 2017). To some extent, the connections between topics are likely to reflect technological developments in standardization: although most of the papers studied communication standards throughout the whole review period (2012-2021), notably the link between standards, automation and IoT only proliferates in the last years of the review (after three early papers appeared in 2014-2016, the topic gained prominence from 2018 onwards). From this perspective, our review of the technical standardization literature may be a new data source for future managerial studies on technology trajectories.

2.5.3 Interpretative perspectives on standardization research

As shown by our review of the literature, research about standardization is dispersed across various academic disciplines and topics; however, the overlap and the connections between disciplines and topics reveal the emergence of key trends that suggest burgeoning theoretical consistency and represent the opportunity for further integration. By focusing on the links between disciplines and topics, we show that this dispersed literature tends to converge into a coherent field of research. Standardization research emerges from our analysis as an evolving research program in which the nurturing and articulation of various and often disparate ideas gives impetus and originality to new theorizing across disciplines and topics (e.g., Lakatos, 1970). To help generate the Lakatosian interpretive understanding of the hard 'core' of ideas distinctive to the standardization research program, we interpret the reviewed literature on an aggregate level by proposing and discussing four interpretative perspectives that summarize the core insights from standardization research.

There are four emerging overarching discourses in the decade of literature that we reviewed, which represent four interpretative perspectives of inter-related topics within the standardization literature: (i) standardization management within or between organizations, (ii) standardization for sustainability and energy transition, (iii) social and human aspects of standardization, and (iv) technical standardization. Figure 2-4 shows which topics underlie each of the four perspectives, and which connections already exist across the boundaries between perspectives. Table 2-5 provides an overview of these perspectives. It also shows to what degree the perspectives are oriented *horizontally*, by providing the percentage of included topics that we coded as *horizontal versus vertical* (both as a raw number and weighted by the number of papers covering each topic).

Following Lakatos (1970), these perspectives represent the sets of protective belt theories that, we suggest, can be clearly derived from the most frequent connections between disciplines and topics in standardization research. Through the brief discussion of these perspectives, our approach seeks to draw from the core concepts in this variegate literature to suggest new opportunities for researchers and practitioners to develop the standardization research program further while keeping its protective belt of conceptual distinctiveness. For this reason, these four interpretative perspectives incorporate both the interdisciplinary complexity of the literature and its paramount attention to practice-oriented topics aimed at solving standardization issues for firms, businesses, and society.

	MANAGING STANDARDIZATION WITHIN AND BETWEEN ORGANIZATIONS	STANDARDIZATION FOR SUSTAINABILITY AND ENERGY TRANSITION	SOCIAL AND HUMAN ASPECTS OF STANDARDIZATION	TECHNICAL STANDARDIZATION
	Horizontal ◄	———	———	► *Vertical*
HORIZONTAL ORIENTATION[a]	**64%**	**46%**	**38%**	**18%**
HORIZONTAL ORIENTATION[b]	**77%**	**37%**	**24%**	**13%**
MAIN THEORETICAL SETTING	Innovation ecosystems; diffusion of knowledge; IPR, standards competition and corporate strategy, harmonization of standards	Energy impact assessment; cost-benefit analysis; feed-in tariffs; policy analysis; global multi-stakeholder initiatives	Legitimacy of standard-developing processes; unintended consequences; anticipatory standards; frameworks for social norms and values; governmentality of standards; sociology of quantification	Technological trajectories and technology adoption
MAIN EMPIRICAL SETTING	Standards in the tech and energy sectors; accounting and reporting standards; standards for the public sector; standards for international cooperation and trade	Standards for renewables; standards for agriculture; eco-labels; water and food certifications; standards and SDGs; standards for smart grids; CSR	Cultural standards in communities and local contexts; labor and living standards; standards in and for education; privacy issues from automation and artificial intelligence	Standards in 5G and 6G; interoperability of smart devices through standardized chips and sensors; compatibility and quality standards of smart cities; biomedical privacy; data encryption; protocols of cryptography
TOPICS INCLUDED	Technology development and adoption; Corporate strategy; Management of innovation; Standards competition; IPR; Network analysis and effects; Supply chain and operations management; Public sector; CSR; Marketing and consumer behavior; Knowledge diffusion	Energy policy; Impact assessment; Multi-stakeholder initiatives; Accounting and finance; Renewable Portfolio Standards; Agriculture; Pricing; Renewable Fuel Standards; Metrology/instruments; Legitimacy; Trade; Harmonization; CSR	Education; Healthcare; Privacy and cybersecurity; Legitimacy; Accounting and finance; Local context; Human rights; Standards pervasiveness	Telecommunications; Automation; Privacy and cybersecurity; Physics; Metrology/instruments; Technology development and adoption; Civil engineering and transportation; Interoperability; Safety; Chemistry; Energy engineering

Table 2-5 – Research perspectives on standardization (2012–2021)

[a] percentage of horizontal topics; [b] weighted by no. of papers per topic

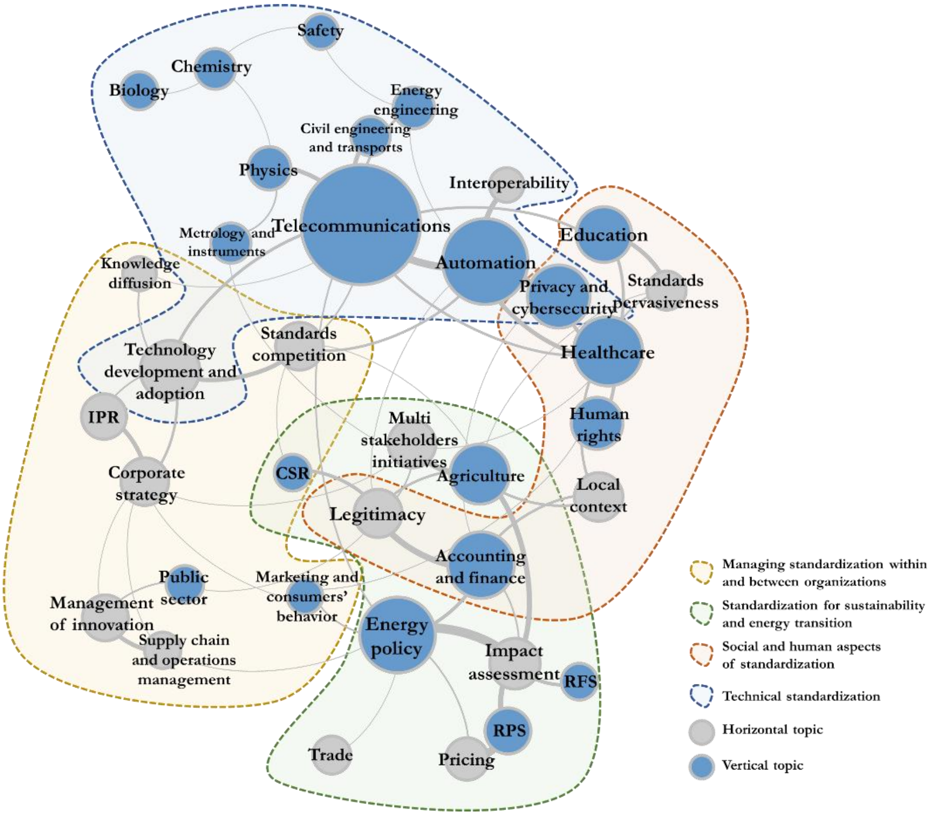


Figure 2-4 – Network visualization of the interpretative perspectives of standardization research (2012-2021)

Managing standardization within and between organizations. In our review, the economic and organizational nature of standards and standardization makes the *economics/management* discipline the linking pin of the standardization research program. The figures and our discussion of the literature show the broad array of topics that are researched as part of this perspective. We both see that scholars from different sub-disciplines of management take an interest in standards and standardization as a phenomenon, and that insights from studying the phenomenon are used to develop theory in the respective sub-disciplines. Examples of this phenomenon include approaches to the field from strategic management (e.g., Ranganathan & Rosenkopf, 2014; Teece, 2018; Toh & Miller, 2017), innovation management (e.g., Blind et al.. 2017; Foucart & Li, 2021) organizational theory (e.g., Brunsson et al., 2012; Haack et al., 2012) and international management (e.g., Brem

& Nylund, 2021; Fransen, Kolk, & Rivera-Santos, 2019; Kraus, Meier, Eggers, Bouncken, & Schuessler, 2016). Standardization management seems to emerge as a meta-lens that captures the distinctiveness of the standardization research program by providing flexibility and malleability in the definitions and operationalizations of standards across topics. Future research is needed to bridge this intellectual portability with the theoretical awareness of the distinctiveness of a standardization approach versus competing or collaborating theories across subfields of management research (i.e., strategic management or organization theories).

Standardization for sustainability and the energy transition. Not surprising given the increasing relevance of sustainability in the broader social science disciplines in the last decade, our review of the literature shows that there is wide agreement on the key role of standards for reaching sustainability goals and addressing grand challenges like climate change. Their role in driving the energy transition is widely researched across the entire period that we considered. The centrality of standardization theorizing in the energy transition field depends on the relevance of quality and compatibility standards in ensuring coordination between all actors involved in these complex socio-technical systems (e.g., van de Kaa, Kamp, & Rezaei, 2017). Interestingly, in most of this research the standardization lens remains phenomenological: there is limited attention to standards and standardization as a theoretical lens, or as an emerging discipline. On the contrary, standards are seen as 'objects' of analysis that apply to technical considerations of energy transition as much as to other technical or technological components. From this perspective, we see the need for theoretical development of the role of standards as conceptual constructs that can enrich our understanding of the technical correlates of sustainability across topics and disciplines.

A new theoretical attention to standardization can be also fueled by the surging stream of research on the economic assessment of the energy transition: as shown by this perspective, different types of cost-benefit analyses are conducted to ensure that stakeholders meet the requirements of, among others, renewable portfolio standards (Alizada, 2018), renewable fuel standards (Huang, Khanna, Önal, & Chen, 2013), environmental management standards (ISO 14001) (Husted et al., 2016), and Corporate Average Fuel Economy (CAFE) standards (Sen, Noori, & Tatari, 2017). This development of the literature can foster interdisciplinary collaboration between economists, policy experts, engineers, and energy/environmental scholars. In this evolving field, standardization can be seen as a conceptual lens integrating the links between technical and economic aspects of the energy transition.

Remarkably, our analysis also reveals what is not yet researched within this perspective – these are opportunities for future research. Despite the substantial body of work on legitimacy and fair stakeholder representation in other areas of standardization, which include accounting (e.g., Botzem, 2014; Durocher et al., 2019) and agricultural value chains (e.g., Arnold & Loconto, 2021; Reinecke et al., 2012) this topic is notably absent in the literature on energy transition. Considering the theoretical relevance of corporate vested interests and the imbalance between the power of diverse stakeholders for the development of the standardization research program across disciplines (i.e., sociology, accounting, policy studies, ethics and sustainability), we call for further work incorporating this debate into the research agenda of standardization.

Social and human aspects of standardization. Considering that the standardization research program inherently bridges technical and social topics across disciplines, there is no doubt that a prevalent perspective of research addresses the broad and often disparate societal aspects of standardization. Given its breadth, this perspective appears relatively heterogeneous in terms of topics and representation across disciplines. However, a few key trends emerge that can guide our interpretive effort. Research under this perspective includes for example the body of work on standards in privacy/cybersecurity (Rossi, 2021), e.g., in relation to healthcare (e.g., Bhardwaj & Kumar, 2021; Prodanoff, White-Williams, & Chi, 2021). Furthermore, given the rising attention to standards in the context of sustainability, we see in this perspective an increasing amount of research on human rights topics, such as labor standards (e.g., Baumann-Pauly, Nolan, van Heerden, & Samway, 2017; Van Roozendaal, 2015). Large parts of this research draw on knowledge from the *ethics/sustainability*, *law/regulation/policy*, and *sociology* disciplines. This work tends to have consistent managerial relevance, mainly from a Corporate Social Responsibility (CSR) standpoint, and this is why we also see recent work from the management discipline that engages with such perspective in this context (e.g., Husted et al., 2016; Silvestre et al. 2020; Van Roozendaal, 2015). In our view, future research is needed to integrate the analysis of the human and social aspects of standardization with its technical underpinnings. Although in a nascent phase in this literature, work on the social and ethical aspects of AI could represent an interesting starting point to advance this perspective into the theoretical integration of the multi-faceted nature of contemporary standards.

Technical standardization. As already shown by our review, and with no surprise given the relative prevalence of technical literature in our dataset, research on technical standardization represents a very substantial part of our literature review, yet is mostly isolated from the other perspectives. This dual pattern of most frequent representation in the literature and yet isolation from the interdisciplinary corpus of research represents simultaneously a strength and a weakness of this perspective. Indeed, it reveals the theoretical fragility of standardization in the technical disciplines (in which, as already discussed, standards are often confined to the a-theoretical role of objects, tools, or artifacts). Still, the relative conceptual under-development of the understanding of standards in this literature represents an undoubted opportunity for integration with other disciplines, as suggested in the final paragraph of the previous perspective. The main reasons for this isolation include the relatively high technical specialization of journals and research communities, whose languages are often impermeable to researchers from other disciplines. Moreover, we observe in the literature the remarked tendency to choose new blossoming and often 'hot' topics that can attract attention and research grants (e.g., new communication networks and smart grids) because they are in need of technical research for their development (Fan et al., 2013; Han et al., 2020). However, we see a clear trade-off between the singular attractiveness of these topics and the goal of developing a theoretically cohesive and progressive standardization research program.

Despite this risk of isolation, the most promising opportunities for integration come from research on *Telecommunications* and *Automation*, which are the most frequent and closely related topics in this perspective. To the extent that ICT and automation permeate many other fields, these two topics are also the key drivers of cross-fertilization across disciplines. We also suggest that theories on technology development and management could further contribute to the integration of this perspective with others (Henfridsson, Mathiassen, & Svahn, 2014). To the extent that ongoing technological developments drive firms' innovation and ultimately their long-term performance, this perspective could serve as an extensive data source to track technology trajectories, which could be further integrated into managerial research aimed at investigating the connections between technological choices of firms and their innovation success (e.g., Moreira, Klueter, & Tasselli, 2020).

2.6 Discussion and research agenda

To our knowledge, this paper provides the first large-scale review of literature on standards and standardization across management and other academic disciplines. Our work is motivated by the ubiquity of standards, and by their importance for organizations, policymaking and many other actors in society. In the literature, this is often mentioned in the context of major issues affecting business and society, such that standards are named as key for ecosystems (Bogers, Sims, & West, 2019; Shipilov & Gawer, 2020), the platform economy (Jacobides et al., 2024; Tassey, 2000; Teece, 2018), sociotechnical transitions towards a more sustainable society (Geels, 2004), and achieving the targets of the United Nations' Sustainable Development Goals (SDGs) (van Tulder & van Mil, 2023). Yet, while there are many references to standards in these overarching contexts, these references often remain relatively vague on how standards can contribute to such transformations of business and society. Arguably, developing such an understanding also involves a normative stance on how standards can contribute to goals, such as economic efficiency, sustainability, ethics, fairness, and technological impartiality. Our comprehensive review of research in the period 2012-2021 takes stock of the insights that already exist on this contribution, and envisages promising directions for future research. In doing so, we observe research that (i) is scattered across academic disciplines and topics, yet (ii) can be seen as revolving around standardization as a common phenomenon. We also see some work taking a normative stance – such as the research on standards in agricultural value chains with its strong focus on ethics and sustainability (e.g., Arnold & Loconto, 2021; Meemken, 2020; Wijen & Chiroleu-Assouline, 2019).

A large share of the reviewed research (approximately 70%) focuses on standards in specific areas of business, society, and technology, such as telecommunications, healthcare, agriculture, and the energy transition. This research tends to view standards as means to solve particular problems and studies their specific applications. The very diverse application areas addressed in this work reflect standards being recognized as tools that can solve a large variety of issues. Mirroring Lakatos (1970), such research can be qualified as 'centrifugal' because the variety of topics that are addressed reinforces the scattered nature of knowledge in the field. Only a smaller share of the reviewed work aims to integrate knowledge on standardization, and treats it as its main object of interest. We qualify this as 'centripetal' research, due to its potential for pulling the field together and unifying it. Given the risk of centrifugal research drifting a-theoretical themes and topics apart, we suggest that the field as a whole would benefit from more theoretical alignment and integration, focusing on research that aims to develop theory about the core of the most important phenomena. Such consistency may develop from the numerous connections across academic disciplines and topics described in the previous section. Our interpretation of these connections in terms of the 'integrative research perspectives' presented in the section above ((i) managing standardization within and between organizations, (ii) standardization for sustainability and the energy transition, (iii) social and human aspects of standardization, and (iv) technical standardization) is a first step in this direction.

However, we also recognize that, given the nascent and burgeoning phase of this field, many gaps remain to be addressed before having a truly integrative understanding of standardization. In our research agenda, we address the need for more 'centrifugal' research focusing on contents, applications, implementation, and goals of standards. However, given our call for theoretical integration, we concentrate in particular on 'centripetal' research, which is needed to pull the centrifugal forces together and build more coherent knowledge on standardization. Here, we focus on three areas where we see a particular need for interdisciplinary research to fill this gap: (i) a process approach to standardization, (ii) new approaches to understanding and measuring the impact of standards, and (iii) studies on standardization policy and governance.

2.6.1 'Centrifugal' research directions: focus on the content, applications, and goals of standards

The majority of the papers in our review, especially in the technical disciplines, address vertical (i.e., content-oriented) topics (87% of the papers in the perspective 'technical standardization', 76% in the perspective 'social and human aspects in standardization', and 63% in the perspective 'standardization for sustainability and the energy transition'). This focus on vertical topics, which address specific application areas of standards, means that they contribute to the 'centrifugal' forces in the field. We see a high relevance of such 'centrifugal work' for the large-scale issues that motivate our research agenda (standards' role in shaping the platform economy, ecosystems, sustainable transitions, and the SDGs). Yet, we also notice that the topics covered by these papers are often researched in an isolated fashion or in combination with other vertical topics, meaning that large parts of this research do not aim to contribute to overarching theories about standardization. In the relatively rare instances when research combines 'vertical' and 'horizontal' topics, it can contribute to both the 'centrifugal' and 'centripetal' tendencies in the field. For example, normative work on agricultural value chains (vertical topic) and legitimacy and/or multiple stakeholder initiatives (horizontal topics) (e.g., Arnold & Loconto, 2021; Hospes, 2014; Meemken, 2020; Schouten & Bitzer, 2015) analyzes standards' contributions in the specific agricultural context. At the same time, this research identifies reasons why standards may fall short of expectations for positive contributions to society, which can serve as a basis for further 'centripetal' theorizing. A second example of work that was initially triggered by 'vertical' questions and eventually also contributed to 'horizontal' theorizing is the early work on telecommunication standards ('vertical' topic), which triggered the investigation of standard-essential patents (SEPs, as part of the broader horizontal topic IPR) (e.g., Bekkers, 2001). SEPs are extremely relevant in that field but increasingly also in others, and the early 'centrifugal' work on SEPs in the telecommunications context subsequently developed into a 'centripetal' stream about SEPs across industry contexts (e.g., Bekkers et al., 2012; Kang & Motohashi, 2015; Toh & Miller, 2017). Research on SEPs has been feeding into policy studies across the globe, such as that of the US National Academies of Science (Maskus et al., 2013), and recent studies (e.g., Bekkers, Tur, Henkel, van der Vorst, Driesse, & Contreras, 2022) formed the basis for new proposed legislation on SEPs by the European Commission (2023), recently adopted by the European Parliament (2024).

For the further development of purely 'centrifugal' research, we see an opportunity for interdisciplinary work. Many of the vertical topics that are currently considered from a predominantly technical angle, such as standards for cyber-physical systems (e.g., Framling, Kubler, & Buda, 2014; Jha, Appasani, Ghazali, Pattanayak, Gurjar, Kabalci, & Mohanta, 2021; Nikoukar, Raza, Poole, Gunes, & Dezfouli, 2018; Trappey et al., 2016) or standards for healthcare (Alkraiji, Jackson, & Murray, 2016; Grisot & Vassilakopoulou, 2013; Timmermans, 2015) also have important implications for business and society. Combining viewpoints from the technical disciplines with those of, e.g., *economics/management*, *law/regulation/policy*, and *ethics/sustainability*, can generate deeper knowledge on how standards can contribute to solving large-scale issues. We also consider it important that such work takes a strong normative stance in light of the challenges faced by business and society, especially when it involves the *ethics/sustainability* discipline. Examples of these emerging challenges include the role of standards in robotic surgery and medical automation (Arora et al., 2023; O'Sullivan et al., 2019) and potential discrimination raised by the use of standards in algorithms (Oliva, 2020; Raghavan, Barocas, Kleinberg, & Levy, 2020).

Furthermore, research on predominantly vertical topics, such as telecommunications, privacy and data security, and healthcare, remains relevant for managerial and social science disciplines for two reasons. First, this research provides rich and timely empirical data that can be used by other researchers. For example, work on technical aspects of telecommunication standards may be used to trace technology trajectories in this area, which can be related to other concepts of interest to management researchers, such as strategic decisions. Second, technical research on specific application areas of standards may also deliver insights about the functioning of standards in general (i.e., it may also contribute to the centripetal aspects of our research agenda). As outlined above, some research already combines in-depth studies of vertical topics with contributions to horizontal aspects (e.g., Arnold & Loconto, 2021; Hospes, 2014; Meemken, 2020; Schouten & Bitzer, 2015).

However, our analysis of the literature reveals that there are still many gaps between vertical and horizontal topics, where there is potential for connections (see Figure 2-3). For example, we see potential for investigating the role of CSR standards in the context of corporate strategy, and there appears to be a natural, but still unexplored, link between research on healthcare and education standards with questions related to legitimacy or impact assessment. By creating these and similar hitherto under-investigated connections between vertical and horizontal topics, the gap between 'centrifugal' and 'centripetal' tendencies may be closed in a manner similar to what we observed in the areas of agriculture and telecommunications (e.g., Arnold & Loconto, 2021; Bekkers, 2001; Hospes, 2014; Meemken, 2020; Schouten & Bitzer, 2015). Ultimately, such more application-oriented research can also contribute to further theoretical integration of the field. The path towards theoretical integration is the specific object of the next research agenda section, which focuses on 'centripetal' research directions.

2.6.2 'Centripetal' research directions: towards the emergence of a theory of standardization

The findings of our review suggest that standardization research in management, economics, and the social science disciplines moves towards the direction of progressive theoretical integration (see Table 2-4 and Table 2-5, which show how research in these disciplines addresses mainly horizontal – i.e., theoretical – topics). Building on this insight, we suggest three further directions that can help generate theoretical development on standards as constructs that contribute to explaining major transformations in business and society: (i) Taking a process approach to standardization allows us to identify major gaps in extant research. Addressing these gaps can contribute to further theoretical integration. (ii) While there is a consensus on standards' importance for business and society, a better understanding and improved ways of measuring their impacts are needed to explain how they make this contribution. (iii) Policy and governance of standardization have already been established as areas of research, but new developments in the field necessitate additional research and theorizing. In the subsequent paragraphs, we explain these three points in detail and present our proposals for the next steps.

Process approach to standardization. Previous research has conceptualized standardization as a process, which (i) starts with multiple parties recognizing the need for a standard, then (ii) triggers its development, and is then (iii) followed by the standard's spread, adoption and implementation (de Vries, 2010). While the steps of this process were described more than a decade ago, research so far has especially focused only on the second step – standard development (e.g., Boström & Tamm Hallström, 2013; Jain, 2012; Ranganathan et al., 2018; Toh & Miller, 2017; Wiegmann et al., 2017).

Specifically, we are aware of barely any work on how this process is started up (stage i). This relates to stakeholders' needs and motivations for having a standard. How do standards emerge, and who comes up with the original idea/need of a standard? How does the idea of a certain standard relate to parallel developments in technology, business and society? How are stakeholders mobilized to generate a standard, or to oppose its development? Which forces may counter the initiation of standard development, and which contingencies in this phase affect its further trajectory? Given the widespread recognition of a need for standards to support major transitions in business and society, we see answers to these questions as essential for understanding how standards are created. We call for interdisciplinary research to understand how the initiation of standardization processes is driven by business strategies, sociological developments involving societal stakeholders, legal and regulatory considerations and/or technological development.

Moreover, the study of standard spread, adoption and implementation (stage iii) is vital for understanding managerial actions related to standards, and for measuring how standards affect businesses and society as a whole. Yet, our review shows that previous work has been limited to a few specific settings, such as agricultural value chains studied through a sociological lens (e.g., Arnold & Loconto, 2021; Meemken, 2020), the spread of dominant designs and de-facto standards (e.g., Chen et al., 2017; Suarez et al., 2015), and some work on standard adoption inside organizations (e.g., Boiral, 2007; Sandholtz, 2012). The idiosyncrasies of these settings and the very specific research questions make it difficult to develop generalizable theories on standard adoption and implementation. For example, the work on agricultural value chains (e.g., Arnold & Loconto, 2021; Meemken, 2020) focuses on dynamics and power imbalances between stakeholders in the global north and south, which do not exist in this form in many other industries. The work on adoption of de-facto standards and dominant designs (e.g., Chen et al., 2017; Suarez et al., 2015) primarily studies market-based standardization and largely ignores standards created in phase (ii) in the committee-based and government-based models (cf. David & Greenstein, 1990; Wiegmann et al., 2017).

Research in other settings is therefore needed. Management scholarship can provide important foundations, e.g., by cross-fertilizing with theories of *networks* and *ecosystems* (cf. Bogers et al. 2019; Jacobides, Cennamo, & Gawer, 2018). This can help understand dynamics in the adoption and implementation of standards, which depend on interdependent actors who are likely to be organized in ecosystem-like networks. In addition, we see a specific need for research on *standard taking* (i.e., organizations adopting standards that have been developed by others). This raises relevant questions, which have not yet been investigated. For example, from a strategy perspective, there is a lack of work on managers' decisions about whether to apply existing standards or engage in developing new ones, or how to choose between competing standards. Management scholars may also go beyond current work in organization theory to understand how managers affect the effectiveness of standards adoption.

Standard development (stage ii), as emerging from our review, has been researched most intensively, but we also see scope for additional (interdisciplinary) work here. This part of the process involves designing solutions to be included in standards and decision-making. Current research mostly addresses these elements in isolation: some older studies on the design aspect of standard development build on new product development theories (Nakamura, 1993; Susanto, 1988) and research on decision-making in standard development commonly uses game theory or stakeholder theory (e.g., Farrell & Simcoe, 2012; Jakobs, 2023; van de Kaa & Greeven, 2017). These theoretical perspectives may be combined, reflecting what happens in practice during real standardization processes, where experts who draft a standard may also be the ones to approve that same standard (de Vries, 1999). Therefore, in-depth empirical studies are needed to understand how these parts of the process relate to each other. This research can utilize insights from several academic disciplines. For example, ethicists have studied how standardization can be made inclusive (e.g., Meijer, Wiarda, Doorn, & van de Kaa, 2023), and sociologists study standardization under a collective-action perspective (e.g., Dokko et al., 2012; Lee et al., 2015; Slager et al., 2012; Sydow et al., 2012). Furthermore, extant work on standard development from a managerial perspective (e.g., Baron et al., 2016; Ranganathan et al., 2018; Toh & Miller, 2017) is somewhat lopsided towards the activities of large firms, often in the ICT sector. We see opportunities to extend this research and take the perspective of other actors in standardization. For example, while small and medium enterprises (SMEs) face substantial hurdles in standardization (de Vries, Blind, Mangelsdorf, Verheul, & van der Zwan, 2009) there is barely any research that investigates how they navigate the field.

Understanding and measuring the impacts of standards. Standards have a substantial impact on individuals, businesses, the economy, and society. This impact lays at the foundation of their (potential) role in shaping large developments in business and society. Yet, our understanding of how this impact comes about and how it can be measured remains relatively limited. Previous work focuses on some specific aspects, such as standards' contributions to economic growth and the GDP (e.g., Blind & Jungmittag, 2008; Blind, Jungmittag, & Mangelsdorf, 2011), intra-organizational dynamics spurred by standards (e.g., Boiral, 2007; Sandholtz, 2012), and the impacts of specific standards (e.g., Boiral, Guillaumie, Heras-Saizarbitoria, & Tayo Tene, 2018; Manders, de Vries, & Blind, 2016; Meemken, 2020)[9]. A broader perspective, including a theoretical understanding of the mechanisms behind standards' impacts and empirical evidence for them, is largely missing. Following the process perspective above, work needs to start with a focus on standard implementation. This work should, for example, explain how standards' impacts are contingent on their contexts, how standards interact with each other in creating impact, and how to quantify this impact. Once these questions have been answered, we see a need for more normative research that explains what should be done during the initiation and development stages to achieve standards with desirable impacts.

Given the broad variety of potential impacts, we again see a need for interdisciplinary research. While standards' impacts are largely driven by businesses, the sociological work in our review (e.g., Arnold & Loconto, 2021; Meemken, 2020) shows that standards affect many areas of society, including the most marginalized players. This also brings a strong ethical dimension to the topic, and standards' impacts may also have implications for policy and law.

[9] The latter research may be characterized as 'vertical'.

Studies on standardization policy and governance. Approaches to governing standardization and their underlying policies are key in determining how standardization functions, e.g., in terms of how stakeholders can contribute to standard development, whether all stakeholders' needs are considered, and whether there are effective mechanisms for reaching coordination (e.g., Austin & Milner, 2001; Kanevskaia, 2023; Tate, 2001). These approaches differ across industries, cultures, geographical and national contexts, e.g., in terms of links between standards and regulation, modes of standardization, and the stakeholders that are typically involved (Tate, 2001). Furthermore, recent developments have introduced strong elements of geopolitics into policy and governance of standardization. For example, the Chinese government has been using standardization as a tool to increase national industries' competitiveness (e.g., Gao, 2015; Gao et al., 2021; Gao & Liu, 2012; Kwak et al., 2012), and the European Commission aims to align standards with 'European values' (European Commission, 2022). Standardization policies that have been shared by various governments in recent years seem to emphasize standards that suit national/regional needs (European Commission, 2022; Government of India, 2018; The State Council of the People's Republic of China, 2021; The White House, 2023). Yet, it remains unclear how different approaches to policy and governance, both in general and in light of such recent developments, affect the functioning of standards and standardization.

Our review revealed that the discourse on how governance and policy relate to standards primarily focuses on their role as 'private' governance instruments (e.g., Boström & Tamm Hallström, 2013; de la Plaza Esteban et al., 2014; Flynn & Hacking, 2019; Von Geibler, 2013), whose legitimacy varies depending on the context in which they are developed, used and adopted (e.g., Derkx & Glasbergen, 2014; Manning & Reinecke, 2016). The focus of this research lies on how standards affect the governance of, e.g., value chains and corporate social responsibility initiatives, but it offers few insights on how standards and standardization themselves are governed. Furthermore, the context-specific nature of standards in practice needs to be factored into theoretical alignment and common conceptual integration. Without overarching studies of standards across contexts, a possible centrifugal force may emerge that subjects the definition and meaning of standards to local and often idiosyncratic cultural, political, and organizational contexts. As emerging preliminarily result from our review, we suggest that debates on how standards themselves are governed through law and policy could benefit from the integration of vertical (i.e., research analyzing the development and adoption of standards in specific local contexts; e.g., Manning, Boons, von Hagen, & Reinecke, 2012; Raffaelli, 2019) and horizontal (i.e., research looking for common conceptualizations across different national and geographical contexts; e.g., Botzem & Dobusch, 2012; Brunsson et al., 2012; Derkx & Glasbergen, 2014) views on the topic. Specifically, we suggest that this integrative work should merge two levels of analysis: (i) the macro level to better understand how standardization is governed by national and, if applicable, regional policies, and (ii) the micro level to understand how individual firms and other stakeholders navigate this field.

First, studies on the differences in international approaches to standardization on a macro level should integrate *sociology* and the *law/regulation/policy* disciplines to generate a better understanding of the organizational setup of standardization (e.g., roles played by standard-developing organizations (SDOs) themselves, and by companies, industry consortia, governments, NGOs and other stakeholders). This integrative research is needed to investigate how the setup of standardization contributes to different outcomes, for example in terms of international trade and competitiveness, balance between business and societal interests, and legitimacy of the resulting standards.

Furthermore, we see a need for more integrative 'activist' research that bridges technical and social science disciplines to study how standards can contribute to more fairness on a national and global scale. This work can bridge technical knowledge from IT, engineering and other 'hard' sciences with insights from the ethics and sustainability work identified in our review (e.g., Brako et al., 2021; Flynn & Hacking, 2019; Von Geibler, 2013). In this direction, we also see a promising opportunity for conducting design science research (cf. Romme, 2003; Simon, 1969) that develops new approaches to governing standards at the global level to promote values such as fairness and ethical consumption.

Second, at the micro-level, research is needed to take the perspective of institutional actors, businesses and other stakeholder organizations to understand how they can reap the benefits of standards and standardization (e.g., Tate, 2001). Questions to be investigated include, for example, the kinds of resources and capabilities that firms need to effectively adapt their approaches to standardization in international settings; whether and how firms can use differences in standards across the globe to their advantage; and how policymakers react to firms' strategic behavior to support societally desirable standardization outcomes.

From an institutional perspective, further research should also investigate the hybrid role played by SDOs in the context of standardization policy and governance. SDOs play a central role in guiding standardization processes (Brunsson et al., 2012). There is some work on national standard bodies (Bonner & Potter, 2000; de Vries, 1999; McWilliam, 2001) and some recent research shows the importance of SDOs' management for firms and other actors in standardization (Baron & Spulber, 2018; Wiegmann, Eggers, de Vries, & Blind, 2022). However, there is still a lack of research that investigates more precisely how SDOs are managed, and what effects this has on their ability to effectively facilitate the development and implementation of standards. For example, SDOs are generally seen as neutral facilitators of the standardization process. However, in a world where standards are expected to generate a positive impact on society, it is questionable whether it is possible (or even desirable) for SDOs to be value-free in light of the interests that stakeholders bring to the table. How exactly their role plays out in light of such fundamental dilemmas is an important question that is still unexplored in the current literature. Research may build on a conceptualization of standardization as an activity that occurs in networks of stakeholders with different and often competing utility functions, and in which the SDO takes on the role of a network administrative organization (NAO, cf. Provan, Fish, & Sydow, 2007; Provan & Kenis, 2007). This would allow bridge theories about the governance of standardization with theories on inter-organizational social networks, which might show the process of standard development and adoption as a dynamic network process in which a multitude of different actors is involved (e.g., Stevenson & Greenberg, 2000).

2.7 Conclusions and final remarks

We conclude our review and our research agenda with an overarching question: does the standardization field need its own theories, or can it use, adapt, and merge theories from adjacent fields? Following Lakatos (1970), we suggest that the answer bridges both elements of this duality. Standardization is an emerging field of research in need of more theoretical consistency, without losing its ability to scout, select, and include a wide array of conceptual and phenomenon-led topics across academic disciplines. Our review of contemporary research reveals a balanced tension between the role of social science disciplines (steering the evolution of standardization theorizing) and the role of technical disciplines (providing empirical findings and adding novel phenomenon-driven perspectives). So, we recommended continuing content-related 'vertical' research, conducted by hybrid teams of subject-matter experts and social scientists. Management scholars will play a key role in such teams because they can link organizational decisions to the processes of standards-making and standards-taking, in all their different stages. At the same time, we recommend advancing research on the multiple 'horizontal' themes identified in our study. Such research would again benefit from interdisciplinary teams, enabling the development of novel standardization theories that build on and integrate existing notions from the social science disciplines. With standardization being an important business phenomenon, we believe that it has the potential to develop into a specialism within business science.

3. Rethinking network structure for network effects in standards and platforms adoption[1]

Despite the increasing emphasis on dynamic modelling of network effects and the importance of network structure, the dominance of network-based standards and platforms is partially understood by scholars and difficult to control by practitioners. They overlook fundamental characteristics of a network structure, including the types of interactions between standards and platforms adopters, multisidedness, tie multiplexity, and the conversion from potential to appropriated value both for the network and for its participants. These oversights hinder the practical application of these dynamic models and the theoretical advancement of the field. In our paper, we develop a framework to assess network value for technologies such as standards and platforms considering all mentioned structural characteristics. Looking at these as multi-sided networks, we define five distinct types of network ties between adopters and conceptualize the measurement of potential, actual, and appropriated value both at the network and node level. We also provide guidelines to measure network effects in these contexts empirically. Our framework contributes to the theoretical and policy debates on value measurements in ecosystems and forecasting technology diffusion and dominance.

3.1 Introduction

Network theory is applied in many academic disciplines, rooting in sociology (e.g., Bott, 1958; Mitchell, 1969) and spanning to other social sciences like management

[1] This chapter is under review as: "Grillo, F., de Vries, H.J., van de Kaa, G., & Bekkers, R. – Rethinking network structure for network effects in standards and platforms adoption". Previous versions of this chapter are published in conference proceedings as: "Grillo, F., de Vries, H. J., & van de Kaa, G. (2020). The Application of Network effects to Standards and Platforms. In K. Jakobs, & D. Kim (Eds.), EURAS Proceedings 2022: Standardisation and Open Source (Vol. 17, pp. 223-231). Wissenschaftsverlag Mainz".

and economics (Demange & Wooders, 2005; Jackson, 2010) as well as physical sciences like biology and physics (Bar abasi, 2012; Dunne et al., 2002). In these disciplines, networks are a rich concept that allows us to visualize and analyze, among others, the social interactions, geographical proximity, or economic transactions between network agents (so-called *nodes*), corroborating the value of forming groups rather than acting independently. Specifically in the fields of technology economics and management, networks emerged as key tools to forecast the diffusion and adoption of technologies (Borgatti et al., 2009; Jantsch, 1967). Among these technologies, standards (such as interface' specifications) and platforms (such as social media) raised particular interest since they can be adopted by large masses of users and easily reach market dominance (Dai et al., 2024; Farrell & Saloner, 1985; Shilov & Gawer, 2020; Swann, 2002).

What makes standards and platforms so pervasive is that their adopters are subject to network effects (Heinrich, 2014a; Papachristos, 2020). These effects imply that an increase in the number of adopters of a specific technology enhances its value for current existing adopters (Katz & Shapiro, 1985). This creates a feedback loop, through which the higher the value for adopters, the higher the value created and appropriated by the technology itself and its owners (Gawer and Cusumano, 2014), for example by increasing transaction costs for users when switching to a competing technology (Arthur, 1989; Liebowitz & Margolis, 1995). Often, these feedback loops may escalate and bestow large market shares to the standard or platform.

In this context, value is normally intended as the maximum number of interactions enabled by the technology (at the network level) or for one single adopter (at the node level). For example, the number of systems that can be connected using the same standardized interface defines the network value of that interface, and the number of connections of each system defines their node value. Many scholars in social sciences agree that these feedback loops increase the network value following Metcalfe's law. Referring to the Ethernet protocol, Metcalfe explained that the number of possible interactions (i.e., the potential value of a technology) through a communication standard grows at a quadratic pace, namely to the power of two for every new adopter. This led to the postulate that the size of a network is the primary factor driving the adoption of technologies subject to network effects, such as standards and platforms (Iansiti, 2021; Shankar & Bayus, 2003; Swann, 2002).

The progressive use of network theory sources emphasized how the number of interactions not only depends on the number of nodes participating in the network, but also on the structure of such a network (Freeman, 1982; Granovetter, 1985). However, the link between size and network value and other notions eradicated in the technology and innovation literature lead to an oversimplification of the concepts of network effects and value. For example, there is increasing attention – deriving especially from social network theory – on other types of interactions, including the presence of competition or the formation of cliques, that describe other growth rates that are not quadratic (Li et al., 2018; Oren et al., 1982; Wang et al., 2023). While measuring the value of networks considering all these interactions is per se a challenge, it gets even more complex when adopters can interact in more than one way, for example when consumers on the same platform compete to purchase a product while collaborating with each other by leaving ratings and reviews. Network theorists define the presence of multiple interactions between adopters as *tie multiplexity*, a concept that received little consideration in the technology economics and management literature (Ertug et al., 2023).

Another problem, especially recurring in the digital platforms' literature, is the empirical emphasis on intermediary platforms (e.g., Farronato et al., 2023; Rochet & Tirole, 2003), for example Uber and Airbnb. These platforms are two-sided, meaning that adopters can be divided in two groups (or "sides") based on the different function they perform for the network. Thus, the feedback loops are reinforcing not only within the sides (i.e., same-side network effects), but also between the two sides (i.e., cross-side network effects). This emphasis makes scholars neglect more complex cases of *multisidedness*, where three or more groups of adopters cover different functions for the network and are thus subject to network effects in different ways (Mcintyre et al., 2020). Examples of multi-sided networks include social media platforms or standardized interfaces for electric charging.

Tie multiplexity and network multisidedness are two cases showing how the adoption of these technologies is not only dependent on the size of their networks of adopters, but also on how they are structured (Afuah, 2012; Skilton & Bernardes, 2015; Zhu & Iansiti, 2019). Network structure is increasingly included in empirical studies on network effects, but often these studies focus on one single side and consider limited – albeit important – aspects, such as different types of node centrality or the presence of structural holes (Afuah, 2012).

In this paper, we address this limited understanding on network structure by developing a comprehensive framework to confer a static value to the networks generated in standards and platforms, considering both size and structural characteristics of the network. Scholars are progressively estimating network effects using dynamic models, considering the bandwagon effect that attracts more adopters to the standard or platform (e.g., Farronato et al., 2023; Jullien et al., 2021). Despite the complexity of these models, they tend to overlook important characteristics of network structure and fail to provide a holistic view of value for standards and platforms. Using some fundamentals of network theory, our framework allows to measure the value of networks considering the different types of ties (Afuah, 2012; Economides & Katsamakas, 2006), tie multiplexity (Ertug et al., 2023; Verbrugge, 1979), multisidedness (Hagiu and Wright, 2015), and the value for individual nodes (i.e., the adopters) (Everett & Borgatti, 2005). Besides computing the potential value based on the total number of possible interactions, we provide detailed steps on how to compute the actual value, intended as the real number of interactions, and the appropriated value, namely the value derived from the technology owners and its adopters.

Our framework contributes to the large gap, both related to theory and practice, about forecasting methods for the adoption and diffusion of both standards and platforms. Our theoretical contributions stand in the combination of notions from network theory with the literature on technology adoption and diffusion. Aligning with the mainstream sources of the latter (e.g., Griliches, 1957; Rogers, 1962) that saw adoption curves as sigmoid functions (that is, with asymptotic value creation when the network reaches maturity), we provide insights on how the value function of standards and platforms is not endlessly sloped towards dominance, but can vary based on the structural characteristics of their networks. We also shed more light on how these structural characteristics can define the density of a network differently from the conventional ways of network theorists (Borgatti et al., 2018; Jackson, 2010).

As to the practical contributions, we aim to progress the current methods used by institution at controlling technology dominance. In their recent book chapter on platform M&A regulation, Cheng et al. (2025) describe "a clear need for more sophisticated models to measure value creation and anti-competitive effects". Similar models are also timely for standardization practitioners, for example due to the widespread difficulty among institutions and researchers to determine fair and reasonable licensing prices for standard-essential patents, especially when the standard has reached a wide adoption (Bekkers et al., 2023). By providing a broader view on the relationship between network effects and structure, our framework facilitates a closer estimation of the extent to which standard or platform diffuse over time.

3.2 Prior literature

3.2.1 Standards and platforms adoption

Standards and platforms are two essential concepts in technology and economics that have undergone considerable academic scrutiny in recent years (Di Domenico et al., 2023; Grillo et al., 2024). They are two important coordination mechanisms of technological markets and ecosystems (Miller & Toh, 2020; Reiter et al., 2024). Standards – in this context – are sets of technical specifications that facilitate compatibility or establish quality criteria between various parties (de Vries, 1997). Platforms function as market intermediaries that facilitate transactions and communications among diverse actor groups (Ciborra, 1996; Gawer, 2014; Rochet & Tirole, 2003). Popular examples of the former are the USB set of interfaces (IEC 62680-1-3) or the 20-feet shipping container (ISO 668). Examples of the latter include stores of mobile applications or any online marketplace.

The function of coordination that both standards and platforms perform makes it more valuable to consume them in larger groups (of either individuals or organizations) than standalone. This results in a network effect, since the more adopters are attracted to the network, the more the network owner can harness the value brought by new adopters and attract new ones (Church & Gandal, 1992; Katz & Shapiro, 1986). As enablers of network effects and adjacent economic mechanisms, including excess inertia, path dependence and lock-in, and winner-take-all dynamics (David, 2001; Evans et al., 2011; Katz & Shapiro, 1986; Suarez, 2004; Zhu et al., 2006), standards and platforms are often dominant and yield high contractual and market power to their owners or developers (Blind et al., 2023; OECD, 2018).

Despite these shared mechanisms, literature on the adoption of standards and platforms seems twofold. On the one hand, most literature on platforms discusses network effects as the main – sometimes only – factor driving their adoption (Liu et al., 2021; Rietveld & Schilling, 2020). A reason for this focus is that – unlike standards – platforms were originally conceived as markets that leverage network externalities (Cusumano, 2020; Gawer, 2014). As a result, network effects received much more attention in the platform literature than in standardization[2]. Recently, however, a growing stream of studies is exploring other adoption factors for platforms besides network externalities. These factors are normally described as platform *distinctiveness* strategies (Robertson & Ulrich, 1998), and define ways for the platform to increase adoption without leveraging the "conformity" benefits that arise from its size. Among these strategies, literature posed attention to the platform's legitimacy (Taeuscher et al., 2021; Taeuscher & Rothe, 2021), its openness to complementors and the possibility of multi-homing (Bakos & Halaburda, 2020; Cenamor & Frishammar, 2021; Inoue, 2021), the similarity between complementors' products (Barlow et al., 2019), the complementors' size (Xia et al., 2024), and the variety of product categories (Soublière et al., 2024).

On the other hand, the adoption of standards received broader attention concerning multiple factors (van de Kaa et al., 2011). This breadth relates to the factors driving the adoption, such as their legal enforcement, either voluntary (Guerreiro et al., 2012; Wijen, 2014) or mandated by law (European Commission, 2021; Kamara, 2017), their timing of development (Boiral et al., 2018; Schilling, 2002; 2009; Scott et al., 2017), the actors involved in the development (Markus et al., 2006; Meijer et al., 2023), their input and output legitimacy (Botzem & Dobusch, 2012) or a favorable geopolitical environment (Breeman et al., 2022; Funk & Methe, 2001). Some studies focus, instead, on the adopters' network characteristics and their impact on the value created through the standards. Zhu et al. (2006) showed how the network effects emerged between users of an operating system prevented the adoption of a more open one. Borner et al., (2023) described how producers of smart home devices could derive more value when their products could be compatible through standards. The same breadth applies to the impacts of standards adoption on, for example, innovation and growth (van Oorschot et al., 2018), labor productivity (Acemoglu et al., 2012; Kalyani et al., 2025), industry structure (Vakili, 2016) and enterprise performance (Mirtsch et al., 2021; Shin, 2006).

[2] A simple search of articles within Web of Science including "network effects" and "platform*" in article titles, abstracts and keywords, within the categories of economics, management and business obtains 349 results, with the first source published in year 2000. Despite much earlier studies (first one being in 1992), the same search with the word "standard*" instead of "platform*" obtains only 166 results (searched in January 2025).

3.2.2 Network effects in standards and platforms

As said, research on network effects raised more interest in the platform literature. This field, particularly within digital platforms, provides more evidence both as to the theoretical models and empirical case-studies. Rochet & Tirole (2003) provided the first model of cross-side network effects in two-sided platforms. Building on the theory of consumer demands for telecommunication services of Rohlfs (1974), which later evolved into Metcalfe's law (Gilder, 1993; Swann, 2002), the model of Rochet and Tirole assumes the adopters' benefits as arbitrary and accounts for their dependence on the other side's prices and the pricing model of competing platforms. Armstrong (2006) expanded this model by distinguishing lump-sum fees from transaction-based pricing models and by discussing multiple multi-homing scenarios (i.e., how many platforms can one adopter join simultaneously).

Farrell & Klemperer (2011) use a more discursive approach to model network effects through game theory and describe the presence of switching costs, tipping, and consumers' inertia to adopt. Jullien et al. (2021) describe the possibility of a platform to exclude a subset of adopters on either of the two sides from accessing the platform. Karhu et al. (2024) theorized the existence of negative same-side effects when adopters are rivals on the same platform. Besides these theoretical models, recent empirical literature includes Farronato et al. (2023) and Ploog & Rietveld (2024). The former case-study provides an estimation of network effects as the decrease in transactions of a dog-sitting platform after acquiring a rival platform. The latter shows how targeting early adopters through social network features may fail a firm intention to build network effects.

Except for Karhu et al. (2024) who considered the presence of multiple sides, all these sources focus their attention on two-sided platforms and, except for the empirical case studies, all develop dynamic models using price variations to understand the change in utility perceived by adopters on the two sides of the platform. Armstrong (2006), Farrell & Klemperer (2011) and Jullien et al. (2021) assume all interactions to confer homogeneous benefits (Jullien et al., 2021). With the use of price elasticity, Rochet & Tirole (2003) addressed the problem of heterogeneous interaction value which was further elaborated by Karhu et al. (2024) by introducing the concept of "value unit heterogeneity".

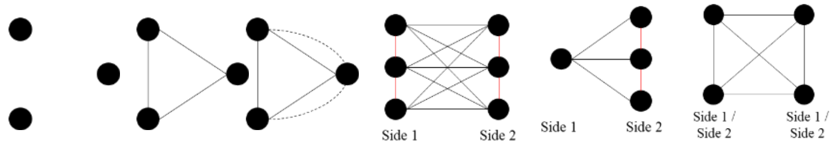
In the standardization literature, all attempts at modelling network effects investigate the categories of standards for interoperability, particularly in the IT sector and telecommunications. Church & Gandal (1992) first modelled the consequences of software provision on the market structure of hardware technologies. They construct network effects as the preference of consumers to buy hardware based on the number of compatible software and their price. They also assume the effects to decrease for increased competition between hardware providers. Abrahamson & Rosenkopf (1997) detach from the economics constructs of network size and prices and made a first attempt at integrating social network theory in standards diffusion. They modelled network effects as dependent on structural characteristics of a network (e.g., core-periphery and island networks) and the number of links between network nodes.

Swann (2002) was the first one to discuss the misguidance of popular network laws, such as the ones of Sarnoff, Metcalfe, and Reed (which we discuss in the next section). He modeled network size to have diminishing returns on the utility of standards' adopters due the emergence of congestion costs and network saturation. Later, Weitzel et al. (2006) detached from the common representation of standards' diffusion as tendent to a monopoly, while showing it as tendent to multiple co-occurring standards. They show that the main factors affecting this scenario are the density of the network and its topology (namely, the possibility of adopters to have different interactions within subsections of a network). Lastly, Heinrich (2014) studied how network effects make standards interconnected to multiple industries and push them towards asymmetric industry structures.

3.3 Formulas for potential network/node value

Besides the models presented earlier, most of which aim at defining an equilibrium function, six mathematical laws provide a static representation of the value of a network in presence of network effects. These laws explain the *potential network value* of the standard/platform, namely the maximum number of interactions that can occur within and between all network sides, given the number of nodes and the way in which they interact. We also derive the formula for node value (often called *ego*-network value) as the number of ties each node can have both within their side and with the other sides. In Table 3-1 we show the six formulas of potential value for both network and node, and classify them as to growth rate and types of interaction they describe.

This exercise helps us classify different network structures based on how nodes from one side interact. We collect formulas for the absence of interaction, or the presence of positive or negative ones. For the positive, we collect formulas for pairwise and group interactions. Chronologically, we distinguish six formulas (Table 3-1a-f). The first three (Table 3-1a-c) are usually associated with one-sided networks. The remaining three (Table 3-1d-f), describe three types of two-sided networks. For each formula, we provide a brief explanation and examples.

	One-sided networks			Two-sided networks		
	a)	b)	c)	d)	e)	f)
Name	Sarnoff's law	Metcalfe's law	Reed's law	Intermediary	Monopoly / Monopsony	Community
Main source	Bilby (1986)	Rohlfs (1974)	Reed (2003)	Economides (1996) Afuah (2012)	Economides (1996) Afuah (2012)	Afuah (2012)
Diagram						
Type of interaction (same-side)	No ties	Positive tie	Positive group tie	Negative tie	No/negative tie	Positive tie
Network value V_{NE}	N	$(N^2-N)/2$	$2^N- N-1$	N_1N_2	$N-1$	$(N^2-N)/2$
Network growth	Linear	Quadratic	Exponential	Linear	Linear	Quadratic
Node value V_{NO}	1	$N-1$	$(2^N/2)-1$	N_2/N_1 (Side 1) N_1/N_2 (Side 2)	N_2 (Side 1) $1/N_2$ (Side 2)	$N-1$
Node growth	No growth	Linear	Exponential	Depends on which side grows faster	Linear (Side 1) Negative (Side 2)	Linear

● Node —— Positive tie ---- Positive group tie —— Negative tie

Table 3-1 – Classification of network effects

David Sarnoff, a pioneer of broadcast television, posited that the value of a broadcasting network increases linearly with the number of users of that network (Table 3-1a) (Bilby, 1986; Gilder, 1993). This means that each user buying a radio or television would provide the same marginal value to the broadcasting network. Sarnoff's law was developed at a time when communication technologies were centralized, implying a user-to-device interaction. Thus, there was no interaction between the nodes (spectators). Consequently, each node would not be connected to anything else in the network except for the device used (e.g., radio or television), meaning that each participating node would only add one tie to the network ($V_{NO}=1$).

In the 1980s, communication technologies with user-to-user interaction became more popular. With the introduction of the first mobile communication standards and the Ethernet protocol, a second type of network effect – already existent in the telegraph and the telex – raised attention. In this case, each node joining a communication network could now interact with every other node, meaning that the additional network value provided to the network (and to each user) continued to increase with the number of users. This implies a quadratic, rather than linear, growth of the value of the network (Table 3-1b). Building on the work of Rohlfs (1974) on the interdependence of consumer demand functions in telecommunication, Robert Metcalfe, the inventor of the Ethernet, formulated his law in 1980 as $V_{NE}=(N^2-N)/2$ [3]. From such principle, the marginal value derived by each node corresponds to $V_{NO}=N-1$, where every node joining the network is tied to all other nodes through a pairwise interaction (other than itself, hence the –1).

Many scholars saw Metcalfe's law as a breakthrough in understanding the dynamics of a globalized network economy and the first real economic explanation of the Internet (Shapiro & Varian, 1999). The law was later backed up by empirical data (Metcalfe, 2013; Zhang et al., 2015). However, the same combinatorial formula had been used by network theorists long before Metcalfe applied it to communication networks. By counting how many ties exist in a fully connected network, Metcalfe's law corresponds to the denominator in the formula for network density (Borgatti et al., 2018; Knoke & Kuklinski, 1988). This analogy is important as we later build our framework starting from these two formulas.

Building on Metcalfe's law, David Reed (2003) (Table 3-1c) noticed that some ties were more valuable than others when users shared network features. Reed used data on eBay auctions to show that groups of users that engaged with community tools (e.g., group chats or review services) would derive more value than those who did not, increasing the overall value of the network. These tools facilitate group ties between two or more users (in contrast to Metcalfe's pairwise ties). The formula that

[3] The original formulation of Metcalfe is $V_{NE}=N^2-N$, and accounts for all pair-wise interaction between ethernet users (a *directed* network). The formula reported here applies to *undirected* networks, where each tie/interaction is counted once. This conversion is done to uniform with the formulations of Sarnoff and Reed.

counts all combinations of group and pairwise ties is $V_{NE}=2^N-N-1$. Network value would then grow exponentially, and not quadratically, and increase at compound rates, not at constant ones.

We derived the marginal value of a single node as $V_{NO}=(2^N/2)-1$, which counts the number of possible interactions for each node. Users performing groupwise interactions likely share common interests, geographical positions, backgrounds, and other features that could make their interaction more valuable. Besides eBay-like platforms, group ties can be performed by adopters of e.g., any platform a recommendation system, or through multicast standard protocols (e.g., the Wi-Fi multicast from IEEE 802.11 or the multicast DNS from IETF RFC 6762).

The increase of studies on two-sided platforms raised the attention on network structures with two different groups of users (Afuah, 2012). Intermediary networks (Table 3-1d) reflect every standard or platform that functions as a connector between suppliers and customers of a specific product or service. An example for standards is any interface that allows interoperability between two types of products. Applications for on-demand services or delivery of products represent, instead, examples of intermediary platforms. The potential network value results from $V_{NE}=(N_1)(N_2)$, where subscripts 1 and 2 represent the sides of customers and suppliers/vendors. Accordingly, the two-sided network value increases linearly with every node joining either of the two sides.

Despite not formally including it in the formulas, Afuah (2012) conceptualizes the "opportunistic behavior" of some nodes as acting in their own interest, using the examples of networks with transactions. Especially in these networks, same-side nodes normally exhibit competitive (or negative) ties. This can be due to the rivalry they have in the product market, or because each new competing node lowers the bargaining power of all same-side nodes when transacting with the other side. Network literature normally hypothesizes a scenario of perfect competition to capture this rivalry (Economides, 1996; Gulati et al., 2000). Competing nodes are thus allocated equal shares of ties with the other side of the network, leading to their individual value $V_{NO}=N_2/N_1$.

Some networks may then include, by their own nature, one node on either of the two sides (Table 3-1e), leading to a monopoly or monopsony structure. This depends on whether the single node is on the supply or the demand side. Some proprietary standards represent a monopolistic structure when they are designed for one specific product to be compatible with more complementary products (Chien & Chu, 2008).

An example could be Google APIs for third parties to embed Google Maps in websites or mobile applications. Similarly, a monopsony occurs when more users compete to produce complementary goods for one "buying" platform (e.g., in a public tender). For this type of two-sided networks, the overall network value is linearly related to the total number of nodes ($V_{NE}=N-1$). The node value differs between the monopolist that benefits from interacting with all the cross-side nodes ($V_{NO}=N_2$) and the nodes on the competitive side ($V_{NO}=1/N_2$).

Finally, networks can be represented as communities (Table 3-1f). A community is a set of nodes that can cover two roles at any point in time (e.g., buyer and seller, content creator and content viewer, teacher and student, sender and receiver, etc.) and differ from intermediary platforms where each node only play one specific role. Afuah (2012) cites eBay's marketplace as an example where users can buy and sell items. Consequently, when users join the community, they can perform two types of transactions with every other user and provide a value to the network that equals to $N-1$. Multiplying such marginal value for every node in the community results in a total network value of $V_{NE}=(N^2-N)/2$. Though this type of two-sided network is equivalent to Metcalfe's network (Table 3-1b), Afuah described the aspect of covering two "network roles" for the first time.

3.4 The framework

We aim to provide a replicable way to measure the value of networks of individuals and/or organizations that adopted a standard or a platform. This allows to understand the growth opportunities of different networks because of network effects, and thus understand how firms leveraging standards or platforms reach market dominance and how regulators can intervene. In Section 4.1, we introduce the four key elements of our framework: nodes, ties, sides and subgroups. For each element, we provide definitions, related assumptions, and examples. In Section 4.2, we rearrange the six formulas found in literature into five types of same-side ties. Based on these five types of ties, and thus on the structures present in each side of the network, we explain how to estimate the potential value of the whole network (4.3) and for a single node (4.4). In Section 4.5 we test the growth rates of each structure. In Section 4.6, we include the formulas for converting potential to actual and appropriated value, and provide guidelines to reach these estimates.

3.4.1 Definitions and assumptions

3.4.1.1 Nodes

A network graph shows the ties between a set of nodes (also called *vertices*, *points*, or *agents*). Nodes represent any network agent or stakeholder, such as individuals, communities, firms, or other organizations (Jackson, 2010). Some technical approaches also consider nodes that represent products or artifacts, for example, an electronic device or a building, or even product categories (Leskovec and Krevl, 2014). Nonetheless, such a variety of nodes may pose risks to the accuracy of value measurement. While much literature exists on multimode (or multilayer) networks (Al-Taie & Kadry, 2017; Boccaletti et al., 2014; Kivelä et al., 2014), studying nodes at different levels of granularity may hinder the precision of the measured value. For this reason, we focus on one-mode (homogenous) networks that include, for example, either only individuals, organizations, or artifacts. This guarantees a uniform unit of analysis across all nodes and sides.

3.4.1.2 Ties

A tie (also called *interaction*, *link*, or *edge*) can occur through communications (Borgatti et al., 2009), transactions (Shipilov & Gawer, 2020), or any other similar connection between individuals, products or organizations. For this framework, we include all ties that affect the value of a network: indeed, for some networks, the most valuable ties do not necessarily have a monetary equivalent but rather allow their users – for example – to communicate, share news and media, exchange data, use compatible devices, define quality levels, sell licenses, or even play games together. Besides these examples of positive ties, our framework includes negative ties, arising, for example, from market rivalry between two firms or the access of spamming users who deteriorate the quality of a standard or a platform[4].

Ties are redundant (or reciprocal) when networks are undirected, i.e., node *a* interacting with node *b* implies that node *b* interacts with node *a*, resulting in two ties (as in messaging and social media platforms). Non-redundant ties characterize directed networks, for example, in crowdfunding platforms (if *a* funds *b*, *b* does not necessarily fund *a*). To avoid confusion and to stay aligned with most of the existing

[4] See Hughes-Morgan & Yao (2016), Odlyzko & Tilly (2005), and Vanhaverbeke & Noorderhaven (2001) for case examples.

network laws described earlier, we classify each tie as redundant and count it as one "value unit", regardless of it being bidirectional or unidirectional.

Lastly, in many networks characterizing standards or platforms, the same nodes can perform multiple interactions. For example, social media users can mutually like their posts, publicly leave comments, or chat privately, and each of these ties separately provides value to the central platform. Likewise, devices may exchange e.g., audio, video, and electrical inputs through the same interface standard. In network theory, this phenomenon of multiple interactions between nodes is called *tie multiplexity* (Coleman, 1988; Ertug et al., 2023; Kilduff & Brass, 2010). Multiplexity is usually associated with stronger and more durable relationships between nodes because they can rely on other ties in case one of them expires (Provan et al., 2007). Our framework initially assumes that each of these ties provides equal value to the network, but later we discuss ways to reflect multiplexity and the different value each tie can confer to the network. For example, an e-commerce platform obtains more value from a purchase than from a product review. In Section 4.6 we elaborate on this aspect and describe how the network's value appropriation can be estimated.

3.4.1.3 Sides and subgroups

The adopters of a standard or a platform can be normally divided into two or more sides. Literature on two-sided markets (Parker & Van Alstyne, 2005; Rochet & Tirole, 2003) distinguishes two sides of adopters when they provide benefits to each other while performing different functions. From this notion, we define a side as a set of nodes of which at least one node is required to satisfy the network's function. Consequently, to determine all sides of a network, we need to list all the interactions that can occur through a standard or a platform and all the actors involved in these interactions. We provide an example of this process below.

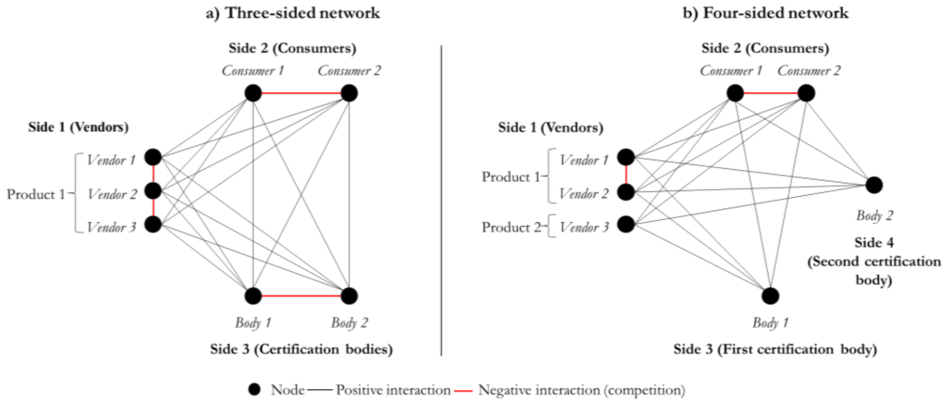


Figure 3-1 – Inclusion criterion for sides and subgroups of a network. An example of a (standard-based) quality certificate

We use the example of a certificate for meeting minimum quality standards to further elaborate on this criterion. Figure 3-1 shows a hypothetical network behind a quality certificate, where dedicated certification bodies ensure the quality levels of specific products. Here, at least three actors, a vendor, a consumer, and a certification body, play a role. This entails three types of positive ties. The first is between bodies and vendors. The latter benefit from the signaling effect of the certificate, and the former from the money they receive from the vendors. The second is between bodies and consumers, because consumers are more aware of the characteristics of the products they buy, and the third is between vendors and consumers, due to the monetary transactions between them.

In Figure 3-1a, we suppose the certificate is issued after the assessment of either Body 1 or 2. These certification bodies are rivals and thus connect through a "negative" interaction because of their substitution effects, since the organization looking for certification should only choose one. The *Fairtrade* certification resembles this type of network structure, where suppliers must be certified by either of the independent auditors, *FLOCERT* being the largest one[5]. In Figure 3-1b, the vendor must instead obtain the validation of its product from multiple bodies, meaning that each body constitutes a side. This partially mirrors the structure of the

[5] https://www.flocert.net/how-to-join-fairtrade/ (Accessed January 2025).

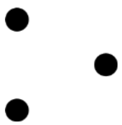
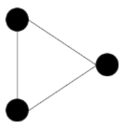
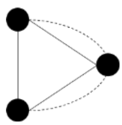
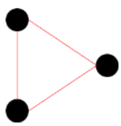
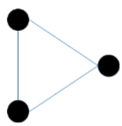
Roundtable on Sustainable Palm Oil (RSPO) certification, where compliance with different sets of standards has to be inspected by multiple certification bodies[6].

Figure 3-1 also shows the subgroups of nodes within the same side. Subgroups may emerge when nodes from the same side, although covering the same role in interacting with the other sides (i.e., vendors), have different same-side relationships. This translates to vendors that benefit from the same certification scheme and who only compete with some of the other certified vendors. In Figure 3-1a, all the vendors manufacture the same product, hence they all compete (i.e. connect through a negative interaction). In Figure 3-1b, we assume they sell different products (e.g., clothes and food, both certified by *Fairtrade*), which are targeted to different consumer groups but are certified by the same bodies. As a result, Side 1 of Figure 3-1b presents two subgroups, one involving two competing vendors and the other a singular vendor.

3.4.2 Five types of same-side ties

All cross-side ties in a network are positive and linear. This is due to the mediating nature of standards and platforms: adopters join a network because they can interact with at least another side of adopters (the cross-side), and the larger this is, the more freedom of choice they have. There would be no reason to join a network when there is no interaction with the adopters on the other sides. Thus, what matters for the network structure (besides the overall number of sides) is what happens within each side. For this reason, for each of the six laws of network effects mentioned in Section 3, we derive five types of ties that describe how nodes can interact within a network side (Table 3-2).

[6] https://rspo.org/as-an-organisation/certification/certification-bodies/ (Accessed January 2025).

Name	a) No tie (Isolation)	b) Positive tie (Cooperation)	c) Positive group tie (Group cooperation)	d) Negative tie (Competition)	e) Positive and negative tie (Co-opetition)
Diagram					
Same-side network effect	None	+	+	−	+ if $\alpha < 0.5$ − if $\alpha > 0.5$

● Node — Positive tie ---- Positive group tie — Negative tie — Positive and negative tie

Table 3-2 – The five types of same-side network ties

Non-interacting nodes (Table 3-2a), following Sarnoff's law (Table 3-1a), form a network structure where nodes reap no value from their own side. Besides the examples of radio and television, many interface standards (e.g., HDMI) and minimum-quality certifications (e.g., the European CE marking) exert no connection between same-side users. In these cases, users benefit from having a wide range of compatible/certified products (cross-side) and not by having other individuals using the same standard (same-side). *Positive ties* between same-side nodes (Table 3-2b) derive from Metcalfe's law (Table 3-1b) and the structure of communities (Table 3-1f). These ties are usually associated with communicating or exchanging information between nodes. Classic examples include the PDF (ISO 32000) and the Bluetooth standard, or most kinds of social media or messaging platforms. *Group-interacting nodes* (Table 3-2c) are explained in Reed's law (Table 3-1c) and apply in all scenarios where a node can simultaneously interact with more nodes in the same network. As said, multicast standard protocols or community tools such as group chats are good examples.

To formulate *negative ties* (Table 3-2d), we build on the intermediary structure (Table 3-1d) from Afuah, (2012)[7] and the notion of perfect competition between nodes. Competition between nodes occurs when the products or services of the nodes are rivals, meaning one cross-side node can decrease (or even exclude) the possibility of the other cross-side nodes using the same product/service. This is usually seen in

[7] In reality, Afuah does not refer to these as "intermediary platforms" but uses the example of eCommerce networks. We opted for a more all-encompassing term given that some standards and platforms can assume such a structure without necessarily being an electronic marketplace.

two-sided platforms where transactions represent the main interaction between the two sides. For standards, quality management certificates such as ISO 9001 can exert this structure since they likely include groups of firms from the same sector.

Ultimately, we formulate the existence of both *positive and negative ties* (Table 3-2e) between nodes. We refer to the situations of co-opetition, widely discussed both for standards (Heikkilä et al., 2023; Riillo et al., 2022) and platforms (Ritala & Hurmelinna-Laukkanen, 2009; Van Dyck et al., 2024). Most standards and platforms include at least one side where nodes are rival, either because of market competition or because the "consumption" of the standard/platform is limited. However, in some cases, this negative effect is compensated either by other positive interactions between the same nodes or an overall increase in network value due to its growth in size.

For example, if we consider ride-hailing platforms (e.g., Uber or Lyft) as two-sided networks, where the competition takes place on both sides (i.e., the passengers' and the drivers' side), there would be little motivation for both types of actors to join such a network. However, while the negative interaction occurs in a limited geographical area and for a limited time frame, both sides derive significant value from many positive same-side ties (e.g., more informed passengers due to more precise ratings). In standardization, many firms similarly cooperate with competing firms to develop standards. To operationalize co-opetition, we construct a competitiveness index α that is designated a value between 0 and 1. If the side is mostly competitive (i.e., $\alpha > 0.5$), the (negative) competing effect prevails over the (positive) cooperative effect, and vice versa, low competition ($\alpha < 0.5$) makes the positive interactions more impactful than the negative ones.

3.4.3 Potential network value (V_{NE})

We now calculate the potential value of a network based on the number of nodes and the types of same-side ties. The total network value includes all same-side network effects (for each side) and the cross-side network effects (common to all sides). Same-side network effects occur when the increase in nodes impacts the value for nodes on the same side. Contrarily, cross-side network effects occur when one side of nodes benefits from the increase in size of other sides (Clements, 2004; Parker & Van Alstyne, 2005). To operationalize the former, we sum all the ties that potentially occur in every side of the network. This estimates the total value that is generated within all sides:

$$Same - side\ network\ effects = \sum_{i=1}^{S} V_i$$

Equation 3-1 – Same-side network effects

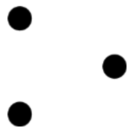
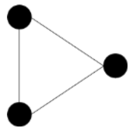
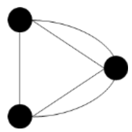
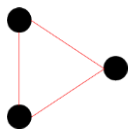
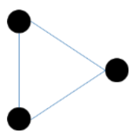
In Equation 3-1, *S* is the total number of sides, and V_i is the side value. V_i depends on its structure, namely the types of ties occurring between its nodes. Table 3-3 presents a formula for side value for each type of same-side tie. When nodes within a single side are not connected, the side does not generate same-side network effects (Table 3-3a). Conversely, suppose nodes within a side are positively connected, either pairwise or as a group. This engenders a same-side effect, corresponding to Metcalfe's and Reed's law (Table 3-3b-c). Notably, negative ties between nodes do not influence the generation of same-side effects at the network level (Table 3-3d), but they do for individual node value (see Section 4.4). Similarly, in a network side characterized by co-opetition, negative ties between nodes are disregarded in calculations. Hence, the valuation of a "co-opeting" side solely considers the positive proportion of ties, which are then multiplied by 1-α, where α denotes the index of competitiveness (Table 3-3e).

The value of from Equation 3-1 should now be added to the cross-side network effects common to all sides. The cross-side network effects result from the maximum number of pairwise combinations occurring between all sides of the network, without including the ties occurring within the sides (that are counted, instead, in Equation 3-1)[8]. Counting all pairwise combinations requires multiplying the number of nodes from each side. We use the pi notation to perform this function in Equation 3-2.

$$Cross - side\ network\ effect = \prod_{i=1}^{S} N_i$$

Equation 3-2 – Cross-side network effects

[8] We assume that each interaction between sides involves every side of the network. In this way, the increase in the size of one side provides additional value to every other side of the network. For example, an increase in the number of users of a social media platform benefits all the other sides (the content creators and the advertisers). If two sides interact separately from the other sides in a network, it would then be more convenient to treat them as a separate network.

Name	Diagram	Side value (*Vi*)
a) No tie		$V_i = 0$
b) Positive tie (Cooperation)		$V_i = (N^2\text{-}N)/2$
c) Positive group tie (Group cooperation)		$V_i = 2^N\text{- }N\text{-}1$
d) Negative tie (Competition)		$V_i = 0$
e) Positive and negative tie (Co-opetition)		$V_i = (1\text{-}\alpha)(N^2\text{-}N)/2$

● Node —— Positive tie —— Negative tie —— Positive and negative tie

Table 3-3 – The side values V_i for each type of tie

The sum of the results of Equation 3-1 and Equation 3-2 is the potential network value, considering the number of nodes, the number of sides, and the type of interaction within each side. Its formula is expressed in Equation 3-3.

$$Potential\ V_{NE} = Same - side\ network\ effects + Cross - side\ network\ effect = \sum_{i=1}^{S} V_i + \prod_{i=1}^{S} N_i$$

Equation 3-3 – Potential network value

3.4.4 Potential node value (V_{NO})

Networks can also be described through the value derived at the "individual" level by focal nodes. We call this dimension node value (V_{NO}), also referred to by network scholars as the *ego-network* (Bott, 1958; Freeman, 1982). The *potential node value* measures all the possible ties a node can have, with nodes on both the same side and other sides of the network. Unlike the potential network value, the node value cannot be automatically obtained through a sum but may require a non-commutative operation (division). The reason for this is that same- and cross-side effects are addends (i.e., they can be summed) only when the focal same side is characterized by positive ties, and thus there is no effect shared among the nodes (either competition or co-opetition). When the effects must be shared, the focal node is in competition (or co-opetition) with other same-side nodes in appropriating the effects coming from the other sides.

We first define the focal cross-side network effects similarly to the overall cross-side effects explained in Equation 3-2. We distinguish the network sides between the side of our focal node (which we call *FS*, standing for focal side) and all remaining sides (named *CS*, standing for cross side). The focal cross-side effects (thus excluding our node's focal side *FS*) can be expressed as:

$$Focal\ cross - side\ network\ effects = \prod_{i=1}^{CS} N_i$$

Equation 3-4 – Focal cross-side network effects

To construct the formulas for the focal same-side network effects, we need to distinguish between structures with and without a negative component. The former case requires a sum with the focal cross-side effects, the latter requires a division. For this reason, in Table 3-4 we directly show the formula for the focal node value after conducting these simple operations. The potential value of a focal node whose side is characterized by either of the first three types of ties (Table 3-4a-c) contains no negative components, thus results from the addition of the same-side node value (zero for Table 3-4a, *N-1* for Table 3-4b, $(2^N/2)-1$ for Table 3-4c) to the cross-side effects. For nodes competing with their same-side nodes (Table 3-4d), we divide the cross-side effects by the number of same-side nodes N_{FS}, showing how each cross-side tie is distributed among the competing nodes. For nodes in co-opetition (Table

3-4e), the negative and positive components – found in Table 3-4b and Table 3-4d – are weighted respectively by the competitiveness index α and its complementary 1-α.

Focal node type of tie	Potential node value (V_{NO})	Same-side network effect
a) No tie	$\prod_{i=1}^{CS} N_i$	None
b) Positive tie (Cooperation)	$N_{FS} - 1 + \prod_{i=1}^{CS} N_i$	+
c) Positive group tie (Group cooperation)	$\frac{2^{N_{FS}}}{2} - 1 + \prod_{i=1}^{CS} N_i$	+
d) Negative tie (Competition)	$\frac{\prod_{i=1}^{CS} N_i}{N_{FS}}$	–
e) Positive and negative tie (Co-opetition)	$\alpha \frac{\prod_{i=1}^{CS} N_i}{N_{FS}} + (1-\alpha)(N_{FS} - 1 + \prod_{i=1}^{CS} N_i)$	+ if α < 0.5 − if α > 0.5

Table 3-4 – Formulas for potential node value

3.4.5 Growth functions

Our main conjecture is that even if two networks have the same size, their value may grow significantly different if they have a different structure. As a result, their nodes may also reap very different values. Using the equations presented earlier, we plot the potential value of a two-sided network (Figure 3-2 and Figure 3-3) and of one participating node (Figure 3-4) for each type of interaction, as a function of the number of same-side nodes on one side. We are interested in studying the trend of these functions, and not in their corresponding values. For simplicity, we assume that the number of nodes from our side increases from 1 to 50, and that network includes one other side of one hundred nodes (N_{CS}=100) with no ties between them. Assuming more nodes on either of the two sides (as in most cases of standards or platforms) would only alter the value on the y-axis disproportionally due to the exponential rate at which Reed's law (i.e., positive group ties) grows.

Figure 3-2 shows how many interactions a two-sided network with 100 nodes on one side potentially generates. On the other side, we show how a gradual increase from 1 to 50 nodes impacts the value functions of the whole network. A side with no ties between same-side nodes has the same value as a network with rival nodes (see Table 3-3). Because the number of cross-side nodes N_{CS} is constant, the two types of ties share the same network value function. The graph shows how the possibility of all nodes to perform group interactions (for example through community tools) boosts their value function compared to the remaining types of ties.

In Figure 3-3, we zoom in the functions with quadratic or linear growth, and notice how cooperating nodes enhance the network value faster than isolated ones. It also highlights how the competitiveness index α moderates the potential value of networks with overlapping positive and negative ties. Altogether, these two figures show how significant differences between the five types of ties emerge even in relatively small networks. The functions shown are subject to diverge even more with larger amounts of participating nodes.

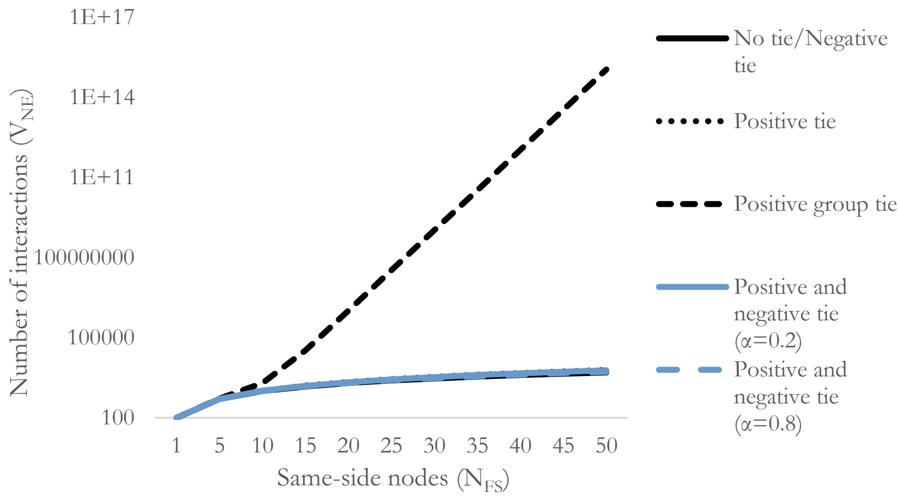


Figure 3-2 – Plotted functions with logarithmic y-axis of potential network value for the five types of ties, cross-side nodes N_{CS}=100

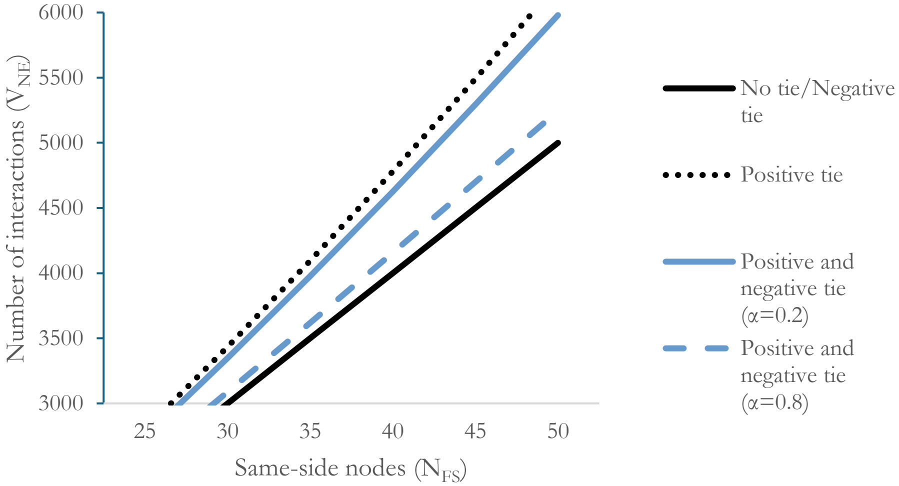


Figure 3-3 – Zoomed functions of potential network value for the five types of ties (excluding positive group ties), cross-side nodes N_{CS} =100

In Figure 3-4, we plot the potential value functions of a focal node. Contrarily to the network functions, here the nodes are affected by whether the interaction is absent (black straight line) or whether they compete (red straight line). The presence of competition splits the cross-side effect between the rival nodes, which tend to minimize their value as more competing nodes enter the network. However, if these rival nodes can also have positive interactions – through for example a rating system, or group chats, the co-opetition stabilizes the value function. The extent of the stabilization depends on the competitiveness index, which we display as more competitive (α=0.8, blue dotted line) and less competitive (α=0.2, blue straight line). With no ties between same-side nodes, the potential node value always corresponds to the number of cross-side nodes (100 in this case).

We observe these as illustrative values and recognize the likelihood of group interactions to bring less value to the network (group interactions rarely imply e.g., a monetary transaction), However, this analysis highlights how enabling a "community" effect, explained in Reed's law, can generate significantly more value if well leveraged. Additionally, it shows how users and adopters are not incentivized to make use of a standard or platform when they cannot interact through same-side interactions or when excessive competition is not compensated by other network benefits.

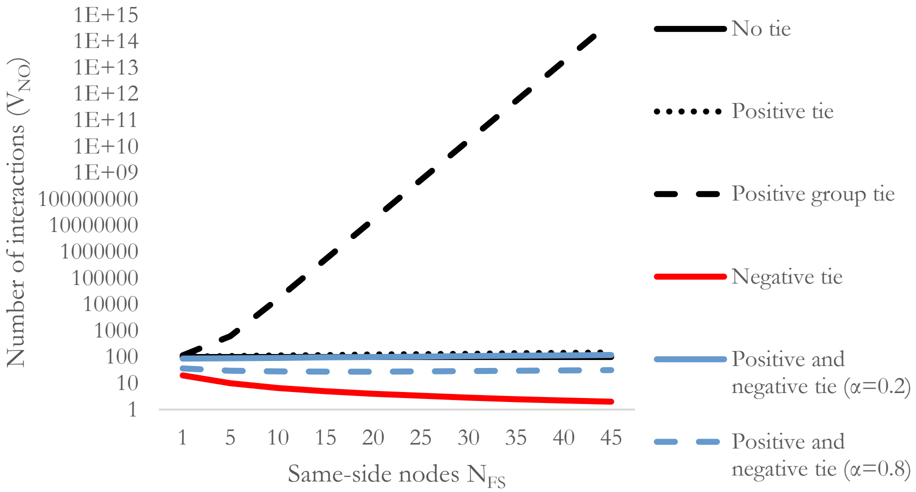


Figure 3-4 – Plotted functions of potential node value for the five types of ties, cross-side nodes N_{CS} =100

3.4.6 Actual and appropriated value

We now propose an approach to estimate the actual and appropriated value both at network and node level. This step is key in understanding why some functions of potential network value supposedly grow unlimitedly and why this rarely occurs in real instances. The actual and appropriated value assess how networks generate value and how they are seized compared to their potential.

3.4.6.1 Actual network value

We start from the standard formula of density commonly used in social network analysis (Borgatti et al., 2018; Knoke & Kuklinski, 1988; Scott, 1991). The formula is reported in Equation 3-5. Using the formula for potential network value from Equation 3-3, we rearranged it into Equation 3-6.

$$Network\ density\ \rho_{NE} = \frac{Actual\ number\ of\ ties}{Potential\ number\ of\ ties} = \frac{Actual\ V_{NE}}{Potential\ V_{NE}}$$

Equation 3-5 – Network density

$$Actual\ V_{NE} = \sum_{i=1}^{S}(V_i \cdot \rho_i) + \prod_{i=1}^{S} N_i \cdot \rho_i$$

Equation 3-6 – Actual network value

To estimate the actual value of a network, it is thus needed to estimate its density. Density is the ratio between all potential and all real ties of a network. It indicates, in percentage terms, the number of ties nodes have with each other (actual V_{NE}), expressed as a proportion of all the ties that could potentially occur (potential V_{NE}). A classic example of a large but non-dense network is the case of phone holders. Although we can potentially reach out to everyone that owns a phone, we realistically call a very small subset of phone owners. The formula from social network analysis (Equation 3-5) calculates the density of a network without "sides". In Equation 3-6, we calculate density for each side *i*.

Density reflects the extent to which nodes "use" their surrounding network, as well as the probability that a tie exists between two random nodes. A density of 100% means that all nodes actively interact with each other. In contrast, a density of 0% describes a network where all nodes are isolated despite the possibility of interacting with others. In Section 4.6.4, we provide a detailed explanation on how to estimate a network density to calculate its actual value.

3.4.6.2 Appropriated network value

Our third value measurement is the appropriated network value. The concepts of appropriability and value appropriation are discussed in both the standards and platforms literature (Jacobides et al., 2006a; Ranganathan et al., 2018; Schilling, 2009; Uzunca et al., 2022). Appropriated value can be defined as the benefits network owners reap from the ties between nodes, for example, via subscriptions, licensing fees, or advertising opportunities (Jacobides et al., 2006; MacDonald & Ryall, 2004; Nambisan & Sawhney, 2011). These benefits may also not be financial, since any agent (organization or individual) may derive social, cultural, or environmental value when adopting a standard or a platform (Kilduff & Brass, 2010).

To estimate the appropriated network value, we construct the average tie value. We multiply the total number of interactions between adopters by the average value they create for the standard or platform. In Equation 3-7, we express the average tie value with σ.

$$Appropriated\ V_{NE} = Actual\ V_{NE} \cdot Average\ tie\ value = \sum_{i=1}^{S}(V_i \cdot \rho_i \cdot \sigma_i) + \prod_{i=1}^{S} N_i \cdot \rho_i \cdot \sigma_i$$

Equation 3-7 – Appropriated network value

The complexities linked to defining all the benefits generated by a network make it non-trivial to calculate the average tie value. As done with a network density, we provide guidelines to estimate the average tie value in Section 4.6.4.

3.4.6.3 Actual and appropriated node value

We also provide a corresponding measurement for the V_{NO}. The actual node value counts the number of existing ties a focal node has with the other (same-side and cross-side) nodes. Actual node value (Equation 3-8) can thus be estimated using the potential node value and the so-called node (or ego-network) density ρ_{NO} (Soh, 2009; Wasserman & Faust, 1994). Node density, correspondingly, results from dividing the number of interactions performed by the focal node (i.e., its *degree*) by the number of all other reachable nodes in the network (i.e., *N-1*), and represents the extent to which a node utilizes its ego-network.

$$Actual\ V_{NO} = Potential\ V_{NO} \cdot \rho_{NO}$$

Equation 3-8 – Actual node value

Analogously to the appropriated V_{NE}, the appropriated V_{NO} (Equation 3-9) results from the actual V_{NO} multiplied by the average tie value.

$$Appropriated\ V_{NO} = Potential\ V_{NO} \cdot \rho_{NO} \cdot \sigma$$

Equation 3-9 – Appropriated node value

3.4.6.4 Estimating density and average tie value

The formulas for both actual and appropriated value present methodological issues. This section provides guidelines on how to address these issues to obtain more accurate value measurements. According to Equation 3-6, the actual network value results from multiplying the same-side and cross-side effects by the network density ϱ, which represents the percentage of real ties out of all potential ties. Nevertheless, obtaining data, often private or proprietary, about the real ties between thousands of users or firms may be burdensome in the case of large networks, especially for dominant standards and platforms.

As a result, scholars may find it more convenient to estimate such percentages using a sampling approach. This can be done by surveying a small sample of entities or individuals from all sides of a network and asking them how many interactions they perform during a specific time frame. Similar approaches to obtaining so-called relational data have been used in the past, including, for example, Provan and Milward (1995) and Battistella et al. (2013).

To make the estimate even more precise, scholars and researchers could measure the appropriated network value, reflecting the real gains the owner(s) of a network realized through network effects. In Section 2.2, we explained how the number of interactions between nodes and their average values can vary across sides and even across nodes. To address these issues, researchers could estimate an average tie value for each side and each overlapping tie in the network. This is a simple task for monetary transactions because their value is already defined by their economic counterparts (prices, license fees, interest rates, etc.) and can be calculated using public databases or other secondary sources.

However, for some non-financial interactions, creating value may be more abstract, for example, in exchanging text messages, assuring quality levels, or establishing joint ventures. Even if our framework is based on an average σ for the whole network, estimating σ for each side provides a better proxy of appropriated value. In this regard, we suggest scholars and researchers to operationalize the tie value by listing all positive and negative ties occurring in a network, as we did in Section 4.1.3, and associating them to the corresponding value they are supposed to generate for the network. This process can be conducted either with the same relational data surveys used to estimate density, or with interviews with relevant experts, both internal and external to the standard/platform. Multi-criteria decision-making (MCDM) tools, such as the analytic hierarchy process (Saaty, 1986) or the best-worst method (Rezaei, 2015), cater well to the use of experts' interviews.

The same mechanism for weighting the density ϱ and the tie values σ applies to the value measurement of focal nodes. Table 3-5 summarizes this procedure.

Step	Reference in formulas	Used for	Estimation methods
Estimate network and node density	ϱ_i, ϱ_{NO}	Actual V_{NE}, actual V_{NO}	Survey on relational data, sampling
Estimate the average tie value	$\sigma, \sigma_i, \sigma_S$	Appropriated V_{NE}, appropriated V_{NO}	Survey on relational data, experts' interviews, MCDM tools

Table 3-5 – Steps to calculate the actual and appropriated value

Network density and average tie value are thus pivotal determinants in shaping the appropriation of a network's benefits for both network users and owners. A robust density and high average tie value can ostensibly mark the network as highly beneficial. Consider the network within a local food delivery platform involving a relatively small number of restaurants as nodes of their network. The high density of interconnected restaurants and the value created by sharing firm standards, such as supply chain processes and business practices, contribute significantly to the value appropriation of the platform. The value obtained by the nodes (restaurants) can also be controlled by the platform owner (that acts as a network orchestrator), for example, by optimizing the position and the offering of the restaurants and reducing the extent of negative ties between them.

Conversely, having low values for either of these indicators may render the network unsustainable or disadvantageous, potentially influencing the nodes' network access or retention. In the previous section, we showed how group ties immediately boost the potential value of a network, but are unlikely to produce highly valuable ties. For example, despite reaching millions of users, one single user's review on e.g., an online marketplace may not generate substantial marginal value. In the context of co-opetition, the dynamic interplay between competition and cooperation among firms adds a nuanced dimension to the average tie value. Positive, cooperative ties often outweigh and contribute more to the overall network value. In contrast, negative, competitive ties, though important, typically bring less value. This dynamic emphasizes the strategic importance of managing these ties to balance cooperation and competition and maximize appropriated value.

3.5 Importance of network structure to platforms and standards adoption

Our framework paves the way to multiple reflections on network structure and technology adoption. The effects that arise when adopters enter a network through a standard or a platform have shown to heavily depend on the network structure. We initially hinted at the general interpretation that a network value only depends on its size. Scholars have gradually detached from this view, also thanks to studies such as Rowley (1997) and Afuah (2012). Despite this progress, many sources described in Section 2 show some oversights across the technology and innovation literature related to the use of network structure. These oversights prevent a holistic view of a standard's or a platform's ability to generate value through networks.

Since the early literature on innovation diffusion, the adoption of technologies was seen either as a sigmoid (Griliches, 1957; Rogers, 1962) or as a concave (Bass, 1969) function, as the rate of new adopters peaked before collapsing when the product would reach maturity. Earlier studies on network effects (Gilder, 1993; Rohlfs, 1974) have instead conceptualized the potential value of a network as an ever-growing function. While this had implications for economic theory, it has the limit of describing a fictitious value that deviates from the actual value deriving from real networks. Odlyzko & Tilly (2005) made a first attempt to explain how the concept of decreasing returns applies to technologies subject to network effects, by describing a communication network that grows at logarithmic (and not quadratic) rates. We bring this idea forward, first by discussing factors that change the value functions of networks and nodes over time. Second, through the measurement of actual and appropriated values, which mitigate the overly optimistic predictions of potential values. It is thus important to consider, as part of the network structure, the ability of technology owners and adopters to leverage highly dense networks (i.e., with a high percentage of real interactions) and to convert interaction into real value.

The main factor we discuss throughout the framework is the type of same-side ties between adopters, that determines the creation of same-side network effects. While Rohlfs (1974), Gilder (1993), and Odlyzko & Tilly (2004) among others refer to positive interaction between network members, we describe ties that can cause competition, cooperation, group and sub-group formation, and multiplexity, both in terms of overlapping ties of the same type, or between positive and negative ties, implying co-opetition between adopters. We show that enabling competition between adopters may increase the network value linearly with its enlargement in size, but may minimize the adopters' welfare if not properly compensated with other "positive" interactions. We also show how group interactions create exponential value and may attract many adopters if properly converted in real value.

Other factors we discuss are the interaction with cross-side nodes and how multisidedness affects the value functions. Overlooking this creates the problem of overemphasizing two-sided networks in digital platforms, ignoring for example social media platforms, where users, content creators, and advertisers jointly create value, or collaboration platforms for e.g., infrastructure management, where multiple groups of stakeholders collaborate. If a platform manages to open its network to other sides, it may obtain a drastic increase on its potential to create value. This can be done in many ways, for example pursuing gamification strategies (chats, ranking systems, leaderboards), use of referral and reward programs, loyalty badges or partnership programs, or incentivizing crowdsourcing and user entrepreneurship. Conversely, the presence of multi-homing (i.e., the ability of an adopter to join several rival platforms) may generate larger benefits to the adopter but lower the appropriated value of each competing platform (see Bakos & Halaburda, 2020).

Studies on the diffusion of standards suffer from similar generalizability issues. First, the emphasis of these studies is often on one side only, since they typically focus on the final user of the standard and not (for example) on who supplies the standardized product/service or performs conformity assessments. Second, studies on network effects in standards only consider standards for compatibility and interoperability, and largely ignore other types of standards, such as those included in quality certificates or related to safety (see Boiral et al., 2018). Despite product compatibility has shown to increase switching costs and the likelihood of creating a user lock-in, these other types also suggest a potential network effect where their network structure plays a major role. Referring to the same quality standards or the same safety procedures, for example, is a way for organizations to create value and lower transaction costs proportionally to the number of other organizations referring to the same standards. Our example of a quality certificate in Section 4.1.3 shows this possibility. This opens many opportunities for standardization scholars to study network effects for these types of standards beyond compatibility and interoperability.

The expanding literature on innovation ecosystems defines them as large networks of technology adopters that jointly create value through "non-generic" complementarities (Baldwin et al., 2024; Jacobides et al., 2018) and where standards and platforms can facilitate coordination (Teece, 2018). These complementarities do not necessarily imply a direct correlation in terms of price elasticity and demand functions between adopters (i.e., the economic definition of complementarity), but rather the interdependence between the firms' value proposition (Bogers et al., 2019;

Shipilov & Gawer, 2020). This is another reason explaining why network effects should be studied beyond two-sided marketplaces or compatibility standards, and not measured only using price variations.

Lastly, we discuss the relationship between standards and platforms based on their ability to exert network effects on their adopters. This relationship gains little attention in literature, whereas the mainstream relationship describes standards as boundary resources within platform ecosystems, helping to reduce information asymmetries, transaction costs, and the variety of interfaces and protocols through which complementors can access the platform (Shapiro & Varian, 1999; Srinivasan & Venkatraman, 2020), increasing their openness and competitive advantage, especially in digital ecosystems (Miller & Toh, 2020; Narayanan & Chen, 2012). Although this relationship helps understanding the importance of the degree of standardization of platform ecosystems, it is of equal importance to understand how standards and platforms follow similar patterns of adoption and reach market dominance. Our review of the literature shows how standardization scholars have made important steps in integrating network theory when measuring network effects (Abrahamson & Rosenkopf, 1997; Swann, 2002). Unfortunately, there were few to no follow-up studies in recent years. Platforms scholars, instead, expanded the theory on network effects by discussing e.g., the importance of multiple sides and cross-side effects. This relationship between standards and platforms was only conceptually described in few previous studies (e.g., Shipilov & Gawer, 2020; Teece, 2018) and we set the basis for more empirical investigation.

3.6 Conclusions

3.6.1 Theoretical contributions

Our research offers several theoretical contributions to the intersecting fields of technology management and economics using network theory. The extant literature across these fields has often marked network effects as a key driving force behind the societal and economic impacts of standards and platforms (Abdelkafi et al., 2021; Gawer, 2021; Karanović et al., 2021). A burgeoning interest in quantitatively predicting such phenomena has emerged in recent years, particularly in relation to platforms (Farronato et al., 2023; Karhu et al., 2024). However, scholars have called for conceptual order in network theory and its applications (Cennamo, 2021; Mcintyre & Srinivasan, 2016).

Table 3-6 shows how our paper positions within the literature in terms of strengths and limitations. Recognizing the many previous attempts to operationalize the value of a network, we observe three primary approaches in the existing literature. The first comes from platform economics. While these models recognize that ties may have heterogeneous values (e.g., consumers' and buyers' price elasticity in Rochet and Tirole, 2003), they are mostly limited to two-sided networks whose sides have identical structures, rarely distinguishing whether the nodes within these networks compete or not, and using price as the only estimate of value creation. To quote Economides (1996), "*This positive feedback loop seems explosive, and indeed it would be, except for the inherent downward slope of the demand curve*". We go further than these econometric models by considering all possible networks with more than two sides and those with different types of ties than positive pairwise ones, as well as other units of value than transaction prices.

A recent notable exception in this field is the work of Karhu et al. (2024). Their model for platform externalities accounts for multiple sides and includes "value unit heterogeneity" as a constant, explaining the extent to which transactions are heterogeneously valuable. We add to this by suggesting ways to weight each side's number of ties by their average value (i.e., σ) and techniques to estimate such a value. They also pave the way to distinguish other types of same-side effects by introducing negative externalities due to rivalry, and other reinforcing effects such as communication (which they call "social network connectivity") and compatibility. Our framework takes these possibilities into account and includes the possibility of group formation within a network side and overlapping positive and negative effects (coopetition).

	Platform economics		Standardization		Network theory	Our framework
(examples of) Sources	Rochet & Tirole (2003), Armstrong (2006), Farrell & Klemperer (2011), Jullien et al. (2021)	Karhu et al. (2024)	Church & Gandal (1992)	Abrahamson & Rosenkopf (1997), Swann (2002), Weitzel et al. (2006)	Knoke & Kuklinski (1988), Scott (1991), Jackson (2010), Borgatti et al. (2018)	/
Referred laws	No law referred	Metcalfe	No law referred	Sarnoff, Metcalfe, Reed	Metcalfe	Sarnoff, Metcalfe, Reed, Economides, Afuah
Types of same-side ties	None	Competition (negative), communication and complementarity (positive)	Compatibility and competition	Communication	Communication (positive)	Positive (pairwise or in groups), negative, and both (co-opetition)
N. of sides	Two-sided (S=2)	Multi-sided (s_i)	One-sided	One-sided	One-sided	Multi-sided ($\sum_{i=1}^{S}$)
Time dimension	Both static and dynamic	Dynamic	Static	Dynamic	Static	Static
Tie value	Homogeneous and heterogeneous (but price dependent)	Heterogenous (*value unit heterogeneity*)	Heterogeneous (but price dependent)	Homogeneous	Homogeneous	Heterogeneous (σ)

Table 3-6 – Positioning our contribution to the existing literature

The second approach is derived from standardization scholars. The first attempt we could retrieve at modelling network effects is by Church & Gandal (1992). In their attempt to model how network effects in the hardware market could reach equilibrium or de-facto standardization, they accounted for both a positive (compatibility) and a negative (competition) effect between hardware producers. The model focuses on one side and, similarly to platform economists, uses price as measurement of consumer surplus. The models of Abrahamson & Rosenkopf (1997), Swann (2002) and Weitzel et al. (2006) all describe the effects incurring in one side of a network, specifically that of users of communication standards. Furthermore, while they account for interactions through communication, they all exclude the possibility of competition between users, narrowing down the generalizability of their results only to communication networks and other few cases of networks with only positive pairwise interactions.

Another aspect that differentiates our approach from the one of most of platform economists and standardization scholars is the attempt to model network effects dynamically, often using differential equations to study the changes in value over time. They often refer to the so-called bandwagon effect that attracts new adopters (Henshel & Johnston, 1987; Rohlfs, 2003; Weitzel et al., 2006). Such effect convinces adopters to join a network not for its current state, but for its opportunities to grow, igniting the feedback loop described in network effects. While we do not directly model the network and node functions using time, and thus provide a static estimation, we do discuss their variations in relation to an increase in size. Our key contribution, in this context, is to take the structural aspects discussed earlier into consideration when using these widely discussed dynamic models.

The last approach we discuss is the one of network theorists and their interpretation of potential network value in measuring the density of a network. Their approach provides a unifying formula instead of an all-encompassing framework and uses the same formula of Metcalfe's law to estimate the maximum number of pairwise interactions between nodes. Our investigation of five types of ties offers further insight into how value-creation mechanisms function. Additionally, our framework clarifies how nodes and entire networks relate when harnessing these interactions, and this contributes to the debate on the relationship between network and ego-network dynamics (Ahuja, 2000; Yan & Guan, 2018).

3.6.2 Implications for practitioners

The examples we use in this paper suggest an immediate connection with business practice. Below, we explore how understanding network effects is relevant for regulators/policy-makers[9], standard-setting organizations, and for private firms.

The first implication of our framework regards market monopolies and increasing returns of scale driven by network effects. The framework allows policymakers to map the current network and enforce possible changes in its configuration, for example, by opening the platform or standard for other firms, thus allowing competition on the supplier side while keeping the user advantages of network effects. One example of this is the European Digital Markets Act (DMA), where gatekeepers (i.e., digital platforms with a significant number of interacting users) are

---

[9] Including governmental and non-governmental bodies at national, regional and at global levels involved in the process of standard development, and to regulating bodies of platforms such as national and regional competition or privacy authorities.

required to be interoperable with competing platforms, allowing for more balanced competition (Björkegren & Farronato, 2021; European Commission, 2020; Larouche & De Streel, 2021).

Similar efforts are emerging in the U.S. market, where the Federal Trade Commission (FTC) established the new "Office for Technology" to contrast the nature of antitrust issues in digital and technological marketplaces. Technological dominance driven by network effects also results in harnessing labor conditions within platform ecosystems. Platforms often have significant control over the labor force, and practices that circumvent labor rights can be exploitative. This is highlighted by the recent efforts by policymakers in this regard (European Parliament, 2023; Fabo et al., 2017; U.S. Department of Labor, 2019).

The hypothetical monopoly test (or SSNIP, Small but Significant Non-transitory Increase in Price), the as-efficient competitor (AEC) and the Herfindahl-Hirschman Index (HHI) for market concentration are among the tools used by the European Commission and the FTC to measure potential market dominance, and there is much debate around their adequateness (Gaudin & Mantzari, 2022; Hausemer et al., 2021; U.S. Department of Justice & Federal Trade Commission, 2010). Using our framework, authorities can go beyond the concepts of market and book value, based on other – sometimes arbitrary – factors, and monitor dominating firms by observing the growth of the networks of standards and platforms they are part of and studying their ties to other firms. In general, we notice a large misalignment between the importance that research gives to network effects in the context of technology adoption, and how these are disregarded by institutions. Besides the recent case in the UK about the large acquisition by Microsoft of the videogame colossus Activision, where there is large reference to the risks posed by excessively strong network effects (CMA, 2023), many recent instances fail to consider them in a structured way to assess dominant positions and abuses. This happens despite the numerous calls on the need to involve them in such assessments (OECD, 2018)

Our framework also addresses the work of Standard-Setting Organizations (SSOs). It can help them understand the adoption and success of standards and the value of the standards they are developing. Particularly for standards development, a better understanding of network effects can lead firms to take strategic decisions in terms of alliances and technological portfolios (Cohen et al., 2016; Toh & Miller, 2017). Thus, SSOs could employ our framework to balance the levels of competition and cooperation among such firms. Besides, two other tensions characterize standardization practice nowadays. One is the SSOs' difficulty in including more classes of stakeholders in the standards' development process to reach a broader consensus among different societal groups (Wiarda et al., 2022; Wu & de Vries, 2022). Our framework can advise SSOs in understanding the trade-offs involved in the inclusion (or exclusion) or these stakeholders. The other is the use of or the establishment of fair and reasonable prices for the licenses of standard-essential patents (European Commission, 2023; Rosa, 2022). One of the main issues here stands in the definition of prices once the standard is widely adopted (Bekkers et al., 2023). Quantifying the adoption not only based on the number of users but on its network structure can create a common reference and facilitate the comparability with standards that are differently structured.

Lastly, our framework has managerial implications for firms that either own a standard or a platform or that participate in ecosystems coordinated by standards or platforms. Managers can employ the variables used in our framework (i.e., network density and average tie value) to measure firm performance. To pursue group ties with exponential returns, firms should incentivize interactions of this kind. In the case of standards, this can occur by conceding open-source licenses (McClean et al., 2021; Vir Singh et al., 2011). Similarly, platform firms should aim to trigger more user-generated content and peer-to-peer interactions, enabling the sharing of high-valuable knowledge and content among small communities (Panico & Cennamo, 2020; Subramanian et al., 2021). When firms decide to use a standard or a platform and join their networks, they can pre-emptively assess the costs and benefits they could derive from their potential ego-network. This gives them an alternative method to measure the competition and target the right firms with whom to establish strategic partnerships (for examples on electric vehicles and telecommunications see Teubner et al., 2021 and Anderson et al., 2022). Network effects also play a central role in new market segments in the tech industry, making it necessary to understand their functioning to keep the pace of new technologies. Examples include cloud gaming and generative Artificial Intelligence (AI)[10].

[10] In the recent stance against Microsoft for its acquisition of the videogame powerhouse Activision-Blizzard-King, UK's Competition and Market Authority (CMA) voiced concerns that this acquisition could create excessive network effects, potentially stifle competition, and lead to monopolistic control in the gaming industry (CMA, 2023). As to generative AI, Google and Microsoft are setting standards by providing references respectively to AI's foundation models, AI models trained on broad sets of user data (Google, 2023) and to responsible AI (Demarco et al., 2021). The CMA, accordingly, cites

3.6.3 Limitations and future research agenda

Acknowledging the ambition involved in proposing a universal evaluative method for diverse networks of standards or platforms, we recognize certain limitations of our model, which provide potential avenues for improvement.

Firstly, we take a set of assumptions that partially limit the scope of our framework. We assume ties to be of the redundant type (i.e., our networks are undirected) and networks to be one-mode (comprising nodes of the same granularity), and thereby overlook the importance of a node's position to assess its ego value. To address this limitation, we advocate incorporating concepts from social network theory, including the strength of the ties connecting the nodes, the number of structural holes in the network, nodes' prestige, betweenness or eigenvector centrality, and network cohesion.

The second limitation is that we consider networks to be static (see Table 3-6). A dynamic analysis could consider multiple competing networks, where actors can choose which network to join, depending on the expected future value and a potential bandwagon effect (Henshel & Johnston, 1987; Rohlfs, 2003), anticipating others to join as well. Such choices result in increasing and decreasing network values, and either a game theoretical approach (as in Farrell & Klemperer, 2011) or the use of differential equations (as in Øverby & Audestad, 2021) could teach us more on the dynamic evolution of our framework over time.

Lastly, empirical work can support and strengthen our framework. For example, it could consider characteristics of individual ties (e.g., tie strength and directionality) rather than average tie values, as we do in our framework. It can also examine the individual behavior of nodes (rather than that of groups of nodes like sides or subgroups). Empirical work could also provide richer detail on the dynamics of each network structure.

network effects among the monetization strategies of generative AI (CMA, 2023). These examples show how network effects can generate revenues in key strategic segments of the tech industry.

4. Effects of participating in technical standardization on the economic performance of firms[1]

It is often assumed that engagement in technical standardization yields positive outcomes for firms, particularly in terms of their economic performance. Yet, empirical evidence supporting this relationship is still limited. Using a dataset covering membership of 45,000 firms in 191 standard-setting organizations (SSOs), and compiling a time panel covering 1996 to 2014, this study investigates this relationship, as well as the moderating effects of (1) the competition between participating firms and (2) the number of members of the SSO. We find that the effect of participating is indeed positive, but gradually decreases over the years. Additionally, we observe diminishing returns to economic performance as the number of SSO participations increases, particularly when firms engage with three or more SSOs. Our analysis later zooms in on firms that participate in only one SSO, which we coin as focused standardization players (FSPs), and that hypothetically suffer from highly competitive SSOs. Instead, we find that FSPs engaging in more competitive SSO yield higher economic benefits. We also find these benefits to occur in smaller SSOs. Interpreting these results, we contribute to the ongoing research on SSO composition by discussing the trade-off between SSOs' size and internal competition.

4.1 Introduction

Technical standardization plays a crucial role in shaping technological markets by ensuring interoperability, safety, and quality across products and services. This

---

[1] This chapter is under preparation for a journal submission. The current title and author list reads as: "Grillo, F., van de Kaa, G., Bekkers, R., de Vries, H. J., Sterzi, V. – Effects of participating in technical standardization on the economic performance of firms". A previous version of this article is published in conference proceedings as: "Grillo, F., van de Kaa, G., Bekkers, R., & Sterzi, V. (2024). Who leads Standard-Setting Organizations? The influence of network embeddedness on firm performance. Proceedings of the 28th EURAS Annual Standardisation Conference - Comprehensive Standardisation for Societal Challenges".

process facilitates the development of shared rules and specifications that allow various stakeholders to innovate and compete on a common ground (David & Greenstein, 1990; de Vries, 2010). Here, standard-setting organizations (SSOs) play a key role by facilitating the collaborative environment around which the specifications behind a technical standard are developed and decided (Delcamp & Leiponen, 2014; Teubner et al., 2021). The positive effects of technical standards on markets and firms are manifold. For markets, standards facilitate the diffusion of new technologies by ensuring compatibility and interoperability, thus reducing uncertainty for consumers (Lin & Huang, 2014; Ronnen, 1991; Toh & Pyun, 2024). For firms, adopting and developing standards can lower production costs, enhance product quality, and provide access to larger markets (Tassey, 2000). There are also costs that literature discusses as outweighing these gains. They include reductions in product variety and reduction in entry barriers for firms resulting in more competitive and saturated markets (Farrell & Klemperer, 2011; Farrell & Saloner, 1985).

Different stakeholders, including firms, universities, and political institutions, voluntarily participate in SSOs by promoting their interest in technical committees or working groups, and eventually appropriate value (Ahuja et al., 2013; Schilling, 2009) and profit from the innovation brought by new standards (Teece, 1986, 2018). The (at least, in principle) neutral nature of SSOs should require firms to prioritize reaching consensus for an optimal solution over the participants' individual economic interest (Blind & Mangelsdorf, 2016; Toh & Miller, 2017). However, the collaborative search for such a solution becomes a battle between firms' vested interests to – for example – embed their proprietary technologies into the standard or align it with their current R&D efforts (Farrell & Simcoe, 2012; Lorenz et al., 2019).

Besides the direct benefits of reaching and adopting a common standard, firms also benefit from the relationships built with other specialized players and the access to state-of-the-art industry knowledge. Networks of relationships have risen to prominence in the modern discourse on strategic management and economics of innovation, as their structure can be analyzed to identify patterns of firms' strategies (Bushee et al., 2023; Gilsing et al., 2008; Katz & Shapiro, 1985; van de Kaa, 2018). Networking with peers is a fundamental aspect of standardization, and plays a major role in determining firms' appropriability of benefits from standardization. In this context, two key factors often discussed are the size and the internal competition of the collaboration network, as these influence firms' capacity to capture value from networking and turn them into improved market performance (e.g., Aggarwal et al., 2011; Axelrod et al., 1995; Bresnahan & Greenstein, 1999; Kamps et al., 2017).

As firms' relationships in SSOs and the balance of their interests are timely topics in the economics and management literature, our paper identifies two open debates. The first relates to the economic benefits firms may expect from the engagement in technical standardization. While much literature emphasizes the link between developing standards and a better innovation output for firms (see also Leiponen, 2008; Rysman & Simcoe, 2008), we seek to find evidence whether, to what extent, and when firms can also expect a better economic performance. Firms that participate in the development of standards can "design the rules of a game" before playing it, thereby creating uncertainty and gaining access to strategic information before their competitors (Dattée et al., 2018). Although some empirical literature has tested the existence of economic returns to participation in SSOs (Waguespack & Fleming, 2009; Wakke et al., 2016; Wu & de Vries, 2022; Xiong et al., 2024), these analyses are bounded to geographical and sectorial settings that limit the generalizability of their findings.

The second debate relates to the presence of power asymmetries between groups of stakeholders within SSOs. These distinct groups can relate to different membership tiers (e.g., sponsors versus regular members), different firms' sizes (large and dominant players versus SMEs) or different industry roles (e.g., producers versus users). These tensions may accentuate when the technical committees include too many or too few members. An example of the former case is when the adherence of many firms shifts the focus from the quality of the technical specifications to the compatibility with the firms' existing products (Aggarwal et al., 2011). As to the latter case, it may occur that a small group of firms governs and leads the decision-making process of the SSO (Baron & Kanevskaia, 2023; Bresnahan & Greenstein, 1999). The history of technical standardization is dotted with scenarios of opportunistic behavior by firms caused by these tensions[2]. Although such cases narrate situations

---

[2] Some examples of such behaviors include: (1) the anticompetitive behavior of Rambus. in the development of standards for semiconductors in the SSO JEDEC (Federal Trade Commission, 2002; Swanson & Baumol, 2005); (2) Motorola and, later, Samsung delaying the mobile standardization process by refusing to offer fair and reasonable licenses for their standard-essential patents (Bekkers et al., 2002; European Commission, 2014; Jones, 2014); (3) Intel and its competitive positioning for the establishment of IEEE 802.11 standard (i.e. Wi-Fi) (Fontana & Greenstein, 2021; Greenstein, 2012; Trappey et al., 2017); (4) IBM in the mainframe computer industry (den Uijl, 2015); (5) Sun Microsystems in the SSO "ECMA" for the sponsorship of Java as a dominant standard (Garud et al., 2002).

where the "goliaths" dominate and the smaller players suffer, it remains unclear whether the latter compensate the fierce competition fueled by larger players with the benefits derived by participation.

These two debates come together in our research question. We ask: "What is the relationship between firms' participation in technical SSOs, competition between member firms and the size of the SSO on the one hand, and firms' economic performance, on the other?". To address this question, we compile a large dataset of 191 SSOs over two decades with the financial data of 45,000 member firms. We first investigate all firms' variation in economic performance while participating in an SSO. In the second part of the paper, we zoom on firms with participation in only one SSO, to explore how internal competition and size of the SSO impact their economic performance. We coin the term "focused standardization players" – "FSPs" hereinafter – to refer to these firms. Measuring their change in productivity per employee, our analysis finds several novel results. First, we find that firms (including FSPs) perform better from the same year they enter in an SSO up until two years later. Second, we find that a higher competition between SSO members has a positive impact on FSPs' economic performance. Third, FSPs improve their economic performance more in smaller SSOs. Lastly, we test and find that size and internal competition are significant factors when considered together in the same statistical analysis, meaning that they could form a trade-off in improving FSPs' economic performance.

Discussing our results, we position them in current debates related to firms' economic performance during standardization and in other contexts of interfirm collaboration. Our findings show the importance for firms to consider involvement in technical standardization, especially if their competitors do so. They also witness how beneficial is participation for FSPs, despite the costly entry barriers (e.g., membership fees and staffing costs). Additionally, the risks deriving from disclosing their proprietary technologies may be compensated by the benefits obtained by accessing other firms' technologies and the strategic relationships built with them. In other words, the perks of cooperation may overcome the downsides of competition for FSPs. Our results also have implications for SSOs' governance, for example about their optimal number of members and the right balance between competitors and complementors, as well as concerning how different types of standards may lead to different changes in economic performance. We conclude the paper acknowledging the limitations of our study, including those of our identification strategy, and suggesting next steps for follow-on research.

4.2 Literature review and hypotheses

4.2.1 Firms' participation in technical standardization

Setting standards is often a prerequisite for new technical fields to emerge. Firms differ in the role they play – and thus their influence – during the standardization process. Conventionally, members of technical SSOs can be divided into four groups (Baron & Spulber, 2018; Lemstra et al., 2011; Updegrove, 2006). "Leaders" are those firms who actively participate by heavily investing in R&D, aiming to steer the standardization process towards their business-critical activities. "Contributors" are active participants that share their knowledge in technical committees by means of, for example, technical reports, change requests, and patent disclosures (Hussinger & Schwiebacher, 2015). "Followers" and "spectators", instead, include firms taking part in the process only to absorb technical knowledge related to the standards. They may differ based on the presence and extent of voting rights, which may vary across SSOs: sometimes, followers can vote while spectators cannot. Regardless of their membership, firms that are more likely to participate are on average larger, with high export activities and R&D expenses (Blind & Mangelsdorf, 2013; Wakke et al., 2015) and participate because of competitive pressures or a fitting technology profile with the SSO (Zhang et al., 2020). However, despite the positive relationship between R&D expenses and participation, firms with very high R&D investments are less likely to participate to avoid sharing their technical know-how to rivals (Blind, 2006).

4.2.2 Firms' benefits from participating in technical standardization

Multiple case studies in the literature associate firms' participation in standardization with positive economic and financial returns. There are four key moments when these returns may manifest. The first moment is when the firm announces the intention to join the SSO, this may result in an increase of the firm's stock price valuation. Aggarwal et al. (2011) found a 4% increase for firms announcing their participation in IT standardization.

The second moment occurs when the firm participates in the technical committees and working groups of the SSO, and can learn from the technical knowledge provided during the meetings. These "learning" benefits may take time and active participation to manifest, and the sole act of joining normally is not enough for these benefits to occur. An increase in performance[3] during this stage was shown for German firms in the manufacturing sector (Wakke et al., 2016). Similarly, Chinese firms exhibited a positive relationship between participation and their return on assets (Xiong et al., 2024) and their performance as perceived by their allies (Wu & de Vries, 2022). Startups were shown to increase their chances of an initial public offering when actively participating in the development of open standards for the Internet Engineering Task Force (Waguespack & Fleming, 2009). Lastly, a longitudinal study on multiple SSOs showed a decrease of the cost of equity for SSO participants, lowering their perceived market risks and making them more appealing to investors (Deng et al., 2022).

The third moment is when a firm chooses to implement a standard. If the firm decides to announce this, a signaling effect can increase the credibility and the stock price of firms and may protract up until the adoption and the assessment of conformity (Manders, 2015). When firms start implementing the standard in their products, processes, or management systems, those that participated in its development can typically benefit more from its implementation than non-participants because they know at the earliest stage what the requirements will be and the firm's input enhances the chances that these requirements meet the firm's interests (de Vries & Wiegmann, 2017). Furthermore, the implementation of standards was shown to have a positive impact on the innovation-related activities of firms who developed them. Supporting empirical research include increased citations to members' patent portfolios (Delcamp & Leiponen, 2014; Rysman & Simcoe, 2008) and a better integration of R&D activities with the development of products (Lorenz et al., 2019). The positive relationship between innovation output and economic performance (e.g., Teece, 1986) may confirm the economic benefits also for this third moment. Additional economic effects may then emerge when the firm obtains conformity to the standard, by means of a self-declaration of conformity or a certificate[4] (Manders, 2015; Wiegmann et al., 2023).

The focus on balancing interests and exploitation of interfirm relationships puts the spotlight on the second moment of this process. The cited evidence bounded to

[3] Estimated as the error term of firms' profit function with number of employees and capital stock as regressors. The error term captured the firms' increase in profit not driven by increase in size (number of employees) or equity (capital stock).
[4] For example, the certification of conformity to the Wi-Fi standard issued by the Wi-Fi alliance. See https://www.wi-fi.org/certification

geographical contexts and sectors requires further causal investigation with a broader scope and more generalizable results. Based on this evidence, we hypothesize the following:

HP1: Participating in one or more standard-setting organizations increases a firm's economic performance.

Besides mere participation, we are also interested in exploring whether investing more resources into standardization impacts firms' economic performance. Previously, we outlined four types of SSO membership, mostly dependent on the firms' proactivity to influence the process towards their interest (see also Simcoe, 2012). Besides paying for more membership rights, firms may decide to increase their involvement in standardization through other investments. Examples of these investments include participating in multiple technical committees or multiple SSOs, establishing technological agreements with other members, and investing in R&D for technologies that may become essential for the standard. These activities are knowingly expensive due to, for example, admission fees, experts' working hours, and travel expenses (Abdelkafi et al., 2021).

Nevertheless, despite the costs mentioned, literature agrees that the more resources firms invest in setting standards, the higher are the benefits they reap. For example, firms entering into multiple joint R&D projects and other technological agreements are shown to benefit from a better competitive advantage during the standard-setting process. Several studies expressed this concept through the firm's centrality within interorganizational networks (e.g., Bushee et al., 2023; Gilsing et al., 2008; Soh, 2009; Vanhaverbeke & Noorderhaven, 2001). Leiponen (2008) showed that being affiliated with both a "formal" standard body and "informal" consortia increases a firm networking opportunities, and thus the chances that its technical contributions are included in the standard. De Vries & Veurink (2017) showed that firms' financial investments in standard setting are compensated by higher sales or lower production costs. The amount of meeting participations of a firm during standard setting was demonstrated to positively correlate to the number of patents and their citations (Gandal et al., 2004). In return, firms may disclose these patents to be essential to the standard as an additional form of active participation in the standard-setting process. In line with our reasoning, Bekkers et al. (2011) showed that more involvement in the standardization process (measured as the firm's weight in the voting procedures) increases the chances of having these patents claimed as essential by the SSO. The recognition of a patent as essential to a standard is widely associated with a higher market value of the proprietary firms(e.g., Hussinger & Schwiebacher, 2015; Miller & Toh, 2020).

Altogether, these represent different forms of investment of resources into the standardization process. Among these, firms may commit to standardization by sitting in more SSOs at the same time for several reasons, such as to increase the previously cited networking opportunities, or to better understand the status of product markets crowded with complementary (e.g., Wi-Fi and 5G) or rival (e.g., Bluetooth and NFC) standards. As an important and unexplored form of resource investment, we are interested in testing the existing evidence on this specific case. Thus, we formulate the following hypothesis:

HP2: The number of standard setting organizations in which a firm participates is positively associated with the firm's economic performance.

4.2.3 Internal competition between members of standard-setting organizations

Participating in standards' working groups is an opportunity for firms to learn more about their competitors' technology portfolios and technical know-how relevant for the standards they are developing. In these instances, internal competition between member firms can occur in two ways. The first one is when firms participating in the development of a standard also compete in the commercialization of rival products that use the same standard (Heikkilä et al., 2023; Riillo et al., 2022). The second one occurs when firms (typically large multi-product firms) cooperate for one standard while being rivals in different product-market segments or even different industries (Granstrand et al., 1997; Lee & Kapoor, 2017; van Wegberg, 2004). In addition, besides competitors, the interoperability brought by technical standards makes it likely to see other stakeholders such as complementors, suppliers and customers, participate in the same tables (Baron & Pohlmann, 2013). This diversity in the composition of standard developers raises questions about the advantages and disadvantages brought by internal cooperation and competition in SSOs.

Market competition can have both positive and negative effects on firms. On the one hand, economic theory discusses the positive effects as being long-term collective gains, such as the optimal allocation of market resources, a level playing field that is easier to regulate, and a desirable technological progress. On the other hand, higher competition reduces the ability of individual firms to exert market power and capture value from their investments in R&D (Griliches, 1986; Nickell, 1996). In the context of standardization, an example of collective gain is when a standard gets widely implemented in products, leading to improved interoperability of products and lower prices. While this represents a positive achievement for the SSO and the consumers, it may not be the same for individual firms that invested resources in the development of that standard.

4.2.4 Effects of higher internal competition on focused standardization players

This multitude of stakes may disincentivize the collaborative participation of smaller and resource-constrained firms and exacerbate opportunistic behavior of larger ones (Leiponen, 2008). Large firms, for example, may exert stronger influence either directly or indirectly in the standard developing process. In return, the larger a firm, the more compelling it is to ally with them during standards development (Axelrod et al., 1995). This opportunistic behavior emerges, for example, when firms have large investments in complementary products for which the standard provides the interface specification (Ranganathan et al., 2018). Likewise, Simcoe (2012) showed how, for similar reasons, larger firms are willing to join crowded technical committees with concentrated power among few members, despite the large member base. These behaviors may explain why large firms are reluctant to join SSOs with a high number of direct rivals (Axelrod et al., 1995). In smaller SSOs, the level of technical committee and SSO may be similar in case there is only one main committee. In a study on standards' consortia, Kamps et al. (2017) found that SSOs with high internal competition had a higher tendency of opportunistic behavior and a shorter life cycle compared to more collaborative ones.

While most literature focuses on large firms, it remains unclear whether their prominent role in SSOs has repercussions on what we call focused standardization players (FSPs). There is little evidence on the benefits of FSPs derived specifically from participating in the development of technical standards. In most cases, firms that sporadically engage in technical SSOs are also small (Miller & Toh, 2020). For this reason, we build on the existing literature that mostly focuses on SMEs and startups to formulate our hypothesis.

Indeed, there are many cases where smaller players cover a key role by providing specialized knowledge to the development of the specifications. R&D intensive SMEs are shown to avoid SSO participation because they refrain from sharing their knowledge to competitors (Blind & Mangelsdorf, 2013). Besides potential "thefts" of knowledge, SMEs generally consider standardization as a burdensome process designed for larger firms and that is too costly for them. They may also lack knowledge on the criticalities of the process and/or people that are competent enough to participate (de Vries et al., 2009; European Commission, 2006). In the case of startups in the IT industry, Chen et al. (2017) show there is higher likelihood that their technologies fail when they engage in standardization before the emergence of a dominant industry standard. The same study argues that startups' technologies are instead more likely to disrupt the industry when a dominant standard already exists, because in this phase their larger competitors face higher market saturation. Russell et al. (2022) describe benefits for startups only when the SSO develops freely available open standards. This was shown during the early development years of the internet, when regulators attacked larger firms and startups such as 3Com and Cisco Systems could grow without worrying about political barriers.

Besides few exceptions (e.g., de Vries, 2006), the literature suggests more benefits to larger players and a lower propension of smaller firms to participate in SSOs where internal and external dynamics make the development process more competitive. The main reasons for this imbalance are the opportunistic behavior of larger firms, the high entry barriers, and the sharing of specialized proprietary knowledge that large firms may exploit more than smaller firms. We use this reasoning to hypothesize – with respect to HP1 – that FSPs face the same situation.

HP3: Participating in SSOs with higher competition among their members leads to lower economic performance gains for focused standardization players.

4.2.5 Effects of SSO size on focused standardization players

The debate around the optimal size of SSOs, in terms of number of participants, is central and common to the most disparate areas of standards (e.g., Alfraih, 2016; Durán-García et al., 2011; Hassan et al., 2018). Literature on technical standardization has focused mostly on the size of "informal" alliances of firms (Teubner et al., 2021), and the debate around size still seems unresolved. Some studies emphasize positive effects for SSO members when the SSO is larger. Wu & de Vries (2022) describe a positive relationship between the size of technical standards alliances and the performance of firms in the Chinese IT and automotive sectors. In addition, standardization committees that are too small may not have enough knowledge and stakeholders' interests represented (Abdelkafi et al., 2021; Bar & Leiponen, 2014).

Similar to our previous hypothesis, the majority of supporting evidence on the effects of SSO size investigates large firms. For example, Axelrod et al. (1995) find that large firms engaged in the battle for Unix operating systems standards could maximize their utility when participating in larger alliances. Phelps (2010) finds that joining large alliances gives large firms more access to diverse information and incentivizes them to invest in innovation. He focused on large firms due to the lack of accurate data for smaller ones. Large SSOs can also trigger positive network effects between the members, especially in those instances where many members are also users of the standard and the same standard facilitates the interoperability between users' products (Katz & Shapiro, 1994). There is supporting evidence that smaller firms capture more value from positive network effects than larger ones in saturated markets, since saturation favors product differentiation over economies of scale (e.g., Zhu et al., 2003). Smaller firms may also benefit more from larger SSOs since they have more chances to gain information on the competitors' technology portfolios (Blind & Mangelsdorf, 2016). We are interested in studying the effects of SSO size on FSPs' economic performance. As such, we build on the cited evidence on larger firms and the reasonings made for smaller ones and, with respect to HP1, we hypothesize the following:

HP4a: Participating in SSOs with a higher number of member firms leads to higher economic performance gains for focused standardization players.

A divergent line of reasoning, however, emerges about the negative network effects of SSOs with larger memberships. We start by following the literature about interorganizational networks and so-called small-world effects originating in sociology (Milgram, 1967; Watts, 1999). These theories endorse the positive effects that denser networks with stronger ties between collaborating organizations have on their members (see e.g., Baum et al., 2003; Kraatz, 1998). Schilling & Phelps (2007) demonstrate that firms joining smaller interfirm alliances exhibited higher innovation outputs. Similar conclusions are found in some sources about platform ecosystems (Farronato et al., 2023; Iansiti, 2021; Jullien et al., 2021; Kauffman et al., 2000) where it is deemed that complementary firms participating in smaller and specialized platform ecosystems obtain more economic benefits. In the standardization literature, Aggarwal et al. (2011) argue that a higher number of members reduces the stock market valuation of firms. They also explain how these negative effects may have stronger repercussions on smaller firms, due to their higher dependency on the fewer SSOs they belong to. Another downside occurs when the SSO involves large technical committees, since firms become less influential in the decision making and voting processes (Dokko & Rosenkopf, 2010). Although this source considers firms of all sizes, we expect larger firms to be more capable than focused ones to cope with this problem. Indeed, Axelrod et al. (1995) assume that the size of firms is correlated to their ability to influence the standardization process, thus leading to smaller firms being more inclined to participate in smaller SSOs to be able to defend their interests. In light of the literature on small-world effect and the limited evidence for standardization, we hypothesize the opposing scenario of HP4a:

HP4b: Participating in SSOs with a lower number of member firms leads to higher economic performance gains for focused standardization players.

4.3 Data and methodology

In this section, we describe our research approach. Our study seeks to identify patterns in firms' economic performance in relation to their participation in standard-setting organizations (SSOs). To test our hypotheses, we build a panel consisting of firm-SSO membership for each observed year, and analyze it by means of the ordinary least squares (OLS) method. Given our objective to assess the effect of SSO participation on firms' economic performance, the panel structure of our dataset allows us to track firms over time through a fixed effects model, reducing concerns related to cross-sectional heterogeneity.

4.3.1 Dataset composition

We use data on firms engaged in standard-setting activities within the ICT industry during the period 1996–2014. To build the panel, we use data provided by the Searle Center Database (SCDB) (Baron & Spulber, 2018) on the membership of approximately 56,000 firms in a total of 191 SSOs, aggregating a total of around 290,000 observations (firms' memberships in SSOs).

SCDB data contained some missing intervals in SSO-year observations, so we developed a method to deal with such missing data in a systematic way[5]. Table 4-1

[5] For disparate reasons described by the authors of the SCDB, the database lacks data on specific SSOs for some years. More relevant is the lack of membership data for the Bluetooth Special Interest Group, because of its large size in terms of members. To compensate for this omission, we create new observations with the following assumption: if a firm is part of an SSO in the years e.g., 2010 and 2012, and there is no data available for 2011, we assume it was part of it also in 2011. This is valid for a maximum of four years of missing data interval, which is the highest interval occurring in multiple instances in the dataset. In the few instances where missing intervals are longer than four years, we assume the firm left the SSO at the start of the interval and joined it for a second time at the end of

displays the most recurring SSOs in our dataset in terms of observations and number of participating firms. Most of the SSOs operate either in the information technology and telecommunication industries, but some exceptions are present (e.g., healthcare and advertisement graphics).

Our hypotheses apply at the level of "SSOs". However, SSOs may be structured into different hierarchical subdivisions where meetings, and thus relationships and decisions, take place. In most cases, these subdivisions are called technical committees (TCs) or working groups (WGs). The former normally define broader areas for standards' development, while the latter facilitate the technical work on single modules that, altogether, form a unique technological architecture (e.g., the Bluetooth technology). To better understand the level of analysis of our approach, for each of the 191 SSOs present in our dataset, we classified whether they were divided into TCs, WGs, or both. Additionally, we checked if they could be considered "informal" alliances, born by initiative of a small group of private firms to solve a specific coordination problem in the market, or "formal" SSOs, that are typically recognized by public actors such as international institutions or national governments.

The detailed results of this check are included in Table 7-7 in Appendix 1. The majority of SSOs in our dataset (156 out of 191) are to be considered "informal", 73 of which operate through WGs. Additional 26 SSOs are divided into WGs but are to be considered as "formal". Based on this analysis, we can conclude that most of our dataset includes membership data for SSOs whose standards are developed for a single technological architecture, whether through working groups or not. This allows us to associate, to a fair extent, the characteristics of the SSO (e.g., its level of competition and its number of members) to the networking and learning dynamics affecting the economic performance of participating firms.

We matched SSO membership data with firms' financial data and indicators, number of employees, generic and specific sectors (respectively two-digit and four-digit NACE codes), collected from the Bureau van Dijk's Orbis database. In this step, data were carefully cleaned and tested to reach uniformity across the observations. This includes the harmonization of multiple firms' names through the SCDB "standardized names" and a manual verification of all mistakes within data outliers.

---

the missing interval. Instead, if a firm is listed as a member at the start of a missing interval and not at the end of it, we assume it left the SSO at the start of the interval.

The availability of financial data only to a limited number of firms, and/or for a limited number of years in the observed period, reduces our observations to roughly 44,000 firms, 30,000 of which are FSPs. Besides being "focused" due to their participation in only one SSO, FSPs are also smaller than non-FSPs on average, as shown in Table 7-8 in Appendix 2.

Table 4-2 shows the twenty most recurring firms in our dataset in terms of number of SSOs participations on average, together with their sector, average revenues and number of employees. The table is led by U.S. and Japanese firms, though some European firms are present (the table does not include Samsung Electronics, NTT., LG Electronics and Alcatel Lucent for some undisclosed data on their number of employees during the observed period). Table 4-3 displays the ten most recurring four-digit sectors and the number of corresponding firms. Although the table highlights a prevalence of technical industries, the relatively low number of firms represented (14,000 out of 37,000 linked to a sector) also describes a long tail of other (including non-technical) sectors. The sectors starting with "Other" (four in Table 4-3) represent a residual category where multi-product firms (with a scope broader than the adjacent codes) typically fall, showing a high representation of this kind of firms. Lastly, Table 4-4 exhibits the distribution of observations across the years. The distribution is skewed towards the last years due to the emergence and enlargement of many technical SSOs in that period, especially driven by the Bluetooth Special Interest Group (SIG). The table also shows that the average duration of a firm membership was slightly less than four years.

Name[6]	Total member firms (1996-2014)	Total firms' membership observations (1996-2014)	Scope
ASTM	2,070	7,723	Material testing standards for industries and products
ATIS	580	2,956	Telecommunications industry standards for communication systems and services
Bluetooth SIG	13,368	29,480	Wireless communication standards for personal area networks
CTA	5,021	14,685	Consumer electronics standards for devices and innovation
CTIA	917	2,760	Wireless communication standards for cellular technologies
ETSI	788	2,590	ICT system standards for global telecommunications and broadcasting
HIMSS	1,333	3,474	Healthcare IT standards for patient data and technology
IDEAlliance	994	3,729	Media communication standards for publishing and advertising industries
INTERNET2	629	3,190	Networking standards for research and education institutions
JEDEC	639	3,533	Semiconductor device standards for electronics industry
OASIS	982	3,261	Information exchange standards for open data interoperability
PCI	1,908	8,492	Hardware interface standards for PCI connections
TIA	1,871	6,442	Telecommunications infrastructure standards for communication networks
TM	1,211	3,390	Digital transformation standards for telecommunications and IT services
TOG	806	3,191	Enterprise technology standards for open software and systems
UPnP	872	8,617	Device connectivity standards for universal plug-and-play systems
VESA	652	2,746	Video electronics standards for displays and interfaces
W3C	981	4,596	Web standards for internet technologies and protocols
Wi-Fi	793	2,408	Certifications for wireless local area network security and interoperability
WiMax	766	2,357	Broadband wireless network standards for telecommunications

Table 4-1 – Twenty most recurring SSOs in our dataset (in terms of number of observations)

[6] Full names are in Appendix 3

Firm name	Country	Two-digit sector code	SSO participations (yearly average)	Revenues (yearly average, $ millions)	N. Employees (yearly average, thousands)
Intel	US	26	48	40,761	91
NEC	JP	62	47	38,966	134
Microsoft	US	58	46	53,639	79
Fujitsu	JP	62	45	46,758	154
HP	US	26	45	92,964	228
Hitachi	JP	62	44	97,465	353
Nokia	FI	26	42	47,093	86
Cisco Systems	US	26	40	34,910	58
Toshiba	JP	26	39	64,486	196
Motorola Solutions	US	26	38	18,689	67
Ericsson	SE	62	37	15,328	19
Siemens	DE	27	34	93,339	421
Mitsubishi	JP	46	33	64,715	53
Oracle	US	58	32	23,899	84
Texas Instruments	US	26	31	12,032	32
Orange	FR	61	29	58,491	186
NXP Semiconductors	NL	26	28	4,624	28
Marvell Technology Group	BM	26	28	3,381	7
Qualcomm	US	26	28	13,212	18
Philips	NL	26	25	35,915	144
Sector code legend	26: Manufacture of computer, electronic and optical products 27: Manufacture of electrical equipment 46: Wholesale trade, except of motor vehicles and motorcycles 58: Publishing activities 61: Telecommunications 62: Computer programming, consultancy and related activities				

Table 4-2 – Twenty most recurring firms in our dataset (in terms of number of SSO participations each year on average)

Four-digit sector code	Sector description	Number of firms	Frequency
6201	Computer programming activities	2,758	7.4%
7490	Other professional, scientific and technical activities (not elsewhere classified)	1,652	4.4%
6190	Other telecommunications activities	1,536	4.1%
5829	Other software publishing	1,473	3.9%
2611	Manufacture of electronic components	1,400	3.7%
6209	Other information technology and computer service activities	1,194	3.2%
7022	Business and other management consultancy activities	1,075	2.9%
2630	Manufacture of communication equipment	980	2.6%
7112	Engineering activities and related technical consultancy	812	2.2%
6202	Computer consultancy activities	808	2.2%

Table 4-3 – Ten most recurring specific (four-digit) sectors

Year	Number of active SSOs	Number of active firms	Participations per firms (rounded average)	Observations	Frequency
1996	4	324	1	360	0.1%
1997	9	499	2	983	0.4%
1998	12	282	5	1,273	0.5%
1999	17	427	3	1,468	0.6%
2000	51	2,835	2	5,187	2.0%
2001	67	2,319	3	7,205	2.8%
2002	73	1,333	6	7,676	3.0%
2003	85	2,517	4	9,668	3.7%
2004	95	2,063	5	11,244	4.3%
2005	105	2,961	5	14,366	5.5%
2006	132	2,701	6	17,362	6.7%
2007	143	2,176	8	17,888	6.9%
2008	160	1,709	11	19,016	7.3%
2009	169	7,925	3	25,738	9.9%
2010	139	1,484	16	23,677	9.1%
2011	140	1,358	18	24,014	9.3%
2012	138	1,879	13	24,265	9.4%
2013	138	6,580	5	30,697	11.8%
2014	113	2,766	6	17,052	6.6%
			Total:	259,139	100%
		Average firm permanence in an SSO (years):		3.82	

Table 4-4 – Distribution of observations per SSO by year

4.3.2 Identification strategy

Equations 4-1 to 4-4 show the ordinary-least squares (OLS) regression equations for HP1, HP2, HP3 and HP4 respectively.

$$Economic\ performance_{firm,t} = \beta_0 + (SSO\ Participation_{firm,t})\beta_1 + (Controls_{firm,t})\beta_2 + \varepsilon$$

Equation 4-1 – OLS Regression for hypothesis 1

$$Economic\ performance_{firm,t} = \beta_0 + (Number\ of\ joined\ SSOs_{firm,t})\beta_1 + (Number\ of\ joined\ SSOs_{firm,t})^2\beta_2 + (Controls_{firm,t})\beta_3 + \varepsilon$$

Equation 4-2 – OLS Regression for hypothesis 2

$$Economic\ performance_{firm,t} = \beta_0 + (SSO\ Participation_{firm,t})\beta_1 + (Internal\ competition\ x\ Participation_{SSO,t})\beta_2 + (Controls_{firm,t})\beta_3 + \varepsilon$$

Equation 4-3 – OLS Regression for hypothesis 3

$$Economic\ performance_{firm,t} = \beta_0 + (SSO\ Participation_{firm,t})\beta_1 + (Size\ x\ Participation_{SSO,t})\beta_2 + (Controls_{firm,t})\beta_3 + \varepsilon$$

Equation 4-4 – OLS Regression for hypothesis 4

To test HP1 and HP2, the regressions do not include any moderating variables. The interaction terms of *SSO internal competition* and *SSO size* are included in HP3 and HP4 respectively. We also run a model that includes both moderating variables, to test whether size and competition can explain firms' economic performance during technical standardization when used together as regressors.

As we seek for a causal effect, some potential endogeneity issues should be recognized. First, the model may oversee some omitted variables that could help explaining the effect of participation on economic performance. These include the size of firms (larger firms can benefit more from participating in SSOs), the sector-specific effects (technology intensive firms may benefit more than firms in other sectors), and other exogenous factors (e.g., the general growth of the technology intensive sectors in the observed period). Secondly, the participation in standard-setting activities of firms may indeed be driven by their economic performance, resulting in a reverse causality bias. As we cite – in the previous section – the costly hurdles of developing standards, it may be more likely that firms decide to participate in SSOs when they are in a more favorable financial situation. To mitigate these biases, we introduce one and two-year lags and opt for fixed effects models[7]. By including fixed effects, we are able to control for all effects that vary across firms, such as their sector and country. We then include firm size as part of our controls (see later section on control variables).

4.3.3 Dependent variables

We use *firms' productivity* as a proxy of their economic performance, aligning with previous literature linking the two concepts (e.g., Bartelsman et al., 2013; Syverson, 2011). To measure productivity, we divide the revenues of a firm by its number of employees for each year. In our analysis, we use the natural logarithm of this ratio to reduce the dispersion of the dependent variable. Using a logged dependent variable in the OLS method allows us to interpret the beta coefficients as percentage variations in the dependent variable (*firms' productivity*) following a one-unit increase of the independent or moderating variables.

4.3.4 Independent variables

For HP1 and for the moderating effects (HP3 and HP4), our independent variable is *SSO Participation*, defining the years in which the firm is a member of the SSO (i.e., the year that the firm joins and all the following years until the firm exits the SSO). It is a dummy variable assuming value of 0 when a firm does not participate in any SSO in a given year, and 1 when it is a member of at least one. Due to the completeness of the SCDB, comprising over 191 organizations for technical standards, and following previous studies (Bushee et al., 2023), we assume firms that do not result as members of any SSO in our dataset as not participating in technical standardization in that year. To test HP2, we use the *Number of SSO participations* as our independent variable. This is a discrete variable consisting of the count of SSOs in which a firm is listed as a member in every given year.

[7] The choice of using fixed effects model over random effects has been validated by the Durbin-Wu-Hausman test. Under the null hypothesis, both random and fixed effects models are consistent (that is, the residuals decrease with the increase of the sample), making the random effects model more efficient due to its lower variance. After conducting the cited test, we find that such coefficients are inconsistent over time in the random effects model, rejecting the null hypothesis.

4.3.5 Moderating variables

We study two moderating effects at the SSO level. Following our hypotheses HP3 and HP4, we study these moderating effects only for the subsample of FSPs in our dataset. We identify FSPs as firms that participate in only one SSO in the year of the observation. We are particularly interested in these firms since the attention of institutions and practitioners is shifting to them while most prior literature has focused on larger players[8]. Our operationalization of FSPs may also be associated with smaller firms, since larger firms are normally those active in multiple SSOs. See Table 7-8 in Appendix 2 for descriptive statistics on this distinction.

4.3.5.1 Size

We measure the size of an SSO as the number of firms (both FSPs and large firms) of each SSO every year. Table 4-5 includes the average size of the 20 most recurring SSOs in our dataset. Due to their relatively low barriers to entry and free membership for standards adopters, the Bluetooth Special Interest Group and the Consumer Electronics Association (today Consumer Technology Association) are the largest SSOs in our sample.

4.3.5.2 Competition

To measure the internal competition of an SSO, we use the concentration of sectors associated to the member firms of the SSO. Market concentration is a popular way to estimate the rate of competition in an industry, and its most renowned measure is the Herfindahl-Hirschman index (HHI) (Roberts, 2014). Normally, the HHI measures the concentration of firms in a sector by summing the squared market shares of all firms in that sector. Although we need a similar measure of "unevenness", our goal is opposite, since we need to measure the concentration of sectors within a group of firms (the SSO). For this reason, we build on the original HHI formula, but we instead sum the squared sector shares (computed as the squared percentages of firms in each sector) for all sectors in the SSO every year (see Equation 4-5).

[8] We avoided selecting FSPs based on their revenues or number of employees so that each FSP could be linked with the size and competition of one SSO. Otherwise, we may have had some FSPs linked to multiple indexes of size and competition. Selecting one or computing an average would have made our proxies inconsistent with our intended measures.

$$Concentration_{SSO,year} = \sum_{i=1}^{N} s_i^2$$

Equation 4-5 – Sector concentration index derived from the Herfindahl-Hirschman index

Where *N* is the number of sectors represented by SSO members each year, and *s* is the share of firms in sector *i* within the SSO defined in Equation 4-6 as:

$$s_i = \frac{Firms\ in\ sector_i}{Total\ firms\ in\ SSO}$$

Equation 4-6 – Formula for sector shares within SSOs

Similar approaches are used in the trade literature when measuring the sector concentration of a country's imports or exports (e.g., Bellandi et al., 2018) or by (Ganti & Lazzara, 2022) to measure competition across sectors of the S&P 500 index. As conventionally done in the cited literature, we normalize the concentration index in Equation 4-7.

$$Normalized\ concentration_{SSO,year} = \frac{Concentration_{SSO,year} - \frac{1}{N.\ sectors}}{1 - \frac{1}{N.sectors}}$$

Equation 4-7 – Normalized sector concentration index

We normalize the index for two reasons. First, we turn the measure into a percentage, since the minimum value the HHI can assume is *1/N*, while the minimum value the normalized HHI can assume is zero (in case of a lowly competitive SSO with equally distributed shares across sectors). Both the original and the normalized index have a maximum value of one, indicating the dominance of one sector within the SSO, representing more intense competition. Secondly, the normalized index is no longer dependent on the number of sectors, which could result in a higher correlation with the size of the SSO.

Using a concentration index has some advantages. First, it considers asymmetric shares of sectors' representation within each SSO. For example, in an SSO with ten firms, if nine belonged to sector 61 (Telecommunications) and only one belonged to sector 26 (Manufacture of computers), the concentration index would be higher

(=0.82) than in an SSO with five firms in each sector (=0.5). Second, the HHI is more complete than the other concentration ratios as it requires information on all the firms and not only on the largest ones. Other concentration ratios do not distinguish between markets with fewer firms and those where there is a long tail of firms with smaller market shares (OECD, 2021). Third, there are several problems associated with the use of market shares as a measure of market competition that made us overlook them. Concentration depends not only on the revenues of the various firms involved relative to the market but also on other factors such as cost asymmetries and the ability of firms to "hide" their price changes (Nickell, 1996). We have thus selected this proxy for the previous and other practical reasons (i.e., we do not have revenue data available for all firms, but mostly for the publicly listed ones).

Table 4-5 shows the average size, number of sectors, and concentration indexes (normalized and not) for the 20 most recurring SSOs in our dataset. The American Society for Testing and Materials (ASTM) appears as the least competitive of this set of SSOs due to the larger variety of sectors represented by members. Instead, INTERNET2 appears as the most competitive SSO, since its scope (the development of internet standards for education) makes research institutions (two-digit NACE code 85) almost half of the members. To conduct a robustness check, we use the number of sectors associated to firms in each SSO as an alternative proxy of internal competition. The table also includes the correlation of the competition measures with size. We take these correlations into account when studying competition and size in the same model (HP3 and HP4 together).

4.3.6 Control variables

The use of fixed effects models allows us to inherently control for aspects varying across our unit of observations (namely firms) and that are constant over time. For this reason, our analysis implicitly controls for sectors and country effects among others. Besides these effects, we control for time-varying observable factors at firm level, such as *firm size* (expressed as the natural logarithm of the number of employees), and for dummy years that can capture common shocks, ensuring that time-specific factors do not bias the estimated relationships.

Name[9]	Avg. size	# Two-digit sectors	# Four-digit sectors	Avg. two-digit concentration		Avg. four-digit concentration	
				Real	Normalized	Real	Normalized
ASTM	794	66	217	0.03	2%	0.01	1%
ATIS	172	26	43	0.21	17%	0.17	15%
Bluetooth SIG	5,161	73	344	0.06	4%	0.02	1%
CTA	1,593	64	215	0.07	5%	0.02	2%
CTIA	219	27	50	0.11	7%	0.08	6%
ETSI	398	39	90	0.10	6%	0.06	2%
HIMSS	313	36	68	0.08	6%	0.06	4%
IDEAlliance	262	38	76	0.06	4%	0.04	2%
INTERNET2	264	34	54	0.26	24%	0.24	23%
JEDEC	239	25	46	0.36	33%	0.17	15%
OASIS	208	32	63	0.08	5%	0.05	3%
PCI SIG	664	43	104	0.21	19%	0.06	5%
TIA	436	46	100	0.08	6%	0.04	3%
TM Forum	521	41	86	0.09	7%	0.05	4%
TOG	188	34	62	0.07	4%	0.04	2%
UPnP	606	47	133	0.09	7%	0.03	2%
VESA	144	21	39	0.27	24%	0.11	9%
W3C	271	37	74	0.07	4%	0.04	2%
Wi-Fi Alliance	182	24	46	0.31	28%	0.11	5%
WiMax Forum	174	24	45	0.18	8%	0.11	4%
Correlation with size		52%	80%	-12%	-4%	-12%	-4%

Table 4-5 – Data on the average size and competition of the 20 most recurring SSOs in our dataset

[9] Full names are in Appendix 3

4.4 Empirical results

4.4.1 Firms' economic performance from participating in technical standardization (Re. HP1)

Our first hypothesis poses that firms that are part of at least one SSO see their economic performance increasing. Since economic benefits take time to materialize, we also assume a lag of up to three years between SSO participation and firm productivity. We test HP1 for all firms in our dataset (Table 4-6), and for the subset of FSPs (Table 4-7). Altogether, the two tables show a highly significant positive correlation between firms' participation and productivity. Thus, we accept the first hypothesis.

Firms participating in SSOs experience a productivity increase of 9.5% the same year of participation, 6.6% in the following year, and 2.8% two years later. No significant effect is observed beyond the third year. The diminishing impact of firm participation in SSOs may be attributed to two factors: self-selection bias - where firms choose to participate based on the expectation of higher future revenues - and diminishing returns from knowledge acquisition during the standardization process. In Table 4-7, we focus exclusively on FSPs. Interestingly, the positive correlation persists, indicating that SSO participation is associated with improved economic performance even for focused firms that may have limited experience in developing standards.

The correlation coefficients stem from the comparison with the same firms' productivity in the years they do not participate in any SSO (i.e., fixed effects model). This allows us to say that all external factors that are not tied to the firms' themselves are automatically excluded from being potential confounding factors. We also control for the size of the firms including the number of employees in our models. Extant literature links firms that are large, with high export activities and high R&D expenses with higher likelihood of participation in technical standardization (Blind & Mangelsdorf, 2013; Wakke et al., 2015) and their participation is driven either by competitive pressures or a fit with the SSO's technology profile (Zhang et al., 2020). This means that – to our knowledge – evidence of *more productive* firms likely to participate in technical standardization is only anecdotal.

	Dependent variable: firms' productivity (revenues/n. employees)			
	(1)	(2)	(3)	(4)
SSO Participation (t)	0.095*** (0.013)			
SSO Participation (t-1)		0.066*** (0.013)		
SSO Participation (t-2)			0.028** (0.014)	
SSO Participation (t-3)				-0.006 (0.014)
N. Employees (ln)	-0.331*** (0.025)	-0.330*** (0.025)	-0.337*** (0.025)	-0.355*** (0.025)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	44267	43695	42900	41804
R^2 within	0.088	0.087	0.089	0.096

Table 4-6 – Panel FEs estimation. Effect of SSO participation on firm productivity, including one, two, and three-year lags

***, **, *** represent two-tailed statistical significance at 10%, 5%, and 1% respectively.**

	Dependent variable: firms' productivity (revenues/n. employees)			
	(1)	(2)	(3)	(4)
SSO Participation (t)	0.091*** (0.015)			
SSO Participation (t-1)		0.068*** (0.017)		
SSO Participation (t-2)			0.028 (0.019)	
SSO Participation (t-3)				-0.015 (0.019)
N. Employees (ln)	-0.379*** (0.032)	-0.377*** (0.032)	-0.381*** (0.033)	-0.394*** (0.033)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	28289	27981	27546	26916
R^2 within	0.108	0.105	0.105	0.11

Table 4-7 – Panel FEs estimation. Effect of SSO participation on FSPs' productivity, including one, two, and three-year lags

***, **, *** represent two-tailed statistical significance at 10%, 5%, and 1% respectively.**

However, one may still infer that a healthy income statement may encourage firms to participate in SSOs because they simply can afford it. For this reason, we try to address potential reverse causality by introducing lags. Results show a significant increase of 9.5% of firms' productivity the year they are listed as participants in an

SSO (including the years after the entrance if the firm does not leave the SSO). The same regression introducing one and two-year lags from the firms' entrance in the SSO show significant increases, but with decreasing coefficients (6.6% and 2.8%). This suggests that engaging in standardization has a positive effect on firms that decreases over the next two years. The positive effects of participation seem to disappear after the third year as results become insignificant. The analysis on FSPs shows a slightly weaker increase of 9.1% for the same year and stronger (6.8%) the following year compared to the coefficients for all firms.

4.4.2 Firms' economic performance from participating in multiple SSOs (Re. HP2)

In the previous analysis, we econometrically examined the relationship between firm productivity and SSO participation, where participation was defined as involvement in at least one SSO. In other words, the analysis did not consider the number of SSOs in which a firm participates. In this section, we aim to explore whether firms experience productivity improvements as they participate in multiple SSOs. We thus replace the dummy *SSO* with a variable (*SSO_n*) which reflects the number of SSOs in which a firm participates each year. We then included its quadratic term to control for non-linear effects (See Equation 2).

Figure 4-1 shows the marginal effect of the number of SSOs in which a firm participates on firm's productivity. Results are highly significant for firms participating in up to four SSOs the same year. Firms participating in more than four SSOs do not experience any improvement in their productivity.

From the fifth entry into an SSO onwards, results remain positive but no longer significant considering 90% confidence intervals. As the figure shows, firms' see a minimal increase in productivity when they participate in two SSOs, but they gradually turn into decreasing returns when they participate in three and four SSOs. We therefore reject HP2, since there is no supporting evidence of an increase in a firm's productivity the more SSOs list that firm as a member. This evidence shows that participating in three or more SSOs, on average, requires higher participation costs (e.g., staff, membership fees) than the revenues it generates.

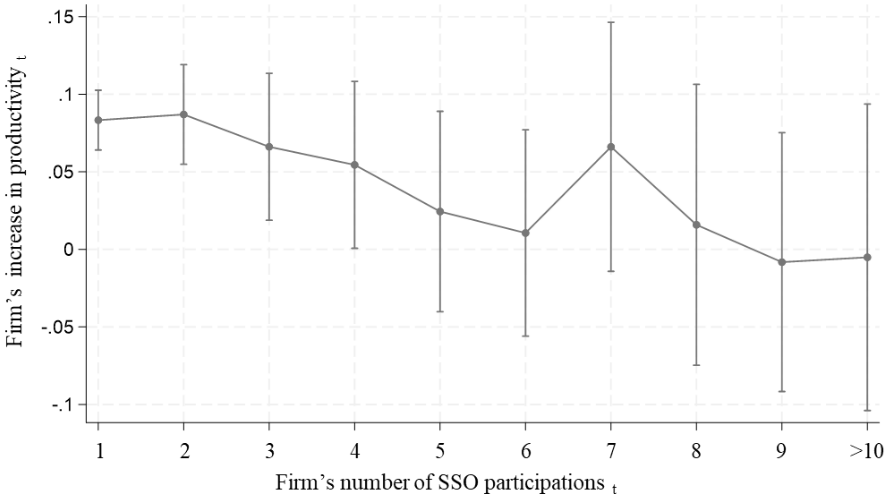


Figure 4-1 – Effects of the number of SSO participations on firms' productivity (90% confidence intervals)

There are some plausible explanations to these decreasing returns. A general discussion can stem from the law of diminishing returns, whose first applications trace back to classical economists on the limited increase of land productivity possibly achievable using the same input factor. In the context of standardization, a similar conclusion can be inferred. Indeed, firms cannot expect to endlessly improve their productivity the more resources they invest in developing standards, whether it is to participate in many SSOs or invest more in technical expertise through, for example, the production of technical reports or the recognition of their patents as essential to the standard. Besides the increased membership costs, it is likely that the participation in multiple SSOs requires the proactivity of firms to obtain economic benefits, for example by hiring more qualified experts. It is therefore difficult for a single firm to sit in multiple SSOs the same year and influence the process in its own favor without significantly impacting their income statement. This lack of proactivity on a large scale may even lead to lower chances that a standard is reached, leading to a generic social loss in a product market (see Kamps et al., 2017).

4.4.3 Effects of competition among SSO members on FSPs' economic performance (Re. HP3)

Table 4-8 shows the results of our analysis including the interaction terms of sectors' concentration, both normalized and not (main analysis), and the number of sectors (robustness check), interacted with the dummy *SSO*. We test for simultaneity relationship and one-year lag relationship, for a total of six models. In the models, we only use specific (four-digit) sectors, since two-digit sectors – probably for being too high level and thus unable to properly proxy SSO competition – would not give significant results. Our six models all lead to the same conclusion: a higher concentration of sectors among the members of an SSO improves the economic benefits FSPs derive from participation, both in the same year of participation and in the following year. We therefore reject HP3. The table shows positive coefficients for the measures of sectors' concentration, namely that a less equal (=more concentrated) distribution of sectors results in more productive FSPs. This translates to a favorable situation for member firms when the SSO has less sectors represented, increasing the likelihood of seeing competitors sitting at the same table when developing standards. This is confirmed by our robustness checks on the number of sectors, which negatively correlate to our dependent variable with high significance.

These results can be explained in different ways. First, rivals in the product market cooperating within SSOs could avoid costly standard battles subsequent to the costly process of developing standards. This may explain the higher coefficients one year after participation. Since our measure of competition estimates the homogeneity of sectors within the SSOs, a higher heterogeneity (=lower competition) may imply higher coordination costs as stakeholders representing different markets may have different interests. Next, most of these SSOs typically develop what are normally referred to as compatibility standards, or standards designed to make products or services interoperable. These standards may prompt the participation of FSPs with high levels of sector-specific expertise to collaborate on the details of single specifications, eventually making the end products more interoperable and thus more marketable.

The same may not apply to, for example, safety standards, whose development may require the presence of a wide array of industry actors representing broader interests than the niche sectorial ones. This is confirmed by ASTM resulting the least competitive within our sample of most recurring SSOs, intuitively due to its tendency to develop safety standards for e.g., materials. Additionally, while firms may have a common interest in higher safety to make the product acceptable in the market and strengthen its image, adhering to safety standards may result in higher transaction costs and a slower marketing of products than adopting compatibility standards. Lastly, our findings are consistent with the study by Bushee et al. (2023) that use the same data from the SCDB. Through network analysis, they show that collaboration with direct competitors improves the firms' information availability and ability to forecast their sales.

	Dependent variable: firms' productivity (revenues/n. employees)					
	(1)	(2)	(3)	(4)	(5)	(6)
SSO Participation (t)	0.126***	0.069***	0.071***			
	(0.021)	(0.019)	(0.017)			
SSO Participation (t-1)				0.105***	0.038*	0.042**
				(0.023)	(0.022)	(0.020)
Number of sectors x SSO Participation (t)	-0.000*** (0.000)					
Concentration x SSO Participation (t)		0.510* (0.279)				
Concentration (normalized) x SSO Participation (t)			0.739** (0.358)			
Number of sectors x SSO Participation (t-1)				-0.000*** (0.000)		
Concentration x SSO Participation (t-1)					0.728** (0.335)	
Concentration (normalized) x SSO Participation (t-1)						0.998** (0.457)
N. Employees (ln)	-0.380***	-0.379***	-0.379***	-0.378***	-0.378***	-0.378***
	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	31245	31245	31245	30938	30938	30938
R^2 within	0.167	0.167	0.167	0.165	0.164	0.164

Table 4-8 – Panel FEs estimation. Moderating effects of different measures of SSO internal competition on FSPs' productivity, including one-year lags

***, **, *** represent two-tailed statistical significance at 10%, 5%, and 1% respectively.**

4.4.4 Effects of SSO's size on FSPs' economic performance (Re. HP4)

Table 4-9 includes the results for the moderating role of SSOs' size on the productivity increase of SSO participants (HP4). We observe a small but highly significant negative effect of SSO's size, specifically of -0.001% for every additional SSO member, on the productivity of FSPs participating in SSOs. This provides evidence that participating in smaller SSOs results in higher productivity for FSPs. We thus reject HP4a and accept HP4b.

As with HP3, these results open several avenues for interpretation. The first interpretation is that larger SSOs, although propaedeutic to build installed base and better promote the standards, may lead to a concentration of influence among large standardization players, making FSPs uninfluential to the decision-making process, as well as to a minimal division of rents among the SSO members. This may particularly occur in large and tiered SSOs with low entry barriers for low-tier regular members but high barriers for sponsor members.

	Dependent variable: firms' productivity (revenues/n. employees)	
	(1)	(2)
SSO Participation (t)	0.113***	
	(0.017)	
SSO Participation (t-1)		0.089***
		(0.019)
Size x SSO Participation (t)	-0.000***	
	(0.000)	
Size x SSO Participation (t-1)		-0.000***
		(0.000)
N. Employees (ln)	-0.380***	-0.378***
	(0.032)	(0.032)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	31245	30938
R^2 within	0.167	0.165

Table 4-9 – Panel FEs estimation. Moderating effects of the size of the SSO on FSPs' productivity, including one-year lags

***, **, *** represent two-tailed statistical significance at 10%, 5%, and 1% respectively.**

Another interpretation is the contrast with the common theorization of standards' diffusion driven by positive network effects. Although the traditional view of e.g., Katz & Shapiro (1994) – higher value derived from each user the more users adopt the standard – was further developed into the likes of decreasing, unequal, or indirect effects (see e.g., Clements, 2004; Weitzel et al., 2006), no literature exists, to our knowledge, on the presence of negative network effects to standards' adoption. Our case does not deal specifically with the adoption of standards but with their development. However, many, if not most, SSO participants are eventually users of the same standard they contributed to develop. In this regard, it is important to distinguish the different role of the FSPs in the SSO, whether they participate as mere adopters (which could likely be the case in the largest SSOs in our sample, i.e., Bluetooth and the Consumer Electronics Association) or are also producers and suppliers of technical knowledge to the development process.

Lastly, this finding is aligned with the theories of interorganizational networks and platform ecosystems described in our review of the literature about small-world and local network effects (e.g., Baum et al., 2003; Evans & Schmalensee, 2010; Farronato et al., 2023; Iansiti, 2021). As in similar contexts of collaboration, SSOs may thus favor appropriation of value among their members when the environment in which they operate is smaller, characterized by a better circulation of information and exchange of knowledge, and able to fulfill the interests of a larger share of members.

4.4.5 Size and competition as concurrent factors

To conclude our analysis, we test the concurrence of size and internal competition as predictors of FSPs' productivity when engaging in technical standardization. Our results are shown in Table 4-10 and confirm – specifically in the sixth model – that larger SSOs negatively affect FSPs' productivity, while a higher concentration of sectors positively affects it. The coefficients become significant when the effects are measured on the FSPs' productivity one year after they become members of the SSO, when internal competition is measured through the normalized concentration of sectors. This means that size and internal competition – when analyzed together – are able to predict FSPs' productivity the year after their entrance in one SSO and can explain how FSPs appropriate value from participating in the development of standards. Despite the non-significant results in the same year of the entrance, we are interested in the effect the year after the FSP enters the SSO to reduce the endogeneity present in our regression.

In computing this regression, we accounted for the risk of overfitting multiple predictors to make our model fit for the analysis and obtain statistical significance. However, the very large number of observations and its strong significance levels in a fixed-effect scenario hints at the potential replicability of these results with other different data. It is also worth noting that SSO size and sectors concentration, in our dataset, are not correlated (i.e., Pearson's coefficient of -4%, see Table 4-5), showing no signs of multicollinearity in our model. For these reasons, the sixth model in Table 4-10 not only confirms our claims that FSPs may benefit more from participating in smaller SSOs with a higher concentration of sectors, but also that these two factors are subject to a trade-off.

	Dependent variable: firms' productivity (revenues/n. employees)					
	(1)	(2)	(3)	(4)	(5)	(6)
SSO Participation (t)	0.117***	0.100***	0.097***			
	(0.024)	(0.022)	(0.020)			
SSO Participation (t-1)				0.100***	0.066***	0.067***
				(0.025)	(0.025)	(0.023)
Size x SSO Participation (t)	-0.000	-0.000***	-0.000***			
	(0.000)	(0.000)	(0.000)			
Size x SSO Participation (t-1)				-0.000	-0.000**	-0.000**
				(0.000)	(0.000)	(0.000)
Number of sectors x SSO Participation (t)	-0.000 (0.000)					
Concentration x SSO Participation (t)		0.265 (0.284)				
Concentration (normalized) x SSO Participation (t)			0.530 (0.357)			
Number of sectors x SSO Participation (t-1)				-0.000 (0.000)		
Concentration x SSO Participation (t-1)					0.474 (0.338)	
Concentration (normalized) x SSO Participation (t-1)						0.760* (0.457)
N. Employees (ln)	-0.380***	-0.380***	-0.380***	-0.378***	-0.378***	-0.378***
	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	31245	31245	31245	30938	30938	30938
R^2 within	0.167	0.168	0.168	0.165	0.165	0.165

Table 4-10 – Panel FEs estimation. Moderating effects of the size of the SSO and the internal competition among SSO members on FSPs' productivity, including one-year lags

***, **, *** represent two-tailed statistical significance at 10%, 5%, and 1% respectively.**

4.5 Concluding remarks

This article explored the relationship between firms' participation in technical SSOs and firms' economic performance, including the moderating effects of competition between member firms and the size of the SSO. Our large-scale analysis of technical standardization across two decades has produced statistically significant results, some of which are expected, others are counterintuitive. Starting from expected results, participating in technical standardization could lead firms to a higher productivity and thus to a better economic performance. These returns last two years on average, with decreasing rates, after which they cannot be reliably measured. Secondly, we find that the number of SSOs a firm can partake each year does not linearly determine these positive returns but is rather linked to decreasing returns when the firm participates in three or more SSOs. Lastly, through the third and fourth hypotheses we find a positive influence on the performance of FSPs of (1) higher competition among SSO members, and (2) fewer SSO members. After running a model with both size and competition as interaction terms, we also find that together they can predict FSPs' performance after one year with significance.

Our results should not lead to the conclusion that participation in standardization is the silver bullet for all firms' financial stability. First, the real creation of value (either from establishing relationships or accessing information) takes place in technical committees and working groups, where firms represented by experts really collaborate on the subject matters of the standards. The lack of committee- or group-level data prevents us from generalizing these findings to all firms participating in technical standardization. However, the prevalence of "informal" SSOs (see Table 11) mitigates this limitation. Second, these returns are clearly not boundless, as they only occur with statistical significance for two years (one in the case of FSPs) and for maximum four SSO participations each year. Also, as discussed in the theoretical background of this paper, the appropriation of value from standardization depends on the ability of the firm to leverage the networking opportunities and access to technical knowledge to make it worth the cost of participation. Presumably, a firm has higher chances to appropriate these benefits if the participation in an SSO is justified by its alignment with the firm technology portfolio or its product market strategy, as these factors are shown to incentivize firms' intention to enter an SSO (Blind, 2006; Zhang et al., 2020).

The positive effects of highly competitive and small SSOs on FSPs' performance have multiple interpretations. From a firms' strategy standpoint, our results show that even for focused SSO actors it is important to collaborate with their competitors. This primarily happens because some FSPs may have very niche and specialized knowledge that – despite being rivals – can complement the knowledge of other specialized FSPs and develop standards that are more advanced technologically. Secondly, firms can get immediate information on their competitors that they can leverage for their own interests (see Waguespack & Fleming, 2009). This process may more likely occur when the SSO is smaller, and the information flow (through, for example, technical reports or informal meetings) is quicker.

Lastly, in our literature review we discuss how economic theory identifies some collective gains for firms when market competition gets more intense. Our results suggest that these collective gains overcome the hurdles that individual firms face when more competitors participate in the same SSO.

The trade-off relationship between (smaller) size and (higher) competition, being two concurrent factors for the productivity improvement of an FSP, suggests that the expansion of an SSO should be targeted to relevant stakeholders, belonging to those few sectors that are aligned with the SSO technology portfolio. In this way, a "healthy" internal competition is fostered, without encouraging detrimental rivalries nor compromising the focus of the standards' developing process. It is also important to mention that these findings relate to the dynamics of the entire SSO. However, the single committees or working groups may be where firms take most of their decisions related to the technical specifications contained in the standards. In this regard, the distinction between (1) committees and working group and (2) standards for compatibility and quality may shed more light on our findings. Most of the SSOs in the sample produce compatibility standards, and these are normally divided in working groups that are interdependent and part of a unique architecture (e.g., the Bluetooth technology). In these cases, the dynamics at the SSO level may be more important than the single working groups. Contrarily, when SSO's committees are associated to separated industries, or when the standards developed provide quality or safety measures (e.g., ASTM), the single committee may have a stronger influence than the whole SSO on the market performance of member firms.

4.5.1 Theoretical contributions

Our findings have theoretical implications for two streams of literature. The first is the field of technical standardization, to which we provide new large-scale evidence of economic benefits at the firm level. Many case-studies in the standardization literature investigate firms' attendance to individual SSOs, such as 3GPP and IETF, and its consequences. As the field seeks more generalizable results, our study on a broader set of SSOs gives a more nuanced understanding on the firm-level benefits of standardization and on the optimal conditions for firms to decide in which SSO to participate and for how long. For example, we provide more clarity to the debate around the size of the SSO and demonstrate a novel relationship between size and competition that contributes to the fervent research stream on the internal dynamics to technical SSOs (e.g., Miller & Toh, 2020; Ranganathan et al., 2018; Yao et al., 2024).

The second stream we contribute to is the broader field of strategic management, both related to private firms and interorganizational networks such as SSOs. We find how competition is not just an elitist phenomenon rewarding dominant players and their opportunistic behavior but rather a mechanism of coordination that favors the exchange of sector-specific technical expertise also among niche players. As said, more heterogeneity in the sectors present in any interfirm organization (including SSOs) may imply higher coordination costs, since different sectors may represent conflicting interests.

Additionally, central to both fields is the debate around the presence of vertical compatibility (i.e., between complementary products) and horizontal compatibility (i.e., between rival products). These phenomena can notably influence the network effects between firms and thus their returns from participation and the effects of competition and size of the SSO/ecosystem (Besen & Farrell, 1994; Chen & Forman, 2006; Matutes & Regibeau, 1988). In the presence of vertical compatibility, the network effects occurring between the producers of two different goods (i.e., indirect network effects) are positive, whereas horizontal compatibility would generate positive effects between the producers of two rival goods (i.e., direct network effects). This means that the function of the standard in terms of compatibility and the presence of switching costs may suggest whether the SSO would be more beneficial to members when it involves vertically compatible producers (i.e., complementors) or producers of horizontally compatible goods (i.e., competitors). We thus contribute to the growing literature that discusses the role of complementors in ecosystems of firms, including SSOs (e.g., Baron & Pohlmann, 2013; Miller & Toh, 2020; Ranganathan et al., 2018; Wen et al., 2022) and the different manifestations of network effects (e.g., Agarwal et al., 2023; Ploog & Rietveld, 2023).

4.5.2 Limitations

We acknowledge some limitations in our analysis. First, as discussed earlier, our dataset does not allow to examine dynamics at the level of technical committees or working groups, but only at the SSO level. While this is beneficial to study multiple SSOs at the same time, it does not warrant the same level of detail that a study on either of these two dimensions would do. However, the prevalence of informal consortia mitigates this limitation. This kind of SSO normally works on the development of standards for a single technological architecture. For this reason, they may either operate without any lower-level division, or may operate through working groups whose work and dynamics are interdependent of each other. This limitation is also related to the type of standards at stake, since establishing interoperability specifications vis-à-vis quality and safety levels may have different repercussions on the firms' economic appropriation from the SSO. Similarly, our analysis is limited to the participation stage of technical standardization, while a more complete overview of standardization benefits would need to investigate firms' economic performance after a standard is implemented in firms' products and services.

Second, the causal associations deriving from this analysis should be further discussed. We use lags, fixed effects and other controls as an attempt to identify a causal effect. We are aware of the limitation that lagged explanatory variables have on such an identification (Bellemare et al., 2015). Besides controlling for all firm- and non-firm-specific effects, the effects described in our regressions are potentially causal because our supposed main source of endogeneity, namely the reverse causality of firm productivity on SSO participation, is not cited in empirical literature. We also identify a potential self-selection bias since firms that decide to participate in any SSO probably do so because they are prepared to appropriate value from this decision. Our fixed effects model, however, measures the variations in productivity for the whole duration of the participation, which is of four years on average. This mitigates this bias considering that it probably hits firms in our sample only for the year they decide to join.

Third, as stated in the methodology and in Footnote 5, our data source for participation in SSOs included some missing intervals of SSO-year observations. We compensated by assuming the same list of members during the missing intervals when these were shorter than four years. Fourth, our dataset mainly includes SSOs in the ICT sector, therefore – despite the importance of ICT for standardization – we are not able to assess whether our findings apply to the many other fields where standardization occur. The same applies to the types of standards developed in this sector, most of which facilitate compatibility and interoperability. As discussed earlier, we cannot generalize our findings to other classes of standards, such as safety or minimum quality.

Lastly, we highlight some setbacks in the operationalization of variables. In HP3 and HP4, FSPs do not necessarily represent small firms. We use literature on small firms (e.g., SMEs and startups) to formulate these hypotheses since there is no literature available on firms with sporadic participation in SSOs. Therefore, our findings related to these two hypotheses should not be considered for small firms. In HP2, our measure of firms' resource investment in standardization represents one of many other components of such an investment, most of which we mention in the review of the related literature. As said, participation in multiple SSOs does not imply that the firm plays an influential role in those SSOs. For this reason, our interpretation of results for HP2 may be complemented with the analysis of other factors measuring firms' investment.

4.5.3 Next steps

The main points we address for a future research agenda is to tackle the issues raised in the limitation. Follow-on studies should improve the identification of a causal effect as some endogeneity may characterize our claims due to unobserved factors exogenous to our regression and the potential presence of omitted variables. The identification and inclusion of an instrumental variable could help fix this endogeneity. One example of instrumental variable is the geographical proximity of firms to the SSOs' headquarters, which supposedly correlates to the inclination of firms to participate but does not correlate to the error term of our regression. Concerning the limited generalizability of our findings, future research should aim at conducting similar analyses in other sectors and with other classes of standards besides compatibility. Similarly, a precise distinction between focused and small players could shed more light on the different classes of stakeholders and contribute to the growing literature on SMEs' participation and stakeholders' inclusivity in standardization.

It could then be worth deepening this study with an investigation on how these value rents emerge depending on the firm's type of membership and the SSO's policies. The main limitation related to the lack of committee-level and working-group-level data suggest that a deeper investigation into these sub-structures may explain our findings with a higher level of detail. As pointed out in our literature review, firms with a more central position in the decision-making process of technical committees and working groups may arguably be more capable of appropriating value from the standards and the related products. However, these central positions come at the expense of producing highly technical contributions and paying expert personnel. Thus, it remains unclear whether SSOs hierarchical tiers – that provide more rights in exchange of higher membership fees – are reflected in the distribution of value among member firms. Some of these organizations – for example, The Bluetooth Special Interest Group and the Consumer Electronics Association, the two largest

SSOs in our dataset – have a large membership of "passive" adopters that may overestimate or underestimate our relationship coefficients. A next step of this research should shed light on this aspect and understand if being in higher tiered positions really leads to a better economic performance due to the ability to steer the standardization process towards a firm's interest. The analysis of SSO tiers can also elaborate on the cited debate around the right balance of competitors and complementors in SSOs and more generally in innovation ecosystems.

Lastly, as we discuss several steps where firms may create and appropriate value due to engagement of standardization, we suggest to further examine the steps of this process besides the one at stake in this article. We investigate the benefits from participation, but these benefits may occur also after the announcement or any other manifestation of the intentions of a firm to participate. And besides participations, firms may obtain further benefits from using the standard (e.g., by lowering productions costs or increasing the sales of products where the standard is implemented).

5. Flexible standardization for place-based and time-based adaptation: the challenge of Sea-Level Rise[1]

Standardization is increasingly used to address societal challenges, but scholars question their ability to address climate adaptation by considering standards as “rigid” tools. Taking sea-level rise as our empirical setting, we explore how place-based and time-based standards can address climate adaptation challenges. A review of adaptation measures and standards reveals a gap between research and standardization practice, that we explore through experts’ deliberation. We conceptualize a flexible standardization process through two relevant dimensions: (1) a scalar dimension, considering place-based specificities and global cooperation and (2) an adaptive dimension, considering evolving sociocultural conditions and technological maturity.

5.1 Introduction

Societal challenges, such as sustainable food production and equal access to education, feature problems that vary across geographies and over time. These two dimensions gained scholarly attention in formulating solutions to these challenges. The geographical dimension is inherent to disciplines such as economic geography and sociology, where the expression *place-based* is used to address spatial disparities, for example in terms of diverging cultures and territorial morphologies (Cutter et al., 2008; Gaubert et al., 2024; Stedman, 2002). The temporal dimension characterizes those disciplines recognized as "evolutionary", such as biology and economics, aiming at studying processes of change beyond static analyses (Geels, 2002; Hoffmann & Sgró, 2011). The combination of these two dimensions accounts for diverging and evolving local contexts, and led to the characterization of economic geography as an evolutionary science (Boschma & Frenken, 2006; Iammarino, 2005).

[1] This chapter is under review as: “Grillo, F., Besana, F., Wiarda, M., de Vries, H. J., Doorn, N., van de Kaa, G. – Flexible standardization for place-based and time-based adaptation: the challenge of Sea-Level Rise”.

Standardization is being increasingly studied as a multi-stakeholder approach to address societal challenges (e.g., Liguori et al., 2022; Uzunca et al., 2018; van de Kaa et al., 2019), but literature that relates standards to geographic and time differences remains scarce. Standards are mistakenly seen as "rigid" tools, unable to vary over time and adapt to local contexts (Valero-Gil et al., 2023; Wijen, 2014). Many definitions of standards contain elements that seem to confirm this perspective. Standards are sets of specifications and guidelines that should be used "extensively", "with multiple clients or customers distributed over time and space" (Thompson et al., 1967, 16), "for common and repeated use" (ISO/IEC, 2004, 4) and "over time by a substantial number of parties" (de Vries, 1997, 161; Grillo et al., 2024, 3). This alleged lack of adaptability to space and time led to the conception of standardization as being almost antithetical to flexibility (Timmermans & Epstein, 2010) and innovation (Farrell & Saloner, 1985), and thus unable to address place-based and time-based societal challenges.

In this article, however, we explore how a flexible approach to standardization can address climate adaptation, a type of societal challenge that is particularly dependent on place and time. Questioning the conventional perception of standardization as a rigid phenomenon, we shed light on its ability to address place-based and time-based specificities typical of adaptation challenges. Broad expertise is needed for climate adaptation, spanning from environmental to political and technical. Standardization, leveraging different subject matter experts across technical committees (Balzarova & Castka, 2012; de Vries, 1999; Teubner et al., 2021) caters well to this breadth. Standard bodies see the pace of climate change as a challenge for standardization processes (CEN and CENELEC, 2021; IEEE Standards Association, 2023; UNECE, 2018). For this reason, they urge other standard setters and stakeholders to employ a flexible approach for adaptation, focusing on risk-based assessment and preliminary life-cycle assessment (CEN and CENELEC, 2016; ISO, 2022).

The concept of flexible standards may help address these difficulties, but their spatial and temporal dimensions have been studied in scattered scholarly efforts (e.g., Braa et al., 2007; van den Ende et al., 2012), and literature misses a comprehensive understanding of these two dimensions in standardization processes. Economic geographers have already combined place-based and time-based concepts, for example into the dynamic proximity-innovation framework (Balland et al., 2015) and the regional path dependence theory (Martin & Sunley, 2006). However, these theories do not fully solve the practical challenges of implementing global policies in local contexts. While standards are marginally discussed as instruments for adaptive policies (Haasnoot et al., 2013), introducing best practices in the process of standards development can make standards more suitable for this type of policy. In addition to these gaps, we elaborate on two other sources of confusion: should everything be standardized? And through which types of standards? On top of the preliminary distinctions between e.g., compatibility vs quality (Tassey, 2000) and process vs product standards (Nadvi & Wältring, 2004), we better investigate the function of different types of standards (de Vries, 1998).

We select sea-level rise (SLR) as our empirical setting of an adaptation challenge. The uncertainty linked to SLR projections, in terms of hazards and exposure (both socioeconomical and environmental) in relation to different geographical regions, makes the coordination of stakeholders in this case a compelling but challenging setting. We employ a mixed-method approach: firstly, we conduct a systematic review of the literature on SLR adaptation measures and make an inventory of corresponding existing standards. This first step maps the state of the art of our setting and empirically shows a "standardization gap" between what is standardized and what SLR adaptation measures are available. Secondly, we engaged a pool of experts to conduct semi-structured interviews and a Q-method survey to explore the implementation of SLR adaptation measures, their location-specific needs, and the potential pathways for standards development.

Our findings indicate which lessons can be learned for the overarching discourse on the place-based and time-based flexibility of standardization. We contextualize the two dimensions into climate adaptation scenarios, and discuss how standard-setting organizations (SSOs) and other stakeholders can consider them in practice during the process of standards development. For this purpose, we build a conceptual matrix that includes the main factors needed to map and prioritize standards for adaptation measures. Additionally, based on experts' consensus, we discuss the case-specific factors that are important for SSOs and other stakeholders approaching SLR adaptation.

5.2 Theory

5.2.1 Place-based adaptation

Place-based approaches emerged as a crucial aspect of economic geography. They consider the unique characteristics of specific locations, such as the local know-how, morphology, and resources (Cutter et al., 2008), and contrast with one-size-fits-all policies by promoting customized development paths (Barca et al., 2012; Bathelt et al., 2024). The importance of these approaches for climate adaptation gave rise to research about *place-based adaptation*, which stems from other place-based approaches for not being temporally constrained (O'Neill & Graham, 2016). Furthermore, place-based adaptation embraces adjacent (and more popular) terms such as community-based (Reid & Huq, 2007) and ecosystem-based (Wamsler et al., 2014) adaptation, by including multiple factors tied to a specific location, such as the social, natural, and economic ones. This comprehensive view reduces the risk of *maladaptation* (IPCC, 2023).

One potential risk of maladaptation is the negative path-dependency derived when lower-income economies adopt new technologies, resulting in the so-called *regional* path-dependency, especially in countries from the Global South (Corradini & Vanino, 2022; Martin & Sunley, 2006). However, as construed by Martin & Sunley (2006), the shocks received by external/global policies can also incentivize regions to catch up and innovate in the form of a positive lock-in (see also Iammarino, 2005). Similarly, place-based adaptation is seen to encourage the development of niche specialized industries, fostering economic growth and stability (Isaksen, 2015). We highlight two important debates characterizing this literature. The first is the technical versus nature-based adaptation (Butts & Adams, 2020; Conte et al., 2021) where nature-based solutions are generally considered more locally adaptable than grey infrastructure (Frantzeskaki, 2019). The second relates to the problematic development of place-based policies for low-income (Glaeser & Gottlieb, 2008; González-Pampillón et al., 2019) and low-density (Hu et al., 2021; Rodríguez-Pose, 2018) communities.

5.2.2 Place-flexible standards

Quantification and uniform reference indicators are fundamental to economic geography (see e.g., Frazier et al., 2013; Wang & Wei, 2021), but standards' suitability to uneven geographies is still debated (e.g., Wiig & Silver, 2019). Literature on the local dimension of standards is abundant and long-standing, albeit scattered. Early standardization literature emphasizes the need for standardization at all geographical levels, focusing on their institutional governance. Specifically, Verman (1973) first discussed the national, regional, and international levels of standardization, emphasizing the importance of coordination between them. This discourse was brought forward in academia (de Vries, 1999; Nadvi, 2008) as well as institutionally (European Council, 1985; ISO/IEC, 2005) with – for example – the processes of regional and national adoption of international standards and the harmonization of

European standards. Nadvi's (2008) "dynamic" perspective suggested that this coordination is not always linear. Some countries tend to harmonize rule-setting with the development of common standards, whereas others diverge.

The challenging coordination between different levels of standard bodies is connected to the second relevant discourse on the geography of standards, which is their fit to different local specificities. Differences relate both to the development and the implementation of these standards. Literature on standards' development emphasizes the importance of global representation and participation for a successful standard (Brandi, 2017; Fransen & Kolk, 2007). As to standards' implementation, literature discusses the hurdles of low-income countries to adopt international standards, leading them to partial adoption (i.e. decoupling, see Mercado et al., 2018; Wijen, 2014), or even exclusion (Johnson, 2019). The lack of capacity-building processes (Boström et al., 2015; Lal et al., 2012) and different endowments of resources (Acemoglu et al., 2012; Alizada, 2018) also contribute to undermine standards' large-scale diffusion in the Global South. The healthcare literature provides empirical cases on how the standards' flexibility – both in terms of development and implementation – can help solving geographical disparities, using the case of data reporting standards (Arora et al., 2023; Braa et al., 2007; Morris & Miller, 2002).

5.2.3 Time-flexible standards

Another use of the terms "flexible" and "dynamic" standards refers to their temporal dimension. This dimension is rooted in evolutionary economics (e.g., Arthur, 1989; Liebowitz & Margolis, 1995; Shapiro & Varian, 1999) where concepts like path-dependence and lock-in led to the consideration of standards as "rigid" tools (Timmermans & Epstein, 2010) that reduce market variety (Verman, 1973). Theories on technological lifecycles emphasized that developing standards for mature technologies is important to avoid blocking further incremental innovation (Foster, 1986; Jantsch, 1967; Utterback & Abernathy, 1975). The standardization literature has shown how flexibility can be achieved through (1) basic, performance, and measurement standards and (2) a flexible standard development process. Basic standards are those preliminary guidelines that do not directly define specifications and parameters, but rather provide common terminology and reference architectures (de Vries, 1998). Together with performance criteria and test methods, they represent the starting point to create other standards in a given sector and raise awareness on their importance (de Vries, 1998; Ho & O'Sullivan, 2017). Literature on adaptive policymaking also emphasizes the need of decision-making tools and regular monitoring procedures in the early stage of uncertain societal issues (Adger, 2003; Haasnoot et al., 2013; Swanson et al., 2010).

Standards' development processes can also be flexible over time (Egyedi & Blind, 2008). Instruments such as life-cycle assessment (Finkbeiner et al., 2006; ISO, 2022), review processes (ISO, 2019), and the issuing of interim and scenario-dependent specifications (CEN and CENELEC, 2016) are ways for standard developers to update the standards according to future scenarios. Evidence from the telecommunication sector shows how a better "democratization" of the development processes helps reach consensus and improve a standards' flexibility. For example, van den Ende et al. (2012) demonstrated that multiple stakeholder categories in technical committees leads to the standard being more adaptable and fit for use to different categories of users. A valid tool for reaching such flexibility is incentivizing committee members to file change requests for further adaptations of the standard (Leiponen, 2008; Schott & Schaefer, 2023).

5.3 Methods

To identify the elements of a flexible standardization process for adaptation challenges, we explore the case of sea-level rise (SLR) through a mixed-method approach, structured in two blocks. In the first one, we investigate the state of the art of SLR adaptation measures through a systematic review of the literature (step 1) and an inventory of available standards for these SLR adaptation measures (step 2). This yields insights into what measures lack standards (step 1) and for which ones standards are available already (step 2). The second block investigates future development perspectives on the role of standards for SLR adaptation according to a selected pool of experts. Here, we first conduct semi-structured interviews (step 3) to explore the implications of SLR adaptation measures, their place-specific needs, and the need, if any, for standardization in this field. Then, we identify the experts' most consensual statements through a Q-method survey (step 4) to identify the least and most agreed standardization areas for SLR adaptation. As such, these last two steps allow us to understand how and when these adaptation measures should be standardized (steps 3 and 4). In Appendix 1, we describe the limitations of our approach.

5.3.1 Empirical setting: adaptation to sea-level rise

During the period 1997-2024, global sea levels rose on average by 9 cm, with projections indicating an increase of up to 2.2 meters by 2100 and 4 meters by 2150 if current greenhouse gas emissions persist (IPCC, 2023). This trend puts countless people and assets at risk, particularly in coastal communities, including the world's largest cities (Cortés Arbués et al., 2024; Lindsey, 2022). Experts suggest that even if global temperature increases are mitigated, sea levels will keep rising due to the earlier emissions and self-reinforcing effects of these (OECD, 2019). This makes Sea Level Rise (SLR) one of the greatest adaptation challenges our society is facing. Similarly to other societal challenges, the consequences of SLR are place-based, for example because of differing coastal structures and human settlements, and time-based, due to the unpredictable evolving nature of climate change, diverging forecasts of sea levels, and increasingly extreme weather conditions.

While institutions have responded to many societal challenges through multi-stakeholder approaches (for example, the roundtables for sustainable food systems or the public-private partnerships for infrastructure development), they have insufficiently pursued such an approach for SLR so far (United Nations, 2024; Word Economic Forum, 2024). However, many of these institutions are explicitly calling for coordinated actions to drive SLR adaptation (European Commission, 2021; IPCC, 2023; United Nations, 2024).

5.3.2 State of the art of SLR: standards and adaptation measures

Step 1: Systematic literature review

To identify climate adaptation measures for SLR, the systematic literature review (

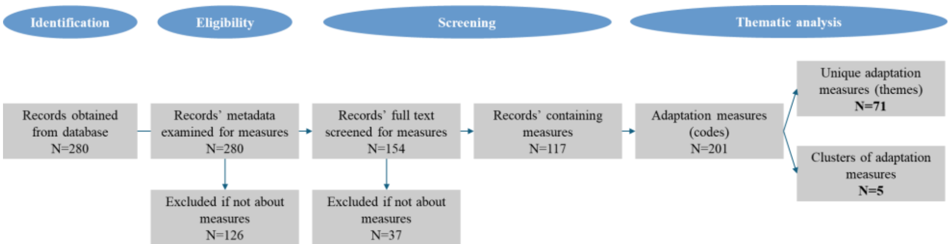


Figure 5-1) drew from the Web of Science. We retrieved any record published between 1900 and 2022 of which its titles, author keywords, or abstract words contain 'climate adaptation' and 'sea level rise'. Additional keywords were excluded to enhance the feasibility of the review. This resulted in 280 records.

We followed the IPCC-inspired Protect, Accommodate, Retreat, and Attack (PARA) model (Dronkers et al., 1990). The strategies of accommodation and retreat imply the acceptance that some coastal areas will be lost. In contrast, protection and attack strategies aim at maintaining the current landmass and, in the latter case, restoring it. In addition to the PARA model classification, we followed Dedekorkut-Howes et al. (2020) by including any non-structural measure (e.g., risk assessment). We refer to this categorization, including non-structural measures as PARA(N).

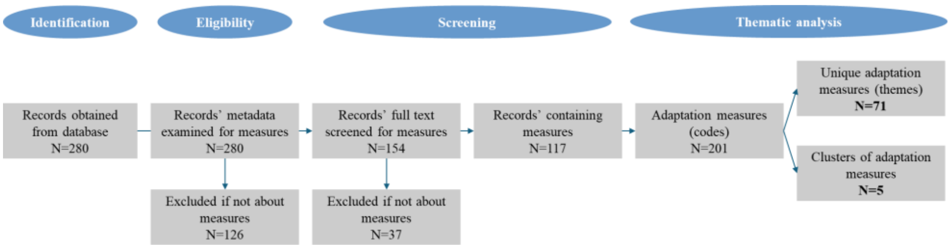


Figure 5-1 – Flow diagram of systematic literature review

Examining titles and abstracts of the 280 papers, we excluded any record that did not mention climate adaptation measures for SLR. This first assessment left 154 of the 280 records. The remaining records were fully screened to validate whether our title and abstract-based selection met our requirements, leaving 117 papers. These were fully thematically analyzed. First, we employed "open" coding of adaptation measures (i.e., the codes) at the sentence level. That means that we analyzed each sentence for mentioning SLR adaptation measures. Both generic measures (e.g., coastal defenses) and specific measures (e.g., levees) were included to mitigate selection bias. Measures may go by multiple names (e.g., beach nourishment, shore nourishment, and beach replenishment). For this reason, we grouped synonyms into uniform themes by means of 'axial coding'.

To enhance this study's comprehensibility, we used 'selective coding' to cluster coherent themes according to the PARA(N) model. This step of the thematic analysis was done by three researchers. Any inter-coder inconsistencies were collectively discussed and resolved. Moreover, the broadness and cross-functional nature of adaptation measures suggested introducing a framework for clustering them into relevant thematic categories. Thus, we purposively assigned each SLR adaptation measure to four clusters based on the field of thematic expertise (e.g., civil engineering, governance, nature-based), using the same process of 'selective coding' described above for the PARA(N) model clusters and operated by three authors. This step resulted in four thematic clusters that will be presented in the results section. Identified measures were compared and supplemented with any additional ones mentioned by the systematic literature review of Dedekorkut-Howes et al. (2020). Overall, the thematic analysis resulted in 71 climate adaptation measures. The complete list of measures and more details on the clusters and the PARA(N) mode can be found in Appendix 2 of this document.

Step 2: Inventory of SLR Standards

We subsequently compiled an inventory of existing standards relevant to SLR adaptation. This 'state of the art' informs us about what opportunities for global standardization are already (partly) covered. The SLR adaptation measures from the systematic literature review has been transposed into a list of keywords that we have used for the inventory research on standards. This keyword list contained the names of the measures, any synonyms, their plural/singular forms, and their British/American spelling to avoid missing out on relevant standards. We conducted the search in the databases of nine Standard-Setting Organizations (SSOs), one of which operates globally (ISO), two regionally (CEN and CROSQ), and six nationally (NEN, BSN, TTBS, BSTI, BSI, and SASO). We purposively selected SSOs from countries and regions with a high exposure to SLR impacts, that would provide a representation of both the Global North and South. The keyword-based research in the standards databases was carried out to identify all potentially relevant standards in the field of SLR adaptation. Later, a further reading of the standards descriptions helped us filter results based on actual relevance, affinity and relatedness to SLR adaptation, helping us to exclude out-of-scope standards. The full list of SSOs, and more details on the technical committees and the standards we collected is available in Appendix 3.

5.3.3 Future outlooks for standards development for SLR adaptation

Step 3: Expert Interviews

To gather knowledge on the current SLR adaptation practice and explore possible entry points for standardization, we conducted 20 semi-structured interviews with experts. We used purposive sampling in combination with snowball sampling to ensure a diverse sample with the following characteristics: a) a distributed pool of experts covering the thematic clusters identified in step 1; b) geographical representation of expertise from both the Global North and Global South; c) a balanced representation of private and public roles (i.e., industry, academia, policy, and civil society); d) high-level experts in the standards development process. Each interview had an average length of one hour. Interviews were recorded, transcribed and thematically analyzed to search for codes that provide knowledge on the possible standardization of SLR adaptation measures. We transposed the research question into coding rules (in the form of sub-questions) guiding the selection of the most relevant statements. Specifically, we researched experts' opinions on a) the priorities and most concrete opportunities for local and global SSOs in the field of SLR adaptation; b) the role of geographical specificities for the standardization of specific SLR adaptation measures; c) the level of (technical/technological) maturity of specific SLR adaptation measures; d) the challenges and blocking factors for the standardization of SLR adaptation measures. More information on the sample of interviewees and the common structure of the interviews can be found in Appendix 4.

Step 4: Understanding perspectives using Q-Method

We conducted a Q-method survey to a purposively selected pool of experts on SLR adaptation measures and standardization distributed across the four thematic clusters, balancing the representation of perspectives from the Global North and the Global South (30 respondents). We selected this method because understanding room for agreement (and disagreement) is important as committee-based standardization is a consensus-driven process. This aligns with the "global" purpose of our research, since the Q-method requires a heterogeneous sample that reflects the diverse worldviews of the population (Cuppen et al., 2010). The Q-method combines quantitative and qualitative techniques, for the purpose of exploring subjectivity and pluralism within diverse groups of stakeholders (Brown, 1980; Stephenson, 1935). Such a method fits the multi-disciplinary and multi-stakeholder dimension of SLR adaptation, and we employ it to understand the main perspectives among SLR experts and the aspects on which they agree more.

Scanning the interviews' transcripts, we collectively coded and validated 30 statements that contributed to our research question (see Section 4.4). 30 respondents ranked statements on a Likert-scale from -3 (highly disagree) to +3 (highly agree). The ranking (the "Q-sort") follows a normal distribution with only three statements for each extreme of the scale. This prompts respondents to carefully select the statements on which they have a stronger opinion. We used *qmethodsoftware.com* to collect Q-sorts from respondents (Lutfallah & Buchanan, 2019). We conducted a so-called factor analysis to draw i) the statistically significant experts' perspectives (i.e., the dominant "factors") and ii) the consensus statements, i.e., those statements similarly positioned in the Likert scales of the two perspectives. To determine which perspectives to include in our study, the software calculated the so-called factor loadings, i.e. the correlation coefficients between each respondents' viewpoints and the two dominant perspectives. In line with other studies (e.g., Brown, 1980; Shabila et al., 2014), we have included the perspectives that had at least two factor loadings correlating with the perspectives at a significance level of $p<0.01$. This significance level is established through the formula expressed in Equation 5-1 (Brown, 1980; McKeown & Thomas, 1988). Both factors also meet the Kaiser-Guttman criterion and Humphrey's rule, strengthening their significance in terms of eigenvalues and standard errors.

$$\boldsymbol{Factor\ loading} > \mathbf{2.58} \times \frac{\mathbf{1}}{\sqrt{\boldsymbol{N\ statements}}} > \mathbf{0.47}$$

Equation 5-1 – Formula to derive factors with significance level of p<0.01

Once the main perspectives were established, we identified the consensus statements. These statements are those whose differences in their z-scores between the two perspectives is lower than 0.40 (Ramlo, 2021; Rodhouse et al., 2021; Zabala, 2014). The z-score of a statement is the weighted average of the ranks given by the defining respondents (Zabala, 2014). Tables with the factor loadings and the respondent's z-scores are included in Appendix 5.

5.4 Results

5.4.1 Adaptation measures for SLR

SLR adaptation measures include any *material* (infrastructural, engineering and natural solutions) and *immaterial* (policy, governance, decision-making & support tools) action that have the objective of preparing or protecting coastal communities, their infrastructure and ecosystems for the impacts of climate change on sea levels. These measures aim to control risks, minimize damages, and enhance resiliency against the effects of SLR, and together they contribute to reducing vulnerabilities. At the same time, they help communities adapt to the changing coastal environment due to SLR. Combining these measures can forge a comprehensive adaptation strategy designed to address the consequences of SLR that are specific to each local domain. The thematic analysis resulted in four thematic clusters of SLR adaptation measures: Civil Engineering & Infrastructure; Risk Assessment Modelling, Safety &

Security; Policy, Governance & Spatial Planning; Nature-Based Solutions. Table 5-1 summarizes the results of this step of our research. It shows the most representative and recurring measures across two dimensions: their thematic relevance and the IPCC's PARA(N) strategies they fulfill. The former dimension systematizes the measures into four core clusters, thereby allowing a discussion on their content and expertise needed. The latter helps to distinguish between the different functions of the measures and their goals according to the IPCC classification. This first overview already shows a rather distributed array of measures across the clusters and the PARA(N) strategies, though with limited measures for the strategies of retreat and attack. The full list of SLR adaptation measures and a description of the clusters and functions can be found in Appendix 2.

Thematic clusters → PARA(N) strategies ↓	Civil Engineering & Infrastructure	Risk Assessment Modelling, Safety & Security	Policy, Governance & Spatial Planning	Nature-Based Solutions
Protect	Dykes and other coastal barriers	Critical infrastructure protection		Living shorelines; Beach nourishment; Dune stabilization
Accommodate	Elevated or floating construction; flood resistant materials; Drainage systems; Infrastructure reinforcement;	Early warning systems		
Retreat			Managed retreat	
Attack				Coastal wetland restoration
Non-structural		Risk-based assessment; Impact simulation Emergency preparedness; Response plans	Participatory governance for decision-making Adaptive planning frameworks Spatial and urban planning Awareness and capacity-building programmes	

Table 5-1 – Grouped SLR adaptation measures categorized across themes and PARA(N) strategies

5.4.2 Existing standards for SLR adaptation

Using the 71 clustered SLR adaptation measures as keywords our search resulted in a total of 1373 standards. A further investigation of the titles and abstracts of the standards revealed that 1093 of these were out of scope, some standards (198) entailed relevant expertise but their scope was irrelevant to SLR, and only a limited number (82) relevant to SLR. More details on these standards can be found in Appendix 3. In Figure 5-2, we display the most cited measures as emerged from the literature review (expressed in percentage out of all cited measures found in the articles analyzed) and compare them to the results of the inventory on existing standards against SLR (percentage on the standards found in the inventory). The graph suggests that many measures for SLR adaptation are currently not covered by standards, resulting in a standardization gap. Specifically, 50 measures out of 71 are not linked to any standard. However, we see some exceptions, for example for dykes, drainage systems, revetments, flood proofing, and emergency planning, for which some standards are already in place. Results indicate that to date, few global standards address SLR through e.g., flood-risk management and nature preservation.

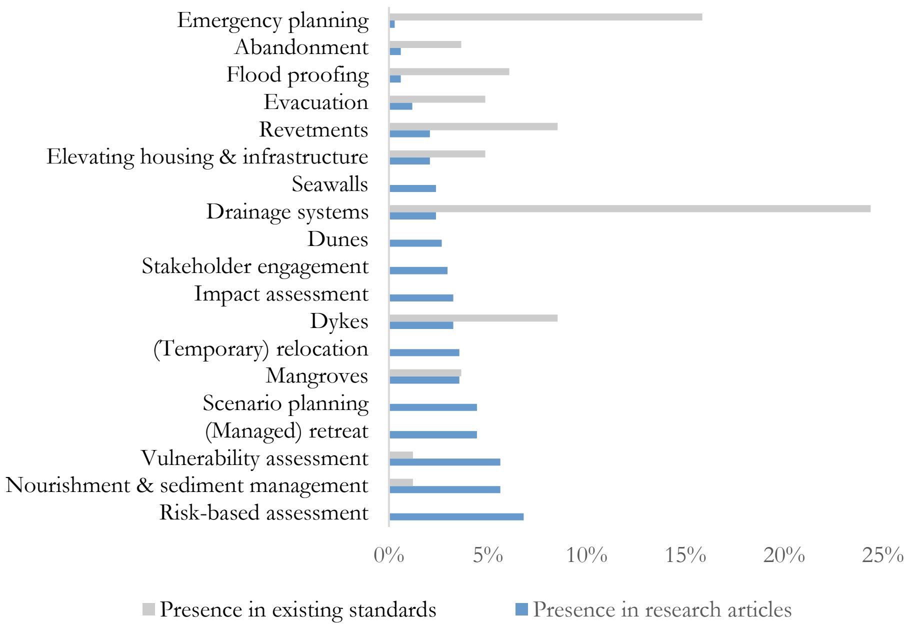


Figure 5-2 – SLR adaptation measures from literature and their associated standards

5.4.3 Challenges and opportunities of standardization for SLR adaptation

After conducting a thematic analysis of the experts' interviews, we present the key takeaways across the four thematic clusters.

Civil Engineering and Infrastructure

The lack of global standards for SLR adaptation in this field is surprising because the sector is characterized by wide global scalability and applicability of materials, products and processes. Indeed, experts identify the need for standards development especially in infrastructure construction protocols, material reinforcement, coastal defenses and drainage systems. As discussed in section 4.2, many standards for drainage systems are already available. Upscaling and adapting them to SLR requirements is needed. Then, experts consider the good degree of maturity attained by practices in floating constructions as an opportunity for standardizing the required materials and quality and security of buildings. The guidelines for architecture, design and construction are reported to be sufficiently mature for standardization, reflecting recent advancements in resilient building techniques.

Moreover, experts indicate that the current measures of civil engineering implemented in flood-prone areas (e.g., dykes and coastal barriers) should be investigated to standardize specific material and construction requirements, taking local characteristics such as temperatures and earthquakes into account. Experts also warned that large infrastructural interventions can sometimes lead to overprotective solutions, not fulfilling sustainability criteria. They suggest the need for a balanced approach between the efficacy and the environmental impact and cost of such measures that should be taken into consideration in the standards development process. To reduce these, hybrid approaches combining nature-based solutions with lighter infrastructural interventions have been recommended. Lastly, experts agreed that standardization should encompass not just the construction and implementation of civil engineering projects but also their ongoing monitoring and maintenance requirements. This ensures that infrastructural interventions remain effective, safe, and resilient over time, adapting to evolving environmental conditions and technological advancements.

Risk Assessment Modelling, Safety & Security

General standards for risk assessment, safety and security are available, but experts recognize a need for more specific standardization for SLR adaptation. The primary focus should be on developing operational standards for risk assessment and impact simulation methods, and their related supporting technologies. This would equip decision-makers and communities worldwide with standardized tools and methodologies to understand, assess, manage and adapt to SLR risks. This necessitates a focused effort on standardizing data requirements, data harmonization, and validity at a global scale which is pivotal for the diffusion of existing risk-based assessment models already implemented locally. Such standards are instrumental in promoting a common understanding and provide the underpinning for decision-making.

Moreover, experts suggest standardization for early warning systems, emergency response protocols, evacuation planning and critical infrastructure protection. Being a thematic cluster with many different consolidated measures and tools, experts acknowledge the difficulty in reaching consensus on a single solution to be standardized due to the high incidence of context-specific factors, such as geographical and infrastructural specificities. Rather, different standards might co-exist and depending on the local situation the most applicable one can be chosen. Nevertheless, experts agree that global standardization efforts may pivot towards promoting preparedness and frameworks of predisposition for these adaptation measures, where communication tools, symbols, technological benchmarks and codes of conduct should be prioritized. Still, the significant local specificity suggests leaving the parameters of such standardized tools to the local implementing bodies. At last, experts pointed out that the scope of global standardization for SLR risk assessment should extend beyond public sector policy guidelines, also targeting private actors.

Policy, Governance & Spatial Planning

Policy and governance experts acknowledge the difficulty of developing structured approaches and standards for coastal management and urban planning in SLR-prone areas. Experts identify a priority in the wider diffusion of adaptive planning approaches that accommodate the high uncertainty and risk associated with climate hazards. They would welcome a high-level policy framework for standard development and indicate that previously cited risk assessment models could set the basis for better scenario analyses and support local decision-making and adaptive planning. The most cited measures for standards development include the issuing of land use and environmental management, and guidelines for implementing shorter policy decision cycles.

Moreover, interviews revealed that the empowerment of multi-sectorial stakeholder engagement is a key element for standards development, as it underpins participatory decision-making. Participation and co-decision making are priorities not exclusively during standards' development, but also in the governance of SLR adaptation strategies. Overall, the complexity of local governance schemes, which are influenced by different decision-making processes and cultural factors, suggests that they cannot be addressed by global standardization, but should instead be tailored by local legislation. Similarly, spatial planning practices are strongly dependent on local territorial specificities. For this reason, experts suggest that international SSOs play a critical role in incentivizing the agency of local actors (both policy makers and communities of individuals) rather than in setting common guidelines.

Nature-Based Solutions

The focus of SLR adaptation measures for Nature-Based Solutions (NBSs) is on harnessing the resilience and protective qualities of natural environments. Experts debate on the possibility (or not) of formalizing nature-based approaches that are already implemented locally into consolidated practices. The strong dependency on local specific factors such as the biological and ecological conditions, the variety of species available or the quantity and characteristics of natural resources deployable (sand for instance) poses questions about the extent to which international standardization can provide any support. Apart from the physical and ecosystem specificities, also the governance context can be different, e.g., the conflicting visions and competing interests on the use of land between different stakeholders. Nevertheless, experts affirm that standardization can play an "enabling" role. Based on the experience with BSI's Indonesian standards for mangroves cultivation, one of our interviewees suggests national SSOs should prioritize the establishment of biological conditions and requirements for healthy vegetation growth.

Experts also recommend the provision of standards that can be related to legislation (e.g., environmental protection standards) and guidelines for policy and governance of ecosystems to manage conflicting visions/interests on land use. Moreover, interviews revealed that the material requirements of certain NBSs (e.g., amount of sand, density of plant) and their changes over due to evolving coastline features can be standardized as a function of coastal features and SLR simulation scenarios, thereby offering a guidance framework adaptable to local conditions. A final consideration from experts suggests that while NBSs provide several adaptation measures, they often cannot serve as standalone solutions in the case of high-risk scenarios. Still, some experts consider NBSs as essential component for any integrated adaptive planning policy, due to their natural adaptation function to mutating shoreline conditions.

5.4.4 Dominant perspectives and consensus statements of SLR experts

In this section, we outline the dominant perspectives among the thematic experts involved in the Q-survey. We also highlight the statements for which there is consensus about their agreement or disagreement among the experts. The two dominant perspectives are reported in Table 5-2. The table shows the rank of each statement along the Likert scale, where +3 represents a strong agreement of the experts with the statement, and -3 represents a strong disagreement. The experts seemingly agree on the standardization priorities. They emphasize the process dimension, this is evident from the high agreement on statements 20, 13, 15 and 23. Statement 20 spotlights the critical need for adaptive planning approaches, hinting at the fact that varying morphological (e.g., due to erosion), technological, and demographical (e.g., community retreats and migration) conditions may require continuous updates of the locally enforced measures. Statements 13 and 15 relate to specific adaptation measures: the former relates to civil engineering infrastructures, whose practices for preventive maintenance should be included in standardized guidelines, to avoid unintended disasters and reduce their risk exposure; the latter shows how preliminary risk-based assessment should be the starting point of every local adaptation plan. Statement 23 unfolds how decision-making standards can facilitate the coordination process of many stakeholders affected by the problem. This multi-stakeholder dimension is also emphasized by highly agreed statement 19.

Besides the many "neutral" statements, for which experts seem not to take a decisive stance, the two dominant perspectives also include statements for which there seems to be general disagreement. In particular, the disagreement towards statements 2 and 6 reveals the urgent need, at least for some measures, of standardization at the global level (i.e., by international and regional SSOs). Furthermore, statement 14 highlights how infrastructures like dykes are not necessarily over-protective solutions, whereas statement 10 indicates that for some more technologically advanced solutions, such as floating houses, there is not yet enough technical maturity allowing for global standards. It is also worth noticing that statement 22, questioning whether cultural factors prevent local policies to be used for global standards, is very debated among the perspectives (scoring -3 in perspective 1 and +3 in perspective 2). For this reason, we also identify (in Figure 5-3) the so-called consensus statements plotting their z-scores. In the figure, the blue "corridor" indicates whether the statements were similarly judged by the experts belonging to the two perspectives. The nine consensus statements (in blue) and their level of agreement/disagreement are used as a baseline for our discussion section.

Statement	Perspective #1	Perspective #2
20) The high risk (probability and impact) embedded in climate hazards suggests that SLR policies must follow adaptive planning approaches	+3	+3
13) Standardization should not neglect monitoring and maintenance requirements for civil engineering and infrastructural interventions	+3	+2
15) Risk-based assessments should be a preliminary step to enable any possible SLR adaptation strategy and measure	+3	+2
23) Tools and protocols that support decision-making for SLR adaption should be a priority for standardization	+2	+3
19) Global standardization for SLR risk assessment should target not only public sector (policy guidelines) but also industry and SMEs	+2	+2
11) Some existing standards in the field of construction and civil engineering could also be used in SLR adaptation contexts	+2	0
16) Standardization should focus on data requirements, harmonization, and validity at a global scale to enable implementation of existing risk-based assessment models	+2	0
21) Multi-sectorial stakeholder engagement should be standardized as a key support tool to pursue participatory decision-making for SLR adaptation measures	+1	+1
8) Global standardization should engage with international organizations (e.g., IPCC, UN, OECD) to leverage expertise and promote collective action	+1	0
1) Global Standardization for SLR adaptation should focus on a set of guidelines that pave the way for local standardization practice	+1	-1
24) The standardization of adaptive policy approaches to coastal management must target a strong reliance on Nature-Based Solutions	+1	-1
25) Nature Based Solutions (NBS) requirements (e.g., conditions for healthy flora growth) should be standardized first	+1	-2
17) Standardization should primarily focus on estimating the risks because thresholds for risk acceptance and SLR adaptation strategies are primarily political choices	0	+1
3) Short-termism in decision-making and planning is among the biggest limiting factors for standardizing SLR adaptation measures	0	0
27) The material and dynamic requirements of some NBS such as sand nourishment and wetlands can be standardized globally (as a function of coastal features)	0	-1
30) Spatial Planning standards for SLR risk-prone areas should focus on solutions that prevent the need for emergency planning	0	-1
5) Global Standardization should start from providing a framework specifically for developing SLR adaptation measures	0	-2
12) Civil engineering practices adopted in flood-prone urban areas seem ready to be standardized.	0	-2
18) Due to the strong local dependency of evacuation plans, global standardization should focus on evacuation preparedness and predisposition	-1	+1
28) NBS can only be a part of adaptation strategies as they rarely represent a standalone solution for SLR scenarios	-1	+1
26) Guidelines on the policy & governance of ecosystems should be standardized first to deal with conflicting visions for land use	-1	0
2) The level of risk (probability and impact) of SLR climate hazards is still too high to provide globally standardized solutions	-1	-3

10) Prototypes and practices for floating construction are mature enough for standardizing its principles	-1	-3
29) The adoption and standardization of NBS is challenging due to conflicting visions and interests on the use of land	-2	+2
9) Any standardization process should embed a protocol (e.g., a questionnaire) to explicitly consider its relationship with climate adaptation	-2	0
4) The lack of standards for data collection, processing and use challenges both the implementation and standardization of SLR adaptation measures	-2	-1
6) Global Standardization should be initiated bottom-up by local standardization bodies (interests of stakeholders)	-2	-2
22) Local governance schemes for SLR adaptation cannot be standardized at a global scale because of cultural factors	-3	+3
7) SLR adaptation measures are so heavily reliant on case by case and place specific inputs that cannot be standardized globally	-3	+1
14) Infrastructural interventions such as dykes and barriers are often overprotective solutions for SLR adaptation	-3	-3

Table 5-2 – Ranks (i.e. Q-sorts) of each statement within the two significant perspectives.

Statements are sorted according to their ranking within Perspective 1. Consensus statements are marked in grey

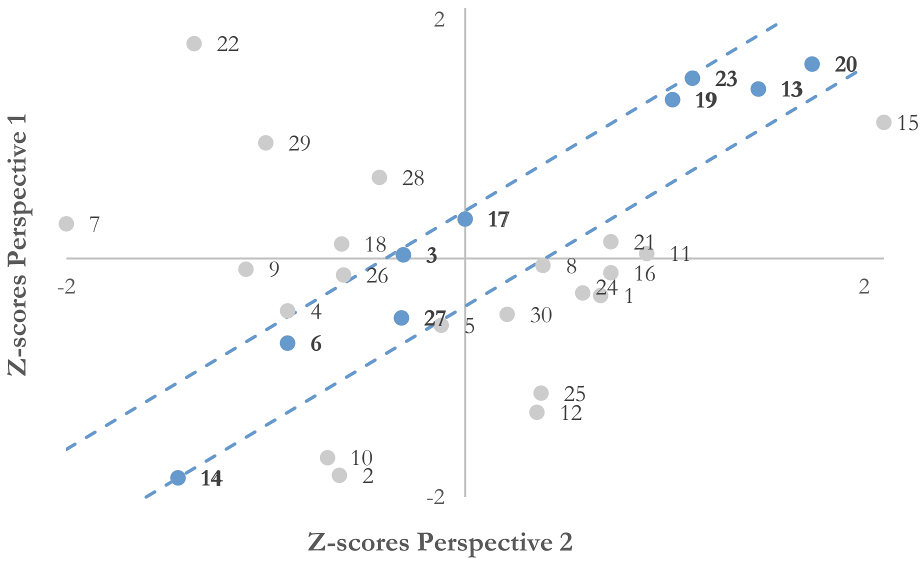


Figure 5-3 – Scatter plot of the 30 statements' z-scores in the two dominant perspectives.

Consensus statements (highlighted in blue) are those within the blue "corridor"

5.5 Case analysis

After describing and analyzing our results, we articulate our discussion into two pillars to design a standardization process suitable for adaptation challenges: a "geographical" approach, that considers local specificities and differing capabilities across national, regional, and international SSOs, and an "adaptive" approach, that considers varying morphological, demographic, and technological characteristics of the adaptation measures over time.

5.5.1 Place-based specificities call for a geographically integrated approach to standardization

Integrated processes involving subnational, national, regional and international SSOs

Experts highlight how global standardization for SLR adaptation is subject to different possibilities and roles of SSOs depending on the specific measure. Certain measures cannot be standardized integrally but their adoption can be enhanced by basic standards covering specific elements of the measure (de Vries, 1998, 1999). However, for some measures, some standards may be developed at the international level, while for others, due to geographical specificities, more localized standards are needed at a regional, national, or subnational level. The most illustrative case of this "scalar" dimension of standardization is the biological and morphological character of nature-based solutions. Here, a neutral vision of the experts on consensus statement n. 27 suggests that there is less room for global standards for nature-based solutions[2]. Two examples are the locally standardized procedures for nourishing sandy beaches, depending on the presence of sediment on the seabed (Lodder et al., 2023), or the existence of national standards on mangrove cultivations by the Indonesian standard body BSN.

The disagreement towards consensus statement n.6 suggests that the process for standardizing SLR adaptation measures (or specific elements) should be a combination of global and local inputs. The global inputs see a direct involvement of international and regional SSOs. These should aim at establishing basic standards, such as a common terminology and frameworks, and indicating what is globally standardizable. Additionally, initial guidelines for performance criteria and test

[2] After collecting our data, the International Union for Conservation of Nature (IUCN) has published a standard for nature-based solutions. In line with our discussion, this standard does not provide globally standardized solutions for all countries. Instead, it provides criteria and indicators for the implementation and the assessment of such solutions. More info at the following link: https://www.iucn.org/our-work/topic/iucn-global-standard-nature-based-solutions

methods can be developed at the international or regional level if the related measures require so. Even considering existing technical committees within international and regional SSOs that can contribute to the issue (e.g., ISO's committee 207 on environmental management), the breadth and pervasiveness of SLR calls for dedicated technical committees that prioritize the development of basic standards. The four thematic clusters proposed in this study can be initial focus areas for these committees, able to tackle specific aspects of the problem in a coordinated manner.

The local approaches, instead, relate to sharing the knowledge about existing and potential measures, creating more grass-root awareness of the problem, developing local stakeholder engagement and training it through capacity-building programs. National SSOs need to cooperate with the national government and authorities that are already in charge of addressing the issue of SLR through legislation. This comes with a double end: firstly, to make sure standards are developed in accordance with the national laws and, where applicable, incorporated and enforced through them; secondly, to cooperate in raising awareness on the possible solutions among local stakeholders, strengthening community cohesion and engagement, and building capacity for future standard adopters In some instances, SSOs should also operate considering the subnational level, for example when some coastal features and human settlements are specific to provinces or municipalities, or in the case of federal political systems[3]. Furthermore, national SSOs can increasingly participate in the development of standards and bring local expertise to an international audience. This implication also strengthens how place-based adaptation should be pursued by leveraging on local knowledge, resources and expertise, including experts from the private sector (see consensus statement 19). This responds to the question raised by Bathelt et al. (2024) about whether a place-based approach is desired or necessary for adaptation challenges, and can solve the doubt of economic geographers regarding place-based development of standards (e.g., Wiig & Silver, 2019).

[3] The Netherlands' water boards, being responsible for water quality and quantity, provide an example of subnational SSO. Despite the coordination at the national level for these areas, these waterboards partly set their own standards. Some requirements differ per water board because of local morphological differences and political preferences, since their board composition is decided upon the election of political parties.

Cooperation between countries to address place-based specificities

Standardizing SLR measures can be challenging due to varying resources, expertise, and governance across countries, with a specific divide between Global North and Global South (Acemoglu et al., 2012; Alizada, 2018), where different countries experiment SLR adaptation tailored to their local context by leveraging on their expertise and resources. Countries in the Global North tend to have greater access to financial resources, more interconnected technical expertise and more mature innovation capacity. Conversely, countries in the Global South face resource constraints, limited access to funding, and a lower technological departing base, which can slow their ability to implement comprehensive SLR adaptation measures, and their standardization (Corradini & Vanino, 2022; Martin & Sunley, 2006). Nonetheless, concerning SLR-specific expertise, some countries in the Global South have reached a more mature stage as they have been confronted with coastal hazards for a longer time.

As to their adaptation strategies, the Global North tends to focus on systemic measures involving technological innovations and infrastructural investments. One example is the national standard for floating constructions in the Netherlands (NTA 8111) that have no corresponding standard in any of the other SSOs we consulted. Countries in the Global South tend to rely more on nature-based solutions and community-engagement approaches due to cultural factors that include different epistemological traditions and the professional and industrial heritage available locally. Experts hint that the disposal of limited financial resources may also lead to privileging sustainable and cost-effective measures instead of massive infrastructure interventions. Confirming Frantzeskaki's (2019) claim, this shows the key role that the Global South will play in developing this long-term vision based on nature and local communities. This difference in SLR adaptation approaches suggests that an integrated approach coordinated globally can prompt mutual learning between different countries, aligning with the discourse on positive path dependency raised by economic geographers (Corradini & Vanino, 2022; Iammarino, 2005; Martin & Sunley, 2006). Lastly, countries in the Global North tend to have greater access to and better quality of data, as well as more capillary research and academic institutions, enabling them to conduct in-depth data elaboration. Collaboration between SSOs in the field of data collection, management and quality represents an opportunity for the foundations of SLR adaptation measures, as agreed by experts (e.g., statement n.15).

Existing frameworks of cooperation among countries in the Global North in complementary fields to SLR can drive knowledge transfer processes to the Global South (Boström et al., 2015; Lal et al., 2012), which today tend to be more reliant on international cooperation. The twinning partnership program of ISO for capacity-building is an example for such cooperation. Therein, the mutual exchange of knowledge, practice and resources can fuel standards development processes for SLR adaptation in a multi-directional flow of knowledge and expertise between Global North and Global South (see Jones et al., 2010).

5.5.2 The temporal dimension of the standardization process

Uncertainty and evolving conditions call for adaptive policy standards

SLR presents a complex and evolving challenge, necessitating a dynamic response strategy. Traditional static approaches to policy formulation do not cater well to the volatile nature of climate change and its impact on coastlines. Consensus statement n.20 unveils the broad agreement among experts that the high risk embedded in climate hazards suggests SLR policies must follow adaptive planning approaches, characterized by flexibility and continuous refinement. The paradigm for planning under conditions of deep uncertainty by Haasnoot et al. (2013) emphasizes the creation of a strategic vision for the future, committing to short-term actions while establishing a framework to guide future actions. The neutral position of experts on short-termism being the main limiting factor for SLR adaptation standards (consensus statement n.3), may suggest that there are some standards for which a short-term perspective is needed, for example for coastal infrastructure (see next paragraph). Concerning long-term actions, the call for policy tools that support decision-making for SLR adaptation should be a standardization priority according to consensus statement n.23. This finding also aligns with the emphasis that Haasnoot et al. (2013) put on decision-support tools: the creation of standards for policy support tools that facilitate scenario analysis, risk assessment, and decision-making under uncertainty. Such standards should ensure these tools are user-friendly and capable of integrating diverse data sources.

Another critical aspect of adaptive approaches that has been strengthened by experts and pinpointed by theory, is the engagement of stakeholders, particularly local communities, in the planning and implementation processes. Local communities are often the first to experience the impacts of SLR and possess valuable knowledge about their environments. Their involvement ensures that adaptation measures are grounded in local realities and address specific community needs and priorities, thus providing community-based adaptation (Reid & Huq, 2007), while fueling a sense of ownership and responsibility, which is crucial for the social sustainability of adaptation measures. Developing standards with guidelines for stakeholder engagement, co-creation and decision-making processes are strategic tools to guide local governance bodies and favor the participation of the widest spectrum of stakeholders. Besides its geographical relevance, increasing the variety of stakeholders in technical committees and incentivizing the entrance of new ones has shown to increase the flexibility over time of the standards by bringing new interests to the table (van den Ende et al., 2012).

Standardizing based on technological maturity

Standardization literature highlights how dominant market-based standards normally emerge when the underlying technologies are mature, e.g., when they hit the so-called "productivity plateau" and their production processes start being cost-driven (Foster, 1986; Jantsch, 1967; Utterback & Abernathy, 1975). Translating this to our research, we show how the available technical expertise of some measures is mature enough, for example in the case of risk-based assessment models and drainage systems, and even for some nature-based solutions, for example the nourishment of sandy beaches. Particularly for risk-based assessment models, there is agreement in statement n. 15 that these should represent a preliminary step to designing any SLR adaptation strategy. Standardization at earlier stages of technology development can be useful as well, by developing basic standards for terminology, measurements and interfaces at earlier stages, and quality standards at later ones (Blind & Gauch, 2009). Standardization holds opportunities to create economies of scale and promote technology diffusion, besides creating positive spillovers for sharing good common practices. In some domains, for measures that are not technically mature enough, such as in floating houses, coastal barriers or some spatial planning approaches, the development of global standards should be postponed, but national standards can be developed already (as exemplified with the case of a standard for floating houses in the Netherlands). This may explain the diverging views between the interviewees and the survey experts on this topic (see e.g., disagreed statements 10 and 12).

Besides risk-assessment models, the highly disagreed consensus statement n. 14 showcases an urgent need for more coastal infrastructures, debunking the belief that these may be "overprotective" and suggesting that the technical know-how (for example on safety procedures and materials) is generally mature. However, ongoing pilots of experimentation (e.g., floating buildings, adaptive approaches, and some nature-based solutions) suggest that certain aspects, specifically for quality and safety standards, or procedural steps and guidelines, may already be subject to standardization, albeit keeping the previously cited adaptive approach to develop a combination of basic and specific standards. For instance, highly agreed consensus statement n.13 emphasizes that standardization should focus on monitoring and maintenance requirements for civil engineering and infrastructural interventions, thereby favoring iterative adjustments, ensuring that infrastructural adaptations remain effective and resilient over time. These "maintenance" standards should include protocols guiding regular professional inspections, data collection, and performance criteria of infrastructural interventions. Additionally, they may incorporate emerging technologies such as remote sensing and real-time data analytics to enhance the accuracy and efficiency of monitoring efforts and inform policy decisions.

5.6 Discussion

Our analysis contributes to two fundamental yet underexplored dimensions of standardization: the geographical and the temporal ones. Our theory section highlights how elements of these dimensions were mentioned in previous standardization and economic geography studies (e.g., Boström et al., 2015; Nadvi, 2008). However, these communities still considered standards as incapable of accounting for dynamic and uneven geographies (e.g., Timmermans & Epstein, 2010; Wiig & Silver, 2019), missing a comprehensive understanding of these dimensions and how they can affect standards' development for adaptation challenges. To facilitate this understanding, we generalize our findings by synthesizing these two dimensions into a conceptual matrix (Figure 5-4). The matrix incorporates the main factors that emerged from our case study and provides decision-makers, primarily SSOs, policymakers and NGOs, with a tool to map and prioritize adaptation measures.

The aim of the scalar axis is to understand which actors play the main role in the process according to the type of adaptation measure. Without place-based specificities, more standards' specifications should be developed by international and regional SSOs. If, instead, a standard is bound to specific geographical conditions, the specifications should be decided by national or subnational SSOs, depending on the extent of specificity and support needed by national authorities (Braa et al., 2007; Dyck & Silvestre, 2019). As Section 5.1 explains, the participation of national SSOs and other local stakeholders is vital for global standardization processes. Our case shows that standards of local nature do not exclude international SSOs from their development process. Place-specific standards require international SSOs to trigger the process by raising awareness and promoting basic standards. This emphasizes the importance of distinguishing between basic standards, performance criteria and test methods, likely suitable for a global standardization, and standards providing parameters and specifications, often characterized by place-specificity. Our analysis also highlighted the problematic lack of technical knowledge in some countries for highly innovative measures. While such measures are riskier to standardize during their early stages, a cooperation between SSOs in the form of mutual learning and capacity building may facilitate a more rapid global diffusion of such knowledge and allow for preliminary standards (see the case of standards for artificial intelligence in Europe and the United States in NIST, 2024; Soler Garrido et al., 2023). In return, quality standards may serve as a source of agreed-upon explicit knowledge on the state of the art of specific products (Nonaka & Takeuchi, 1995).

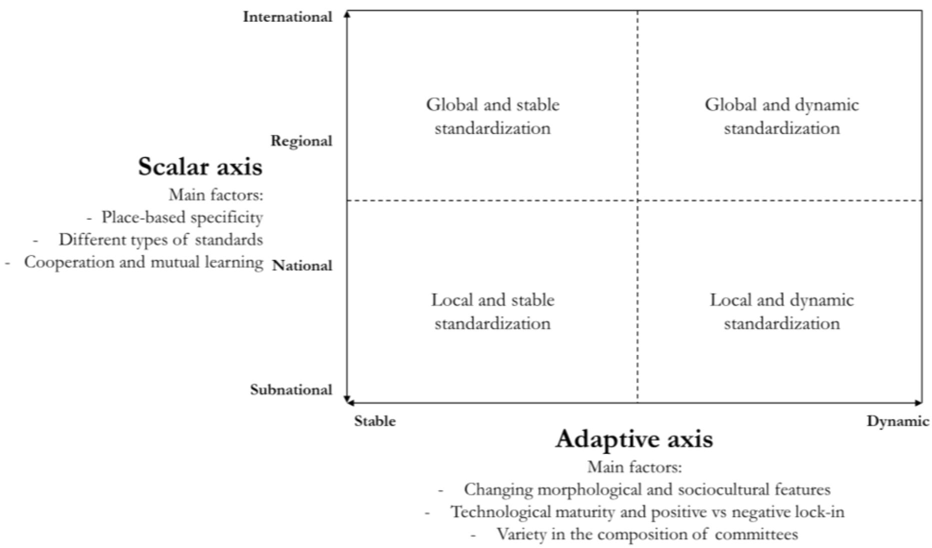


Figure 5-4 – Conceptual matrix of standardization processes for place and time-based adaptation

The adaptive axis encompasses the uncertainty of climate adaptation challenges. While the urgency of some areas calls for short-term interventions, many standardization cases have proven to be successful with long-term planning. This raises the need for a dynamic standards development process (Egyedi & Blind, 2008) aligned with adaptive policy approaches (Haasnoot et al., 2013). The stability of standards implies that specifications are kept rather unchanged for a certain period, with the advantage of lowering transaction and procedural costs (de Vries, 1999; Egyedi & Hashem Sherif, 2008). However, an inclusive committee in terms of countries and stakeholders represented can incentivize the revisions of standards, and thus their adaptability to changing conditions. This dimension is generally underexplored, especially outside of technology standards developed by consortia of firms (e.g., van den Ende et al., 2012). Implementing flexible decision-making tools, such as preliminary life-cycle assessments (Finkbeiner et al., 2006; ISO, 2022), systematic review processes (ISO, 2019) and change requests (e.g., Leiponen, 2008), represent other possible avenues for climate adaptation standards. Another important element of this dimension is the possibility of exploiting specialized lock-ins over time between different regions (Iammarino, 2005; Nilsen et al., 2023). The cooperation between countries creates room for a technological catch-up, emphasizing the need to combine time and geography in standardization and in policies. Besides these measures, stakeholders should consider the communities' characteristics as a time-varying factor. Social norms can change due to, e.g., increasing or decreasing population, coastal urbanization processes, and other sociocultural factors, and this can deeply affect the adoption and the success of standards, as exemplified by the Covid-19 pandemic case (Heß & Blind, 2023).

5.7 Concluding remarks and future developments

Our objective was to pave the way towards a conceptualization and a practical exploration of a flexible standardization process for addressing societal challenges. We selected adaptation challenges as our empirical setting because of their heavy dependence on local contexts and uncertainty about their future evolution. SLR has huge consequences, with implications both in the short and long term (ISO, 2022; OECD, 2019). Nevertheless, sea level rise standardization remains largely unaddressed, both in the context of the Global North and Global South. With this study, we analyzed how such a gap can be filled by employing a global approach, led by standard-setting organizations but coordinated with other global and local stakeholders.

We identified in *place specificity* and *time flexibility* the key dimensions to develop standards in the field, providing detailed guidance on how these should be equally considered in standardization processes. The former fulfills the differing characteristics of (part of) countries and standard-setting organizations worldwide. The latter considers the ongoing developments in terms of demography, morphological features, and technological readiness of adaptation measures. Our initial objectives were to explore how standardization can support adaptation challenges and how economic geographers can leverage this. We provide counterintuitive evidence against the conventional thought that standardization is a rigid phenomenon. This is also explained by the presence of many standards for other evolving and place-dependent sustainability and societal challenges. Building on this evidence, the community of economic geographers can rely on standards as key instruments to address the challenges of achieving scalability both in the Global North and South, allowing the implementation of global policies in local contexts.

Besides the opportunities for standards, we highlighted what types of standards are needed, and we discussed what standards cannot address. To conclude our work, considering our discussion of the results and the conceptual matrix in Figure 5-4, we call for future research on how geographical and temporal factors affect the development of standards, and the combination of these with other dimensions of standardization, such as development and adoption (Hanseth et al., 2006; Lindgren et al., 2021), the market, committee and governmental mode of standardization (Wiegmann et al., 2017), private and public actors (Botzem & Dobusch, 2012), and the concurrent competition and cooperation between such actors (Blind et al., 2023; Riillo et al., 2022). While these dimensions fall out of our scope, they may represent other potential points of attention for adaptation challenges. Finally, our novel methodology employed to identify standardization gaps can help address future foundational research on such challenges.

6. Conclusions

This dissertation has explored the extent to which research on standardization is interdisciplinary and has illustrated possible interdisciplinary directions for the field. Each study answered its respective research question and, collectively, their findings reinforce the view that standardization research develops more theory from interdisciplinary studies. By combining insights from diverse academic disciplines (mainly economics, management, sociology, engineering, and sustainability), the thesis shows that an integration of knowledge is achievable and allows addressing the persistent theoretical and practical challenges of the standardization domain. Chapter 2 assesses the status of this process, showing that standardization is an increasingly interdisciplinary field, and that the disciplines studied in combination with other disciplines are more likely linked to horizontal (i.e., theory-oriented) studies. In Chapters 3-5, the link between interdisciplinary and theory-oriented research is verified, with three interdisciplinary illustrations contributing to the theory on standardization. In sum, the results fulfill the research objective.

The implications of these findings are manyfold. Encouraging the use of interdisciplinarity may fill unfilled gaps in theory and thus open doors to several research directions. However, while the value of interdisciplinary studies is broadly emphasized, it is also important to consider the value that monodisciplinary research still has for the field, especially in the context of pre-normative and legal research. Besides, the call for more interdisciplinary research also has a direct connection with practice. The thesis describes standardization *research* as interdisciplinary, and though little evidence is provided on the extent to which this applies to standardization *practice*, the two phenomena are highly connected. In the following sections, these and other implications are discussed.

6.1 Theoretical contributions

This thesis has three types of theoretical contributions. First, each study provides answers to specific sub-research questions. Second, when viewed together, cross-study patterns emerge that emphasize common themes and advance the theoretical coherence of standardization. Third, the findings can be contextualized within the overarching research streams cited in the Introduction (Table 1-1). The next three subsections address these three categories.

6.1.1 Replies to sub-research questions

Each chapter of this thesis corresponds to a sub-research question (RQ) that was addressed through a dedicated study. The key findings of each chapter are summarized in this sub-section.

Interdisciplinary state-of-the-art (RQ1): *What is the state of the art of the interdisciplinary literature on standardization?* – Chapter 2 answers this through a bibliometric and network analysis of the past decade of standardization research. The study maps six broad academic disciplines engaged in standardization research and identifies how they intersect. It finds that management science and economics form the intellectual core of the field, bridging most other disciplines and providing the "horizontal" theoretical knowledge that applies across contexts. In contrast, technical disciplines (e.g., engineering, computer science, chemistry, physics) contribute with the largest amount of studies but tend to remain isolated within their silos. The literature is clustered into four interpretative research perspectives, each with varying emphasis on theoretical foundations (horizontal knowledge) versus specific standard applications (vertical knowledge). This review highlights ongoing debates and fragmentation in the field, but also demonstrates that greater interdisciplinarity can improve the field's theoretical (or horizontal) consistency. In line with Lakatos' view on scientific research programs, the chapter concludes that combining insights across disciplines is essential to developing a cohesive theory of standardization (Lakatos, 1970).

Network effects and adoption (RQ2): *How can the value of standards and platforms be measured through network effects?* – Chapter 3 addresses this question by integrating economic/management theories on technology adoption with social network theory. The study challenges the common assumption that the value of a standard grows simply as the square of its user base (Metcalfe's Law). Instead, it develops a new framework that measures such value while accounting for network structure and interaction types (including negative network effects, competition between adopters, multi-sided adoption, and tie multiplexity). This framework enables the measurement of both the *potential* value, the *actual* value, and the *appropriated* value of a standard or platform, considering how network structure influences value creation and appropriation. The theoretical contribution lies in giving a mathematical justification to the increasing understanding that network effects are not purely a function of size: the structure and content of the network matter. This result bridges a gap between technology adoption models and social network analysis. Importantly, the study also has a policy implication: it provides more clarity on how standards (and platforms) can achieve market dominance via feedback loops of adoption, which is fueling debates about their regulation[1] (see e.g., CMA, 2023). By better understanding the true network value captured by dominant standards, regulators and scholars can more accurately assess when network-driven market power becomes a concern. In short, RQ2's answer provides a toolset for evaluating network effects in standardization, moving beyond simplistic exponential growth models.

Firms in technical standardization (RQ3): What is the relationship between firms' participation in technical standard-setting organizations (SSOs), the competition among member firms, the size of the SSO, and firms' economic performance? – Chapter 4 tackles this question with a quantitative study in the ICT sector, using an econometric approach to analyze the returns firms gain from standardization activities. The study fills an empirical gap by providing large-scale evidence on how different SSO characteristics affect the performance of participating firms. The findings reveal a nuanced interplay between SSO composition and firm outcomes. In particular, focused standardization players (FSPs, namely those participating in only one technical SSO) tend to benefit more from participating in standardization when the SSO is relatively small and the level of intra-SSO competition is high. In such environments, FSPs see higher economic performance gains, suggesting that they can stand out and derive value even when competing with larger technology firms. Conversely, in very large SSOs or those involving firms from multiple sectors (hence with lower direct competition per firm), the benefits for any firm's performance are less pronounced. This answers RQ3 by highlighting how participation in standards development is not uniformly beneficial – it depends on the competitive dynamics and inclusiveness of the SSO. Theoretically, this contribution links standards consortia structure to firm-level outcomes, bridging industrial organization economics with technical standardization. It also challenges

[1] The debate on network effects for standards became fervent in the 1980s with the battle between video-cassette recorders. Policy interventions have proven to be fundamental to seize network effects for standards: examples include the acceptance of the Global System for Mobile Communications (GSM) standard by the European Telecommunication Standards Institute (ETSI) and the USB Type-C interface by the European Commission. Although promoting interoperability is one main objective of standardization, the ease with which network effects make standards dominant in their markets should also be considered by policymakers.

the notion that only larger technology-intensive firms profit from technical standardization; under the right conditions, FSPs can reap significant gains.

Standards for climate adaptation (RQ4): *How can standardization address sea-level rise (SLR) adaptation, given place-based and time-based specificities?* – Chapter 5 explores this question through a qualitative case study on climate change adaptation, using expert interviews and Q-methodology. It demonstrates that standardization can be a useful tool in tackling evolving societal challenges like SLR if approached with flexibility and contextual sensitivity. The study proposes a multi-stakeholder process to develop place-based and time-based standards that balance global consistency with local needs. By drawing on concepts from the economics of geography and adaptive policymaking, it shows how standards could be designed to avoid lock-in and not inhibit incremental innovation in the face of changing environmental conditions. In practical terms, the chapter introduces a matrix to help prioritize which climate adaptation measures should be standardized first, considering factors such as technological maturity and regional specificity. This answers RQ4 by illustrating that standards need a combination of local and global initiatives. This contribution bridges standardization theory with sustainability science and ethics, highlighting how standards can evolve over time and space through global collaboration. It also addresses a gap between substantial academic research on climate adaptation and the scarcity of standards in that domain, offering a common pathway to standard-setting research and practice. In summary, RQ4's findings expand standardization theory into the realm of environmental adaptation, suggesting that standards can foster innovation and coordination without causing regional path dependence.

6.1.2 Cross-study patterns

Beyond the individual contributions above, the cross-study patterns in this thesis reinforce several overarching theoretical insights about standardization. Each study intentionally combines disciplines – for example, economics/management is paired with another field in Chapters 3, 4, and 5 – and this novel approach to explore the interdisciplinarity of a scientific field provides a first contribution of this doctoral thesis. By exploring standardization through different disciplinary nexuses (economics/management + sociology in Chapter 3; economics/management + IT & engineering in Chapter 4; economics/management + ethics/sustainability in Chapter 5), the chapters are illustrations of how interdisciplinary research can be performed by combining distinct elements from different disciplines. In this section, we first present these elements for each study, then discuss three cross-study patterns that form part of the "protective belts" of standardization theory (Lakatos, 1970). The disciplinary elements of each study are displayed in

Table 6-1, while the cross-study patterns are displayed in Table 6-2. Combined, the observed cross-study patterns and protective belts give us an indication of how standardization is an increasingly interdisciplinary scientific field.

The disciplines of economics and management provide insights into all three interdisciplinary studies. Most of the elements deriving from these two disciplines are theoretical, including, for example, network effects (Katz & Shapiro, 1994), concepts from evolutionary economics such as lock-in and path dependence (Arthur, 1989; Liebowitz & Margolis, 1995), and market competition between firms during standard-setting (Baron & Pohlmann, 2013; Ranganathan et al., 2018). A widely used method in economics, namely the ordinary least squares regression, is employed for the interdisciplinary study of Chapter 4. Sociology brings in the concepts related to network structures and social dynamics, such as tie multiplexity (Ertug et al., 2023; Verbrugge, 1979) and ego-networks (Everett & Borgatti, 2005), used in Chapter 3. It also provides one of the methodologies of Chapter 5, the Q-method, which derives from early studies on sociology (Stephenson, 1935). IT and engineering provide the empirical setting around which Chapter 5 was conducted, namely the standard-setting organizations active in the information and communication technology domain. Ethics and sustainability provide the empirical setting of Chapter 5 and many of the theoretical notions included in the climate adaptation literature, such as the diversity of approaches required in the Global North and Global South (Brandi, 2017), the notion of place-based adaptation (Cutter et al., 2008; O'Neill & Graham, 2016), and the literature on nature-based solutions (Kumar et al., 2020; Lafortezza & Sanesi, 2019).

The first pattern identified is the diversity of approaches that standardization research can embrace. The main sign of this diversity stands in the four methodologies used (bibliometric review, conceptual modeling, econometric analysis, qualitative interviews and surveys), which help cross-validate ideas in different ways. As a result, the studies collectively contribute to a more integrated theory of why and how standards emerge, diffuse, and impact various stakeholders. This diversity also stands in the levels of analysis investigated. Chapter 3 studies the adoption of standards by single individuals/organizations and their ego-networks (micro level); Chapter 4 studies the sector-level effects of standards development on groups of firms (meso level); Chapter 5 explores the role of standards for societal challenges (macro level). Another sign of diversity is the different connotations of "value" that can result from the collaboration between standard setters: Chapter 3 in the form of value derived by users joining the network of standards' adopters, Chapter 4 in the form of economic performance for individual firms, and Chapter 5 as societal and environmental value. This diversity resonates directly with the conclusion of Chapter 2 that interdisciplinarity prompts a rich diversity of research approaches.

A second cross-study pattern is the recurrence of certain theoretical themes across the chapters, suggesting a developing core to the scientific field of standardization. One such theme is the tension between the benefits and risks of standardization – often framed as paradoxes in the literature (e.g., Kim, 2024; van den Ende et al., 2012). This thesis provides new perspectives on three classic debates. (a) Network effects and value creation, since it is often assumed that the more a standard is adopted, the more value it generates without boundaries. However, our network effects study describes that value creation has structural limits and potential negative feedback, thus debunking the idea of unbounded positive returns. (b) Competition benefits smaller and focused firms, as most of the literature has focused on the economic performance of "tech giants", disregarding how niche players can also benefit from the collaboration with their direct competitors. Chapter 4 sheds light on this aspect, showing that the power imbalance in standard-setting organizations can be mitigated by a smaller and more competitive environment. (c) Innovation and lock-in: a common concern is that standards, by creating uniformity, might stifle incremental innovation and lead to technological lock-ins. Yet, our climate adaptation study illustrates how a concerted global and local approach by stakeholders, and the use of decision-making tools, can challenge the notion that standards invariably "freeze" technology. These findings show that standardization entails inherent paradoxes – it can both enable and constrain, depending on how it is managed. Recognizing and theoretically accounting for these dualities is crucial for a consistent theory of standardization, in line with the principle of falsifiability discussed by Popper (Popper, 1934).

A third theme is the role of coordination and collective action: all studies, whether about network adopters, firms in consortia, or stakeholders in climate adaptation, deal with the fundamental problem of coordination between multiple actors. Standards serve as coordination mechanisms that reduce friction in markets and society, and the results of this thesis highlight different aspects of this. For example, Chapter 3 focuses on coordination through networks, Chapter 4 on coordination through market competition, and Chapter 5 on coordination among public and private actors for a societal goal. Despite the different contexts, each posits that standardization is fundamentally about managing interdependence – aligning behaviors, technologies, or expectations across many players. This notion is part of the theoretical core of standardization, around which a consistent scientific field can be built.

As a result, by reflecting on these patterns through a philosophy of science lens, it can be observed that the standardization field is maturing into what Kuhn would call a *paradigm* (Kuhn, 1962) or Lakatos a *research program* (Lakatos, 1970). Chapter 2 draws on Imre Lakatos's ideas to argue that a robust scientific field needs a coherent theoretical core protected by a belt of diverse studies. The work in this thesis contributes to such a core by showing that disparate phenomena – from platform adoption to firm performance to climate adaptation – can all be explained within a unifying framework of standardization theory. The paradigmatic concepts (coordination, network externalities, adoption dynamics, competition vs cooperation, flexibility vs lock-in, etc.) recur, to varying extents, in each study. Thus, the thesis pushes the field closer to the kind of theoretical consistency and unity that was envisioned – in the introduction – as necessary for its growth. In essence, standardization, often studied in fragmented pockets by different disciplines, can indeed be approached as a single interdisciplinary field with common principles. This cross-cutting theoretical contribution is perhaps the most significant outcome of the dissertation.

Discipline ▶ Chapter ▼	Economics / Management	Ethics / Sustainability	Sociology	IT/ Engineering	Law / Regulation / Policy
3	Technology adoption, Network effects, Value creation /appropriation, Platform ecosystems		Network density Tie multiplexity, Ego-networks Estimation methods (e.g., network sampling)		
4	Method (ordinary least squares), Economic benefits from participation in standardization, Market competition			Empirical setting (Technical standardization)	
5	Economics of geography, Evolutionary economics, Levels of standardization (subnational, national, regional, international)	Empirical setting (sea level rise), Global North/South duality, Nature-based solutions	Q-methodology		Adaptive policy making

Table 6-1 – Elements provided by each discipline to the three illustrative chapters

Chapter	Method	Level of analysis	Actors coordinated	Paradoxes	Value
3	Conceptual	Micro	Individuals	Quadratic network effects	Network value
4	Quantitative	Meso	Firms	Benefits of large vs small firms	Economic value
5	Qualitative	Macro	Standard bodies and institutions	Technical lock-in and regional path dependence	Environmental and societal value

Table 6-2 – Cross-study patterns that constitute the "protective belts" of standardization research

6.1.3 Contributions to broader research streams

In addition to reinforcing cross-disciplinary integration, the findings of this thesis advance theory in several research streams. The main research themes addressed (as displayed in Table 1-1) are: philosophy of science, management science, technology adoption, social network theory, economics of technology, economics of geography, and climate adaptation. Key theoretical contributions to such research streams are outlined below.

Philosophy of science: the thesis contributes to the philosophy of science by providing a bibliometric mapping of standardization research as an emerging interdisciplinary field. Science philosophers can build on the combination of bibliometrics, network analysis, and three illustrations to reveal the intellectual structure of a research domain and the patterns of knowledge flow between disciplines. The study identifies management science and economics as bridging disciplines that supply generalized theoretical frameworks ("horizontal" knowledge) across specialized standardization contexts, illustrating how interdisciplinary integration can enhance a field's theoretical coherence. By demonstrating that blending diverse disciplinary perspectives fosters a more unified research program for standardization, the thesis offers a concrete example of a philosophy of science framework to discuss the status of scientific fields.

Management science: the thesis also advances theory in management science. The review in Chapter 2 shows that standardization management within organizations is the most theory-oriented perspective of standardization research. The central role of management science in standardization is in line with de Vries' (2001) view of standardization becoming a specialization within business/management science, although interdisciplinary connections outside of management science are also discussed. This finding also reinforces management science's theoretical generalizability, demonstrating its capacity to structure and unify knowledge across contexts ranging from sociology to engineering. As a demonstration, this thesis also incorporates concepts of several sub-streams of management science, such as organization theory, innovation management, and quality management to a lesser extent.

Technology adoption is a central theoretical stream in Chapter 3. The chapter contributes to this stream by developing a refined model of how technologies (conveyed specifically through standards and platforms) gain value as they are adopted in networks. In doing so, it integrates classical adoption frameworks from economics and management with social network theory, introducing a formal approach that accounts for network structure, multi-sided participation, and heterogeneous network effects in adoption processes. The chapter also discusses how this framework is complementary to previous frameworks on network effects (Karhu et al., 2024) and on innovation diffusion (Rogers, 1962).

Social network theory is also mainly discussed in Chapter 3. Here, specific network characteristics – such as tie multiplexity, network density, and the presence of competitive or negative ties – appear as influencing factors of the aggregate value of a standard. Social network metrics have been widely used in technology and innovation studies (Bekkers et al., 2002; Gilsing et al., 2008), and this study contributes to a better use of such metrics in this context. By formalizing the link between network structure constructs (e.g., tie multiplexity and multisidedness) and collective outcomes (e.g., total platform value or adoption utility), and by providing practical guidelines for their measurements, this study provides a clear quantitative integration of such concepts.

Economics of technology is central to Chapter 4's econometric investigation of firm participation in technical standard-setting. The chapter provides empirical and theoretical insights into how participation affects firm-level economic performance, thus illuminating the strategic value of standardization in technology markets. The findings on group size and competition also have implications for other contexts of cooperation between competing firms discussed in the technology economics literature. These include technological alliances, patent pools, and open-source software consortia. In these contexts, smaller and focused firms may experience similar dynamics, such as higher benefits from cooperating in smaller settings with other "focused" competitors.

Economics of geography is discussed in Chapter 5 as the theoretical lens through which spatial specificity and standardization can be jointly approached. The chapter integrates concepts from economic geography (such as regional heterogeneity, regional path dependence, and local adaptation needs) with standardization theory in the context of climate change adaptation. This interdisciplinary approach demonstrates that global standards can be designed to remain flexible and place-sensitive, thereby aligning universal frameworks with diverse local conditions – a key concern in economic geography. In doing so, the thesis extends this literature stream by showing how path dependency and regional lock-in can be mitigated through adaptive standardization strategies that balance global consistency with geographic variation.

Climate adaptation is the last research stream, discussed in Chapter 5. The climate adaptation scholarship can benefit from such a study by integrating standardization into the related theoretical discourse. The conceptualization of an approach to "adaptive standardization" for sea-level rise response, proposing that standards can be formulated to guide adaptation measures while remaining flexible over time and across different regions, provides a new lens to the field. By bridging insights from adaptive governance, sustainability science, and technical standardization, the chapter broadens the theoretical understanding of climate adaptation measures – resulting in an innovative framework in which coordinated, standardized guidelines support resilience and long-term adaptation without sacrificing local relevance or the capacity to learn and adjust.

6.2 Limitations

Notwithstanding its contributions, this research has several limitations that must be acknowledged.

First, the choice to focus on interdisciplinary questions may distract from the importance of monodisciplinary studies of standardization. For example, the thesis does not delve deeply into what the standardization community calls "pre-normative" or technical research – e.g., detailed engineering studies that precede and inform the setting of standards, or into normative studies of purely legal nature. Such monodisciplinary work remains highly valuable, as it produces the technical and legal ground truths upon which standards are built. By excluding these, this thesis focuses on the socio-economic aspects of standardization. Consequently, the findings of the three illustrative studies are not fully generalizable to all aspects of standardization across every field, especially when comparing hard sciences vs. social sciences. Bridging fundamentally different epistemologies is challenging – for instance, integrating a pure engineering design perspective with a management perspective. These interdisciplinary studies did span a range (from technical ICT standards to social adaptation issues), but they still primarily operate in the realm of standards as socio-technical and organizational phenomena. I caution that the theoretical insights (e.g., about network effects or firm performance) might not directly translate to domains where standardization is driven purely by hard sciences or where the term "standardization" is interpreted differently (such as in mathematics and statistics). In summary, while interdisciplinarity improved theoretical consistency, it did not cover every discipline; there remains a need for dialogue with monodisciplinary research to ensure the theory works in all contexts.

Second, connected to the first issue is the exclusion of the medical and mathematical fields. This results from the decision, in our literature review (Chapter 2), to exclude such research from the dataset. The reasons for this are linked to the terminology and relevance: the term "standard" in medical and mathematical research is overwhelmingly used to mean, among others, "standard treatment", "standard protocol", "standard deviation" or "standard variable", rather than voluntary standards as intended in the standardization community. Including medical papers would have introduced thousands of articles about clinical practice guidelines that fall outside of the scope of this thesis. The medical field does engage in formal standardization (for example, in health informatics or medical device interoperability), and its terminological complexity prevented a systematic review of it. However, while this filtering was necessary to focus our analysis, some contributions from the healthcare domain to standardization theory was still captured. As to the mathematical field, the three studies of this thesis all made use of mathematical and statistical concepts (combinatorics in Chapter 3, regression analysis in Chapter 4, and z-scores in Chapter 5), but none explored the role of standardization for these two fields. This limitation leaves the open dilemma as to what extent do these findings reflect the domains of standardization in healthcare and exact sciences like mathematics and statistics. For example, related to its system of conformity assessment, which is more stringent than that of other industries. Future work could attempt a more nuanced text analysis to include more of the relevant literature. For now, the interdisciplinary theory built here should be seen as most applicable to the disciplines included and only cautiously extended to medical, mathematics, or other excluded domains.

Third, while each study in this thesis combined some disciplines, interdisciplinarity can be taken further, and this work did not explore all possible disciplinary nexuses (as shown in Figure 6-1). The contributions I identified by intersecting fields (e.g., economics + sociology, or economics + sustainability) are therefore illustrative rather than exhaustive. There are other disciplinary "nexus" areas that yield important insights about standardization, which I did not cover. For instance, law and standardization is one intersection briefly touched (for example discussing policymaking and patents). Because of the vastness of each discipline, the theoretical framework I propose lacks elements needed to generalize across all fields. In particular, bridging between very distant fields – say, quantum physics and sociology in the context of standards – might expose other theoretical gaps. The interdisciplinary integration achieved here, therefore, is necessary but not sufficient for a fully general theory. There is still a risk of isolated thinking when moving between hard sciences and social sciences in standardization research. My approach leans towards the latter, so a limitation is that I may not have fully resolved how to integrate the former.

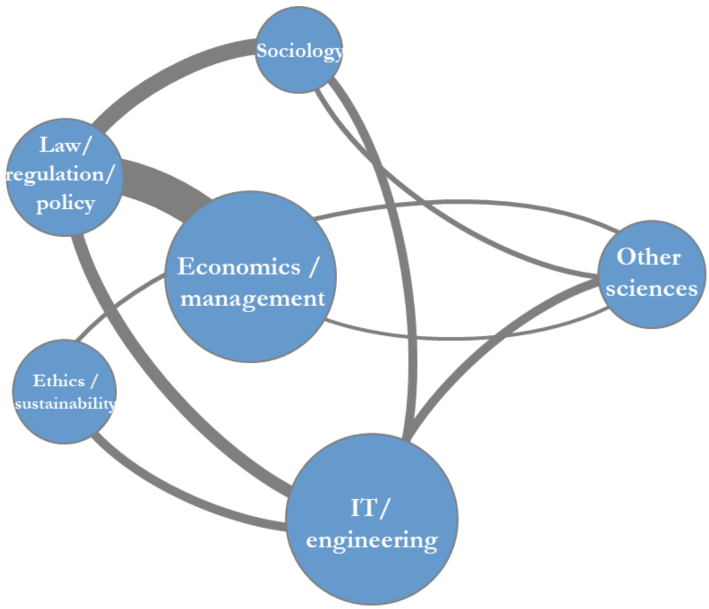


Figure 6-1 – The nexuses unexplored in this thesis

Fourth, the theoretical positioning of this thesis drew on the philosophies of Popper, Kuhn, and Lakatos to argue for standardization as a scientific field. However, I acknowledge that other philosophy of science perspectives were not incorporated, and they might lead to different interpretations. For example, Paul Feyerabend's epistemological anarchism argues against the adherence to any one method, which could imply that standardization research might be based on methodological pluralism rather than coherence. This aligns with this thesis' diversity in terms of methodological approaches. Sociologists of science, like Robert Merton (with norms of open science) or Pierre Bourdieu (science as a social field of power), have also studied how fields emerge and behave. Engaging with these could reveal different nuances to our approach. Our thesis implicitly assumes that the standardization research community should strive for a unified theory (a somewhat Kuhnian or Lakatosian stance). Yet, it is possible that standardization is better served by a multiplicity of theories tailored to different contexts – a more Feyerabendian or pluralist stance. While such arguments are not explored, they may support the importance of having multidisciplinary/monodisciplinary approaches that develop academic disciplines in isolation. Therefore, a limitation is the philosophical narrowness of our theoretical argument. The emergence of standardization as a scientific field might be conceptualized differently by other philosophers, and incorporating those views might qualify or even challenge our conclusions about theoretical consistency. This is left for future scholars to examine, ideally enriching the discussion of what it means for standardization to be considered as a scientific field.

In summary, the limitations of this research include its selective scope of disciplines, the exclusion of certain domains (like medicine) due to terminology barriers, the incomplete generalizability of its interdisciplinary integration, and a constrained philosophical lens. Recognizing these limitations is important, as they define the boundaries of our conclusions and set the basis for an agenda for future research.

6.3 Future research directions

Building on the above limitations and findings, each chapter of this thesis implies several directions for future research.

One immediate avenue deriving from Chapter 2 is to extend the bibliometric study to cover disciplines and topics that could be included only partially. As noted, incorporating medical and mathematical research, as well as other domains such as education or sports, could provide a more complete map of standardization research. These fields can benefit from the connection to other disciplines such as sociology (e.g., the mental health of patients or athletes) or law (e.g., the responsibility of doctors or teachers). A key role in this process is covered by subject matter experts who take charge of understanding, defining, and disseminating the role standards may assume within these interdisciplinary avenues. The review also pointed to emerging themes that deserve more attention, such as standards' role in shaping the platform economy, in orchestrating ecosystems, in enabling sustainable transitions, and in achieving the UN Sustainable Development Goals. Future research could take each of these domains and study how standardization processes are unfolding there – for instance, how standards contribute to the governance of digital platforms or how they can support sustainability and the circular economy. Another suggestion is to update the bibliometric analysis periodically (e.g., every five years) to see how the interdisciplinary network of standardization research evolves, especially as new technologies and concerns (like AI ethics or data privacy) enter the public debate. Performing this update could show if the interdisciplinary trend of standardization research is continuing at the same pace and if the challenge described in this thesis – i.e., the weak connection between hard and social sciences – is being addressed or not. Themes such as the sustainability of telecommunication systems and the ethics of AI systems seem to be increasingly investigated, and assessing the status of this process is key to the progress of the field. This would lead to a better understanding of the theoretical and practical development conveyed by interdisciplinary research.

The conceptual framework proposed in Chapter 3 can be both refined and empirically tested. Future studies could relax some of the simplifying assumptions made. For instance, I assumed an undirected network and single-mode ties; researchers could extend this to directed or weighted networks and multi-layered networks (Boccaletti et al., 2014; Chen et al., 2022; Kivelä et al., 2014), examining how a node's position (centrality, structural holes, etc.) affects its value (Freeman, 1982). Incorporating broader social network metrics (like betweenness centrality, clusters, or tie strength) into the model would provide a more granular understanding of network effects. Another important extension is to move from a static analysis to a dynamic one. Future research could simulate or analytically model scenarios where multiple standards or platforms compete over time, and adopters switch or choose technologies based on expected network growth (a bandwagon effect). Applying game theory (as in e.g., Farrell & Klemperer, 2011) or differential equations for diffusion dynamics could reveal how standards' battles play out under evolving conditions – for example, what tipping points lead to one standard to become dominant. Empirical validation is a crucial next step: studies could collect data on real networks of adopters to calculate network value as per our framework and see if it correlates with market outcomes. One potential avenue would be to explore the extent to which the dynamics between standard adopters apply to standard developers, thus checking if there are network effects between the members of standard bodies. Such empirical work would not only test the framework's predictions but might also uncover additional factors (e.g., the role of network externalities over time, or the impact of external shocks like a security breach on network value).

In Chapter 4, the findings about firms' economic benefits during and after technical standardization could lead to interesting future studies. One direction is to examine other performance outcomes beyond economic/financial metrics. For instance, although the effects on firms' innovation output are already widely studied (e.g., Delcamp & Leiponen, 2014; Rysman & Simcoe, 2008), it would be valuable to see if the same patterns hold for smaller and specialized firms. Another extension is to study different industries: our work focused on ICT, but industries like aerospace, agriculture, chemistry, construction, defense, automotive, healthcare, energy, fair trade, financial services or tourism might have different competitive dynamics in standards setting. Comparative studies across industries or different standard-setting organizations (SSOs) would test the generalizability of the chapter's conclusions. In particular, SSOs may vary in terms of tiers (e.g., sponsors versus regular members) and work disposition (e.g., in committees or working groups), and the impact on firms might differ depending on the SSO governance structure. Future research could also investigate the role of intellectual property in these dynamics. For example, how do standard-essential patents interact with a firm's economic gains? Additionally, the Chapter 4 findings raise a policy question related to the incentives for more small and specialized players to engage in standardization. Research could explore interventions like sponsored participation programs, or the creation of smaller working groups within larger SSOs, and test whether these help these kinds of firms realize the benefits that our study suggests are possible (de Vries et al., 2009).

Lastly, Chapter 5 suggests how SSOs can work on climate adaptation standards by implementing a multi-stakeholder, flexible approach. Observing such a process in action would validate whether the theoretical dimensions identified (place-based vs. global, stable vs. evolving) lead to better standards. Another research avenue is generalizing this approach to other societal grand challenges beyond sea-level rise, such as standards for education or for climate mitigation. Each of these might benefit from the kind of flexible, multi-level standardization strategy proposed, and studying them could refine the approach. Additionally, future research should examine the long-term effectiveness of adaptive standards. Do adaptive standards prevent lock-in and encourage continuous innovation? This could be studied by tracking cases where standards were updated or where local variants were allowed. Finally, Chapter 5 calls for further work on how geographic and temporal factors intersect with other dimensions of standardization (such as the level of competition and cooperation investigated in Chapter 4, or the mix of private/public actors). Studying these intersections could build new theory applicable not just to climate adaptation but to any rapidly evolving field where standards are needed.

6.4 Practical implications

The insights from this research, also due to the practical and managerial nature of standardization, carry several practical implications for different stakeholders involved in standardization. I highlight three broad categories here: private businesses (both large firms and SMEs/startups), standard-setting organizations, and policy makers (governments and regulators).

6.4.1 Implications for private businesses

For private firms, this research offers insights into how engaging with standardization can affect their performance and what strategies might be effective. One clear implication is that participation in standards development can be highly beneficial, but the extent of benefit depends on the firms' characteristics and the context of the SSO. Large multiproduct firms often participate in numerous standard-setting efforts and sometimes influence the setting of standards' specifications due to their market power. Our findings, however, highlight that even firms focused on only a few areas of technical standardization, highly specialized in niche technologies, can gain significant advantages from standardization if they choose their engagements wisely. The findings from Chapter 4 suggest that these focused (and, in most cases, smaller) players should join standard-setting organizations when the other participants are, to a larger extent, their competitors, since this may provide visibility and network opportunities that may translate into better performance. Otherwise, this may result in their competitors determining the rules for their business strategy.

Other practical implications relate to the external validity of the findings from the different interdisciplinary studies. The framework presented in Chapter 3 is intended for all kinds of standards regardless of their type or industry, as long as the adopters of such standards are subject to network effects. As a consequence, managers from all sectors can use it as a tool to reflect on the value their firms appropriate from adopting any standard in their industry. What is worth debating is the extent to which the findings from the other two studies are generalizable beyond their industry of reference. The implications of Chapter 4, for example, may partially apply to firms operating outside of the ICT domain, for example those developing sustainability or safety standards. Likewise, firms engaging in technical standardization may benefit from the pursuit of a flexible standardization process using the strategies outlined in Chapter 5. This includes, for example, the use of change requests already presented in the 3G Partnership Project.

Moreover, as our network effects framework showed, companies that already benefit from network-driven dominance should be mindful of the potential pushback (in terms of regulation or market distrust), and may rather dialogue with policymakers and standard-setting organizations (SSOs) preemptively to address these market issues together (as a form of co-regulation). In practice, this means large firms should support transparency in SSO governance, welcome SMEs and diverse participants, and limit practices that may lead the market to a technical lock-in (for example, by making core patents available on fair, reasonable, and non-discriminatory terms). This would also support the ongoing "vertical disintegration" that technical industries are facing, in favor of a progressive niche specialization (Schmidt & Foss, 2025). Such actions can preempt command-and-control regulatory intervention and ensure the longevity of the standards ecosystem that they also rely on (Kamara, 2017).

6.4.2 Implications for standard-setting organizations

This dissertation's findings have several practical implications for standard-setting organizations (SSOs). First, the composition of the SSO committee should reflect the interdisciplinarity of standardization research, as highlighted in Chapter 2. If standardization research and practice go hand in hand, the interdisciplinarity of research may be reflected in the work of SSOs. In practice, SSOs can leverage their multi-stage process to invite and integrate experts from multiple domains and stakeholder groups into committees, for example ethicists or lawyers. However, since participation is voluntary, an SSO's ability to enforce diversity is limited, and power may remain concentrated among a few stakeholders. Since voluntary participation typically attracts the groups of stakeholders that have more economic stakes, industrial representatives and private firms are often the most present group (Balzarova & Castka, 2012; Bijlmakers, 2022; den Uijl & de Vries, 2013; Ong & Glantz, 2001). SSOs may set inclusive guidelines and outreach strategies for committee formation, but must acknowledge that balanced representation cannot be mandated. This calls for creative incentives and awareness-raising to draw in under-represented expertise, so that standards benefit from the full breadth of interdisciplinary knowledge (Chapter 2) despite structural constraints.

Second, SSOs should adopt more nuanced metrics of success and adapt their strategies in a competitive SSO landscape, as evidenced by Chapters 3 and 4. Chapter 3 introduced a network-based framework for measuring standards adoption, cautioning SSOs against simplistic "bigger is better" assumptions (see also Aggarwal et al., 2011). Traditional network effects theory suggests that a standard's value grows with the size of its user base, but the findings indicate that adoption patterns depend on network structure, which varies much across types of standards. For SSOs, this implies that merely boasting large membership may be misleading, and that it is important to monitor how widely and deeply their standards are actually used, for example through industry feedback or usage networks, to inform standards review processes or the introduction of new work items. Additionally, Chapter 4's identification of a competition/size trade-off means that SSOs operate in an ecosystem where multiple forums often coexist. Indeed, many technology domains face rival SSOs, and firms strategically choose among them (Breeman et al., 2022; Wiegmann et al., 2023). SSOs hold considerable agenda-setting power – they can propose new standards and set the pace – but they cannot assume stakeholders will follow unconditionally. In practice, if an SSO's processes or policies are seen as too onerous or unaligned with member preferences, focused standardization players may shift to smaller, more specialized consortia (Leiponen, 2008; Lerner & Tirole, 2006). Research on competing SSOs shows that restrictive rules (e.g., stringent IPR or voting requirements) can impact the SSO's legitimacy by excluding some actors from participation (Chiao et al., 2007). Therefore, SSOs must carefully balance openness, governance stringency, and scope: they can structure participation by adjusting membership rules or voting schemes to either broaden inclusivity or ensure efficiency, but every choice involves trade-offs in influence and credibility. Ultimately, being aware of the broader standardization network – including rival or complementary SSOs – enables an SSO to position itself optimally, coordinating or differentiating its standards to avoid counterproductive fragmentation while preserving competition (Baron & Pohlmann, 2013).

Third, the need for flexible and context-sensitive standard development (Chapter 5) challenges SSOs to innovate within their procedural bounds. Climate adaptation standards exemplify an area where traditional one-size-fits-all approaches do not work (e.g., Hoffmann & Sgró, 2011). Chapter 5 highlighted the call from experts to develop standards in this domain by considering local conditions and rapidly evolving data, implying that SSOs should allow more place- and time-flexibility in how standards are crafted. In practice, SSOs can exercise flexibility by creating new work modes – for instance, the interplay between globally and locally initiated processes, or facilitating revision cycles by following ISO's procedure or by introducing change requests – to ensure standards remain relevant under changing conditions. Some SSOs have demonstrated this adaptability when prompted by external mandates: CEN/CENELEC, for example, developed a special guide for climate change adaptation in standards in accordance with EU policy, thereby integrating forward-looking resilience principles into standardization (CEN/ and CENELEC, 2016). This example shows that SSOs can adjust their processes (for example, by issuing interim specifications or regularly updated guidelines) to respond to urgent societal needs (de Vries, 1999; Egyedi & Blind, 2008).

6.4.3 Implications for policy makers

An overarching message for policymakers and regulators is that the interdisciplinarity of standardization may have consequences for standards and standardization policy. As our studies show, standardization is not a purely technical endeavor; it encompasses economic, social, and strategic dimensions. Therefore, regulators should foster communication between technical experts, economists, legal experts, and other stakeholders in the formulation of policies related to standards. A pertinent example is the cited need to regulate network-based industries, with legal scholars, economists, and sociologists coming together and working to address the criticalities related to the use of alternative assessment methods for technological dominance, which are alternative to the traditional approaches set out in competition law. This kind of integrated approach will likely become more common, with similar issues regarding, for example, horizontal cooperation agreements (see European Commission, 2023) or standards for cybersecurity. Thus, the suggestion for educators and researchers to form interdisciplinary teams also holds for policymakers. A hint of "interdisciplinary policy" is also visible, for example, in the Chinese and the European policies for standardization (European Commission, 2022; The State Council of the People's Republic of China, 2021), where multiple areas of standards are touched upon.

Another implication for policymakers is linked to the described geopolitical tensions that have arisen in recent years. The chapters of this thesis suggest ways through which governments and standard-setting organizations should collaborate for better national standardization strategies, for example considering the more flexible approaches outlined in Chapter 5 or estimating standards' network value using the framework of Chapter 3. Standardization can confer significant economic and strategic advantages, and it is increasingly treated as a policy priority. In recent years, major economies have indeed recognized this importance and released national standardization strategies (European Commission, 2022; The State Council of the People's Republic of China, 2021; The White House, 2023). These strategies typically aim to strengthen the home region's influence in international standards, ensure that standards support public interests, and invest in the skills and research needed for leadership in standardization. In light of the network effect study in Chapter 3, while international coordination can be achieved despite conflicting interests, the value appropriated by each country may vary, as the mutual benefits in having common global standards (interoperability, larger markets, collective safety) can be offset by higher competition or higher coordination costs.

One example is represented by the EU and the US, which have set up joint dialogues on technology standards (e.g., the Trade and Technology Council) to avoid divergent approaches in critical domains. This kind of collaboration should continue and extend to other domains. Lastly, regulators can use the insights on network dominance and competition from this thesis: when crafting rules (be it competition law guidance for standard-setting or policies for 5G/6G standards), they should consider the network effect dynamics and firm incentives identified in Chapter 3, as recently done by the British competition authority CMA on the antitrust intervention in the Microsoft-Activision merger case (CMA, 2023). For instance, encouraging the participation of smaller firms and new entrants in standards development (perhaps via subsidies or mandates in public-funded projects) could be a policy lever to counteract the tendency of large firms to dominate, thus keeping standardization ecosystems healthy and innovative. This contrasts with the command-and-control approach undertaken by other European tech regulations, such as the Digital Markets Act (European Commission, 2020).

In short, a higher consideration of the different disciplinary natures of standardization, more inclusive standardization policies both by policymakers and SSOs, and more pre-emptive dialogue between stakeholders aiming at a “co-regulation” system rather than a “sanctioning” one, would warrant better standards for a better society.

7. Appendices

Appendix of Chapter 2

Appendix A – Dataset quality, precision, and recall

Our review follows the Preferred Reporting Items for Systematic Reviews and Meta-analyses Protocol (PRISMA-P). The 17 points of the protocol, as described by Shamseer et al. (2015), are explained in Figure 7-1.

To measure the quality of our dataset we assess its precision and recall, where "precision" refers to how pertaining and relevant the papers included in the dataset are, and "recall" expresses the sample's completeness compared to all available sources (Gehanno et al., 2009; Donner et al., 2020). These are inversely related functions, meaning that a very precise dataset is likely to have a low recall and vice-versa (Gehanno et al., 2009). Eventually, we reached an estimated precision level of 87% (that is, while coding the papers, 13% of them were considered out of scope) and an estimated recall of 85%, expressing the extent of standardization literature represented in our sample. Agreeing on the extensive number of papers on standards available in the literature, we aimed for a more precise dataset not to compromise the quality and reliability of our data

Precision is measured as the share of correctly retrieved publications among the total number of retrieved publications (Donner et al., 2020). While categorizing the high-impact dataset (that is, the dataset is filtered according to the citation thresholds found in Table 2-1 of the full paper), we found 202 papers, out of 1555, that did not fit the scope of our definition of standardization. According to the formula by Donner et al. (2020), this means a precision of roughly 87% of our dataset.

Likewise, Donner et al. (2020) define recall as the share of correctly retrieved publications among all relevant publications. To measure recall, we took two independent sources from our dataset that complied with our definition of standardization. We extracted the set of papers citing these sources, and applied the same filters we applied to our dataset, such as the publication year (2012-2021), citation thresholds, and document type (only articles and reviews). Then, we only included the sources that had the word "standardization" or "standardization" in the abstract. From this subset of papers, we checked how many of them were also present in our main dataset by tracking the duplicates. We have completed this exercise for Farrell & Saloner's "*Standardization, Compatibility, and Innovation*" (1985) and for Tassey's "*Standardization in technology-based markets*" (2000), obtaining a result of 89% in the former case (17 out of the 19 skimmed sources were present in our main dataset) and 81% in the latter (21 out of 26 sources), averaging an estimated recall of 85%.

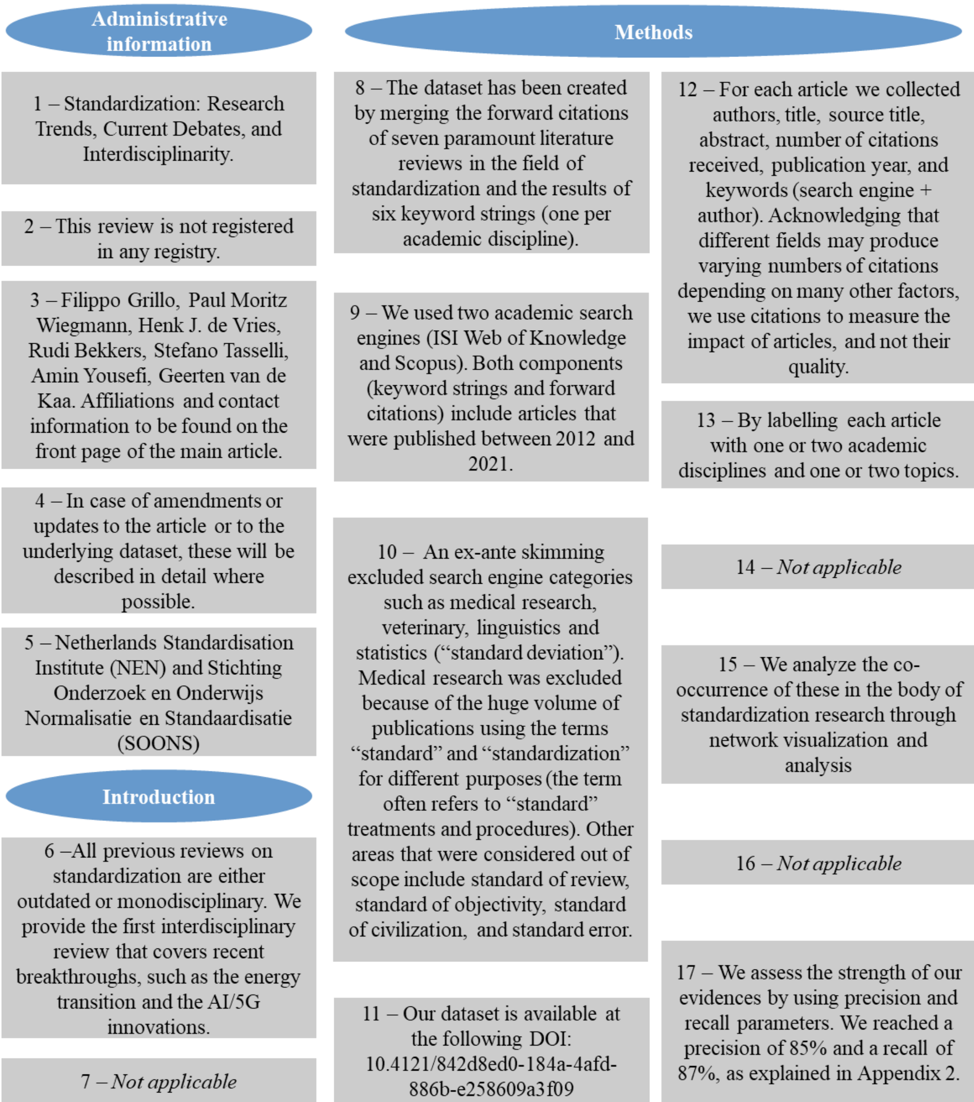


Figure 7-1 – Our systematic approach described through the PRISMA protocol

Appendix B – Network visualization

The network diagrams have been drawn using the software Gephi. The network nodes are based on either academic disciplines (in Figure 2-2) or topics (in

Figure 2-3 and Figure 2-4); the ties between the nodes are based on the number of sources that were categorized with the two nodes (i.e. co-occurrence). All graphs are designed following the same algorithm: the number of co-occurrences determines both the closeness of the nodes and the thickness of the ties. Such a layout is called *ForceAtlas2* in Gephi (Jacomy et al., 2014). This means that if many papers are labeled with e.g., *Telecommunications* and *Education*, these two nodes are close to each other and have a thick line connecting them; in addition, the node's size is determined by the number of papers labeled with the node's topic; lastly, in

Figure 2-3 and Figure 2-4 of the main article, the nodes were colored based on the type of topic (grey for the horizontal topics, blue for the vertical ones). Table 7-1 lists the top ten pairs of topics in terms of co-occurrences in our dataset.

	Topic 1	**Topic 2**	**Papers**
1	Energy policy	Impact assessment	23
2	RPS	Pricing	20
3	Automation	Telecommunications	19
4	Automation	Privacy and cybersecurity	17
5	Accounting and finance	Legitimacy	16
6	Agriculture	Multi Stakeholder Initiatives	16
7	Standards competition	Technology development and adoption	12
8	Telecommunications	Privacy and cybersecurity	10
9	Healthcare	Privacy and cybersecurity	9
10	Telecommunications	Technology development and adoption	8

Table 7-1 – Most recurring connections between topics

Appendix C – Limitations of the dataset

Our review provides a qualitative interpretation to a large set of bibliometric data. The process has been systematic and long, yet some limitations emerged. Although scholars agree that citations are not the sole indicator of the quality of research

(Bornmann & Daniel, 2008), multiple bibliometric reviews (e.g., Jappe, 2020; Liu et al., 2021; Blind & Fenton, 2021) make use of them in order to have a proxy of relevant publications in a specific field. For this reason, we refer to our dataset as made of "impactful" papers, without referring to the quality of such papers. We indeed acknowledge that the quality of a paper can be assessed in many other ways, yet this is seldom feasible in analyzing a large set of sources.

One improvement to our method regards the reliability of our thematic analysis. Even if performed in a sequential and unbiased way, the coding of each paper was limited to four keywords (two academic clusters and two topics), yet more terms could have been included for more profound content analysis. The triple-blinded process, though, ensured that the four keywords represented the focal content of each paper.

To reach a high precision of the dataset, we decided to exclude the medical categories while pooling the papers from search engines. Keywords such as "standard error" and "standard deviation" expanded our dataset with many papers from all medical sciences that did not fit the purpose of this article. However, many papers discussing the function of technical standards in medicine fell under our analysis, thanks to adjacent keywords such as "*Healthcare*" and "*Physics*". Due to this exclusion decision, we do not find the medical field as one of the vertical topics, but we now find it in the horizontal category. In fact, our distinction between horizontal and vertical is not always dichotomic, since some papers may have elements of both.

Lastly, our data include papers until June 2021. This means that our analysis partially reflects research on the Covid pandemic and the potential function of standardization to mitigate its consequences. Likewise, this applies to the Russian-Ukrainian war and the subsequent economic, energetic, and military crises.

Appendix D – Definitions of standards

In Table 7-2 below, we show the process behind the creation of working definitions for *standards*, *standardization*, or adjacent terms. For each discipline, starting from the most cited paper onwards, we extracted either a definition or a characterization for one of these terms. Most of the definitions or characterizations may be limited to an application area (e.g., "measurement" or "sustainability" standards). Once we gathered five definitions, we interpreted them commenting on the context and the function of standards they describe. Finally, we combined them into a unique working definition for each discipline. The table shows quite some diversity in definitions per discipline. The working definitions reflect our attempts to seek commonalities within the discipline. These working definitions differ substantially as well.

Definitions from Ethics/Sustainability		
Sources for definitions	Our interpretation	Working definitions
Standards are norms selected as a model by which to judge and compare people, products or actions, and which provide a common language to evaluators, the evaluated and their audiences (Ponte & Cheyns, 2013)	Emphasizes the measurement function of standards	Standards are voluntary set of norms, procedures or methods for assessing the social and environmental performance of products, processes, people or organizations
Sustainability standards may be understood as "voluntary predefined norms and procedures for organizational behavior with regard to social and/or environmental issues" (Christensen et al., 2017)	Specific to sustainable voluntary standards	
A sustainability standard can be defined as a set of 'voluntary predefined rules, procedures, and methods to systematically assess, measure, audit and/or communicate the social and environmental behavior and/or performance of firms' (Reinecke et al., 2012)	Specific to corporate sustainable voluntary standards, emphasizes the measurement and the communicative functions	
Voluntary standards are governance mechanisms that have recently taken off to achieve a positive impact of corporate actions on social actors and/or the natural environment (Wijen, 2014)	Specific to corporate voluntary standards	
Multi-stakeholder standards as standards that ensure membership of those concerned; with governance open for all stakeholders and with various parties taking on a 'watchdog' function (Balzarova & Castka, 2012, taken from Fransen & Kolk, 2007)	Emphasizes the presence of both private and public actors in the standardization process, and distinguishes governance and control as key stages in the standardization process	

Definitions from Sociology		
Sources for definitions	Our interpretation	Working definitions
Standards, and in particular transnational standards, are formal rules designed to play a coordinating function, through the specification of voluntary 'best practice' rules'.They are developed by non-state organizations and compliance often depends on pressure from third parties. (Schweber, 2013)	Excludes governmental standards. Also, most standards tend to be a compromise between stakeholders: the best practice, if any, is often not acceptable to the majority	Standards are measurements and technical rules built by individuals, groups and institutions for their control and compliance, reproducing particular societal values, beliefs, and assumptions
Standardization is the process by which individuals, groups and institutions construct 'uniformities across time and space' through 'the generation of agreed-upon rules' (Lamont et al., 2014)	Emphasizes the function of standards as solution providers, but excludes standards that set performance criteria or provide test methods	
Standards are the protocols, practices, procedures, and technologies that establish the rules for coordination across sociotechnical systems and, in so doing, establish path dependencies that shape future social and economic priorities. (Carse & Lewis, 2017)	Emphasizes the negative outcomes of standards (path dependency, power concentration). Technologies cannot establish rules, but rather the actors behind such technologies	
Standardization is increasingly recognized as a form of regulation and standards are regarded as 'instruments of control' […] that facilitate coordination by defining the appropriate attributes of the standardized subject, rendering these aspects visible to external inspection and opening up the possibility of sanctioning non-compliance (Slager et al., 2012)	Explains the regulatory function of mandatory standards, whose non-compliance can be sanctioned	
Standardization in the metrological sense results in the creation or definition of equivalent things, whereas standardization in the infrastructural sense refers to extending or implementing standards as technical guides or rules. (Cooper, 2015)	Emphasizes the double function of standards of providing measurement references and technical guidelines	

Definitions from Law/Regulation/Policy		
Sources for definitions	Our interpretation	Working definitions
Renewable Portfolio Standards (RPS) are a relatively new policy mechanism being put to use in several countries […] to reduce costs, link the regulated market outcome to an environmental target, and reduce government involvement (Sun & Nie, 2015)	Specific to RPS, whose function is the one of performance measurement for firms	
An intensity standard refers to a policy which regulates an externality per unit of output (Holland, 2012)	Similarly to RPS, intensity standards are an alternative method to measure firms' emissions	
Standards are tools for the reduction of transaction and agency costs (Botzem, 2014)	Explains the coordinating function of standards	Standards are a form of regulation developed by governments and private actors from business and civil society, usually laid down in a document which is approved by a recognized body
Standards are defined as a form of regulation, i.e. a specific type of rule, which is formed on the basis of a degree of common understanding among standard-setting actors. It comprises a set of solutions to actual or potential problems and is meant for common and repeated use. Standards are usually laid down in a document which is approved by a recognized body. They provide rules, guidelines or characteristics for activities (process-oriented) or results (output-oriented), thereby coordinating interaction (Van Den Hurk & Verhoest, 2016)	Explains the function of standards as regulations (i.e. mandated by a recognized body)	
Private standards are forms of voluntary rule-setting involving non-state actors from business and civil society (Dobusch & Quack, 2013)	Specific to private standards	

Definitions from Economics/Management		
Sources for definitions	Our interpretation	Working definitions
The standardisation of organisations relates to how standards are adopted, diffused, implemented, avoided, and altered in the course of their implementation. Standardisation by organisations concerns the fact that most standards are the product of formal organisations. Last, standardisation can be viewed as a form of organisation. In the latter context, standards provide organisation outside of formal organisations and hence can be perceived as an important governance mechanism (Brunsson et al., 2012)	Provides a useful distinction between three aspects of the standardization process (taking standards, making standards, and the multi-stakeholder governance)	
Technological standards provide foundational platforms on top of which rival firms build their product and service offerings. […] They appear primarily in the form of dominant designs. Dominant designs (e.g., Henry Ford's Model T, Apple's iPhone) emerge via market competition and become de facto standards, unlike the wireless telecom and other types of complex standards that are cooperatively developed (Teece, 2018)	Emphasizes the role of some types of standards (mostly compatibility standards) within ecosystems and their relationship with dominant designs and platforms	Standards are interface specifications and corporate practices that function as coordination mechanisms within innovation ecosystems
A standard defines the overall architecture of a technology system, accompanied by a set of interface specifications among component sub-systems. Standardization is the process of developing, ratifying and implementing standards (Gao et al., 2014)	Similarly to Teece (2018), it emphasizes the role of compatibility standards within ecosystems	
With Corporate Responsibility (CR) standardization we refer to the institutionalization of a standard, i.e. the progressive cognitive validation of a CR-related practice (Haack et al., 2012)	Specific to CR standards	
We define standards as digital technologies that enable, constrain and coordinate numerous actors' actions and interactions in ecosystems, fields or industries (Hinings et al., 2018)	Emphasizes again the role of standards in larger technological architectures (ecosystems, industries)	

Definitions from IT/Engineering		
Sources for definitions	Our interpretation	Working definitions
Standardization activities play a crucial role in securing the IoT ecosystem, both in terms of improving interoperability of IoT devices in general and to pave the way toward wider industry adoption of security solutions (Keoh et al., 2014)	Specific to compatibility and (cyber) safety standards	Standards are documents that ensure interoperability, cybersecurity and performance measurement of technological solutions
Standardization for wireless vehicular communication ensures, as in other domains, interoperability, supports regulations and legislation, and creates larger markets (Festag, 2015)	Emphasizes functions of standards (interoperability, market creation, and support for regulation)	
Standardization helps industry avoid interoperability issues and understand the technology landscape as the new technology frontier is created (Trappey et al., 2017)	Emphasizes the functions of interoperability and coordination (put in other words, the industry actors understanding of the new technology frontier)	
Standards are published documents that serve as a fundamental building block for product or process development and include methods for insuring usability, predictability, safety all parties involved in the manufacture of goods or delivery of services. A standard ensures intra and inter-operability of products and services produced and its compliance is mandatory for product commercialization (Trappey et al., 2016)	Specific to mandatory written standards	
Standardization of indicators provides harmonization in indicators, reliability and transparency in calculation methods and comparability of results (Huovila et al., 2019)	Emphasizes the function of performance measurement	

Definitions from Other sciences		
Sources for definitions	Our interpretation	Working definitions
Technology standards and specifications provide the basis to achieve interoperability, integration, and scalability through standardized protocols and data models (Memon et al., 2014)	Specific to protocols, emphasizes interoperability and scalability	
Standards can be expected to enable interoperability, reduce costs through economies of scale and create mass markets. More generally, common standards facilitate the diffusion of new technologies and the development of entire technological field (Erlinghagen et al., 2015)	Emphasizes interoperability and scalability	
Smart grid ICT standards mainly define communication protocols and interface specifications, but other aspects like cyber security and function modeling are also described (Naumann et al., 2014)	Specific to smart grid ICT standards, in the form of protocols, interface specifications, and cybersecurity standards	Standards are communication protocols, data models, and technical specifications that improve scalability, safety, quality assurance, and interoperability
Standards allow decoupling of design from production from assembly from deployment—and they help to reduce the lack of reproducibility of results that plagues the scientific and technical literature in biology and biotechnology (de Lorenzo & Schmidt, 2018)	Explains the implications of standards on production processes, contextualized to biology and biotechnology	
Standards can improve communication, compatibility, interchangeability, reproducibility, effective use, fitness for use, safety, quality assurance, and ultimately consumer protection and environmental protection (Müller & Arndt, 2012)	Does not provide a definition but lists some advantages of standards	

Table 7-2 – Working definitions for each academic discipline

Appendix E – Definition of standardization for management research

In the full paper, we try to develop a common definition for management research, applicable to all disciplines. We use this appendix to explain the process to arrive at our definition. The International Standardization for Standardization (ISO) and the International Electrotechnical Commission (IEC) define standardization as the activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimal degree of order in a given context. In particular, this activity consists of the processes of formulating, issuing and implementing standards (ISO/IEC, 2004, p. 4).

This definition is limited to standard-setting organizations, without specifying the *actual and potential problems* standards are established for. Discussing the characterizations of standards from 16 definitions, mostly from practitioners, De Vries (1997) formulated a wider definition, drawing the need for *common and repeated use* from the ISO/IEC definition (updated in 2004), to differentiate an agreed solution from a standard. Since then, even if no academic discourse emerged on the definition of standardization, literature from different academic disciplines has produced a wide variety of definitions. Here, we gather terms describing characterizations, actors involved, functions, types of obligation, and other elements from the different "disciplinary" definitions in Appendix D.

First, the definitions incorporate many characterizations of standards, e.g., *norms*, *procedures* or *methods* (discipline 1[1]), *technical rules* (2), *regulations* (3), *interface specifications* and *corporate practices* (4), *documents* (5) or *communication protocols*, *data models*, and *technical specifications* (6). Though most standards are technology-related, this does not apply to all of them, making the appellation *technical rules* appear too specific. The appellation as *documents*, instead, shows how a formalized writing is what distinguishes a standard from a social norm (see also Brunsson et al., 2012; Blind & Fenton, 2021). A second element concerns who develops these standards: *individuals, groups and institutions* (2) or *governments and private actors* (3). The other disciplines do not specify any actor, and this seems to be the best choice, given the vastness of stakeholders' categories that have developed standards in the past. Third, (3) mentions *approved by a recognized body*. This would exclude standards stemming from, for instance, industry consortia, individual companies or NGOs, limiting the scope of our definition. Fourth, some elements combined from the definitions can be annexed to our definition. This applies to the functions of standards, since they *assess social and environmental performance* (1), *facilitate control and compliance* (2), *are coordination mechanism within innovation ecosystems* (4), *ensure interoperability*, *cybersecurity and performance measurement of technological solutions* (5), and *improve scalability, safety, quality assurance, and interoperability* (6). The same applies to aims or benefits of standardization mentioned

[1] The numbering of working definitions refers to disciplines in Table 7-2: 1) *Ethics/sustainability*, 2) *Sociology*, 3) *Law/regulation/policy*, 4) *Economics/management*, 5) *IT/engineering*, 6) *Other sciences*

in some of the definitions (2, 5, 6), and to the two rates of obligation a standard can have, being either (1) *voluntary* or (3) a *form of regulation*. Lastly, to specify *which problems* ISO and IEC refer to, we build from many sources describing them as *coordination problems* (Slager et al., 2012; Schweber, 2013; Van Den Hurk & Verhoest, 2016; Carse & Lewis, 2017). Altogether, these elements lead to our definition of 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. The resulting set of solutions, often expressed in the form of a written document, is the standard.

Appendix F – Descriptive figures of standardization research

This appendix contains extensive information about the dataset that was used by the authors to shape the findings mentioned in the full paper.

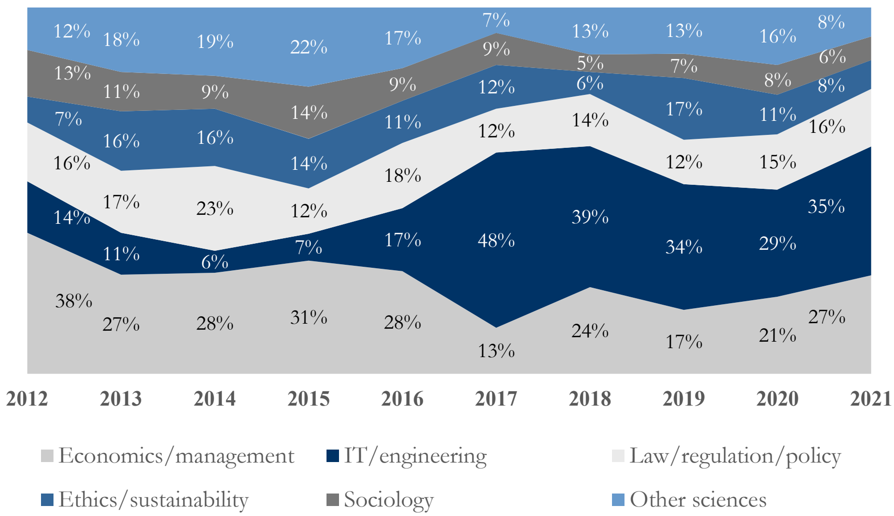


Figure 7-2 – Yearly share in the number of scientific papers on standardization per discipline

Table 7-3 includes a description of the most cited articles for each timespan and for each discipline, while Figure 7-2 exhibits the annual share of each academic discipline in our dataset. The most evident trend is the increase in *IT/engineering* in the last five years. A closer investigation of the papers itself shows that this shift is predominantly driven by the breakthrough of technical research on Industry 4.0 and on 5G telecommunications from 2016 onwards. *Economics/management* is a steadily relevant discipline for standardization studies, but it sees a slight relative decrease in the last five years, concurrent with the surge of *IT/engineering*. *Ethics/sustainability* and *Law/regulation/policy* have kept rather stable shares of standardization research over the years. *Sociology* has been decreasingly impactful: a significant amount of sources deriving from the work of Timmermans and Epstein (2010) and other previous studies (e.g., Timmermans & Almeling, 2009; Thévenot, 2009; Busch, 2011) did not follow up in more recent years.

On the other hand, research topics are the second dimension of our analysis after the academic disciplines. Identifying the core topics in each paper, we distinguish between horizontal and vertical topics. Horizontal topics relate to standardization as such, no matter the technical contents of the standards (e.g., *impact assessment, intellectual property rights (IPR), multi-stakeholder initiatives*) and include academic theories and streams relevant to the standardization field as a whole (e.g., *technology development and adoption, legitimacy, standards competition*). Vertical topics relate to the contents of standards and their area of application (e.g., *renewable portfolio standards, safety, metrology/instruments*), including other technical and scientific domains (e.g., *biology*, *physics*, *education*) and functions or departments of organizations (e.g., *accounting and finance, privacy and cyber security, corporate social responsibility*). Table 7-4 and Table 7-5 show how many papers we coded with each horizontal and vertical topic of standardization and provide working definitions of these topics. Interestingly, we note that the field is quite diverse, and there is no single topic dominating the literature.

Appendix G – Most impactful journals in standardization research

Which research communities are most involved in the standardization field? Scientific journals in which studies are published may form an indication for this. Table 7-6 lists the top ten journals by the number of high-impact publications in our dataset. We grouped them into three main categories: energy and environmental, technical and engineering, and research on management and policy.

Academic discipline	Papers	Top five papers per number of citations (2012-2016)	Top five papers per number of citations (2017-2021)
Ethics/ sustainability	189	Papers on certifications based on agricultural standards for palm oil (Ponte & Cheyns, 2013; Von Geibler, 2013), and coffee (Reinecke et al., 2012), institutions' adoption of sustainability standards (Wijen, 2014), an empirical analysis of labor standards in different countries (Davies & Vadlamannati, 2013).	Papers on certifications based on agricultural standards for palm oil (Brandi, 2017; Higgins & Richards, 2019), the ethics of teaching standards (Elton-Chalcraft et al., 2017), energy access as a living standard (Rao & Pachauri, 2017), and disclosure of sustainability standards (Christensen et al., 2017).
Sociology	146	Two case studies on the legitimacy of global accounting standards (Guerreiro et al., 2012; Albu et al., 2014), a framework for standardization against social inequalities (Lamont et al., 2014), an investigation of responsible investment standards (Slager et al., 2012), a paper on the governmentality of standards in the construction industry (Schweber, 2013).	A position paper on the usage of clicks as a standardized metric in journalism (Christin, 2018), an analysis of the governmental enforcement of labor standards (Fine, 2017), and papers on the use of standardized definitions for population ethnicity in genetics (Panofsky & Bliss, 2017), fair and inclusive infrastructure standards (Carse & Lewis, 2017), and the inclusion of producers in global supply chain governance (Bennett & College, 2017).
Law/ regulation/ policy	251	Two comparative studies of feed-in tariffs vs renewable portfolio standards (Dong, 2012; Sun & Nie, 2015), and papers on the standardization of flood maps to allow local governments to mitigate flood risks (Porter & Demeritt, 2012), emission standards vs emission taxes (Holland, 2012), and standardization to support regulation of electric vehicles (Li et al., 2016).	An essay on how predictive micro directives can prevail on laws and standards (Casey & Niblett, 2017), a paper on the use of education standards by the OECD (Addey, 2017), a comparative study of feed-in tariffs vs renewable portfolio standards (Alizada, 2018), and two papers on how governments regulate via standards and certificates, in the bio-based industry (Ladu & Blind, 2017) and on cybersecurity (Srinivas et al., 2019).
Economics/ management	411	Four conceptual papers on the role of standards in platforms ecosystems (Gawer & Cusumano, 2014) and industrial evolution (Benner & Tripsas, 2012; Cusumano et al., 2014), and the dynamics of standardization in organization theory (Brunsson et al., 2012). A paper on lending and credit standards in the 2008 subprime crisis (Dell'Ariccia et al., 2012).	Papers on the role of standards in innovation ecosystems (Teece, 2018; Hinings et al., 2018; Dattee et al., 2018), and on the energy industry – technology selection for biomass thermochemical conversion (van de Kaa et al., 2017), and impact assessment of wind power plants (Aghbashlo et al., 2018).

IT / engineering	409	Five descriptive papers on novel IT-related standards: IETF's protocols on IoT (Sheng et al., 2013; Keoh et al., 2014), Business Model Process and Notation (BPMN) (Chinosi & Trombetta, 2012), and the general architecture of standards for wireless charging technologies (Lu et al., 2016) and smart grids (Fan et al., 2013).	Three review papers on novel IT-related standards: 5th Generation of networks (Shafi et al., 2017), Direct Current (DC) microgrid technology (Kumar et al., 2017), IoT protocols from IETF, IEEE, IEC and ETSI (Trappey et al., 2017), and two survey papers on unmanned aerial vehicles (UAV) and cellular communications (Fotouhi et al., 2019), and on M2M and IoT technologies (Gazis, 2017).
Other sciences	227	An estimation of the mass of the Higgs boson using a standardized model (The CMS Collaboration, 2015), a paper on the use of standard silicon levels in metal-oxide semiconductors (Abediasl & Hashemi, 2015), a review of standardization of Terahertz (THz) communications (Kürner & Priebe, 2014), a paper on the standardization of performance benchmarking in genetics (Hwang et al., 2015), and a framework for living standards in the healthcare sector (Memon et al., 2014).	An analysis on the use of standard steady-state algorithms in genetics (Corus & Oliveto, 2018), a paper on the use of standard silicon levels in metal-oxide semiconductors (Zhu et al., 2018), a paper on minimal standards for describing new species of agrobacteria (De Lajudie et al., 2019), a paper on the use of standard and non-standard solvents in chromatography (Ghanem & Wang, 2018), and a review on the use of standards to measure biological functions (de Lorenzo & Schmidt, 2018).

Table 7-3 – Content of the top five papers per academic discipline

Horizontal topic	Papers	Description
Technology development and adoption	72	Adoption, diffusion, emergence, architecture, and transfer of technology standards.
Impact assessment	51	Measurement of economic and social impacts of standards and related regulations.
Legitimacy	48	Perception or assumption that a standard or standardization process is desirable, proper, or appropriate within the rules and belief systems in which they operate.
Standards competition	46	Standards battles, the emergence of dominant designs and the factors contributing to market success.
Local context	45	Standardization at the level of individual countries as well as local communities, exploring themes like standards to support authenticity, community standardization, and a variety of socio-cultural factors.
Multi-stakeholder initiatives	45	Partnerships between governments, private actors and society, including quality standards and conformity assessment, such as the standards underlying fair trade and eco-labels.
Corporate strategy	43	Studies on how to strategically use standardization in companies.
Innovation management	40	Interplay between standardization and innovation, both at an institutional and corporate level.
IPR	40	Standard-essential patents, the relationship between SDOs and patent owners, and the trade-off between patenting and standardization.
Pricing	32	Tariffs, royalties, license fees and cost-benefit analysis of standards.
Standards pervasiveness	27	The repercussions of standards in broad societal groups. Includes notions such as standards governmentality, sociology of expectations (how shared expectations of plausible futures shape the evolution of sociotechnical systems), sociology of quantification, and unintended consequences.
Trade	23	The role of standards in facilitating the exchange of goods and services between countries, regions, and institutions, including the role of the WTO and free-trade agreements.
Harmonization	18	The globalization and convergence of standards across different institutional and jurisdictional regimes.
Network analysis and effects	15	The increase of economic and social utility of standards the more adopters they have, generating increasing returns of scale.
Interoperability	15	The compatibility of formats and interfaces. Includes the notion of open standards.
Platforms	14	Organizations comprising two or more groups of customers/stakeholders where standards play the role of boundary resources.
Knowledge diffusion	13	The interplay between standardization and information disclosure between standards' stakeholders.
Meta-governance	7	The management of plural schemas to induce more coordination in the governance of public and private organizations.
History	6	Articles on the history of standards and standardization.

Table 7-4 – Horizontal topics for standardization research

Note: since every paper can be associated with up to two topics, the sum of papers in all rows is higher than the total number of papers in the dataset.

Vertical topic	Papers	Description
Telecommunications	209	Developments in the information technology and telecommunications industry, including wireless communication, 5G, virtualization and data transmission.
Automation	132	IT-related topics such as Industry 4.0, artificial intelligence, IoT and smart cities.
Energy policy	109	Energy value chains and standardization in the management of renewable and non-renewable energy sources, standardization for smart grids, gas efficiency and CO_2 emissions, and standards for electric vehicles.
Healthcare	97	Nursing standards, legal procedures in the healthcare industry and, more recently, the COVID-19 pandemic.
Accounting and Finance	87	Standards on tax, auditing and financial reporting principles, and emerging themes like responsible finance and green finance.
Privacy and cyber security	79	Encryption and cryptography standards and legal implications within the field of privacy.
Agriculture	73	Water and food systems, food supply chains, organic products, and standards on activities like cultivation, irrigation and farming.
Education	63	Standards in higher and lower education, such as teaching standards or professional standards.
Human rights	54	Labor standards, living and minimum wage standards, well-being policies, social work, and standards for equality.
Renewable Portfolio Standards	41	Obligations for companies to produce electricity from renewable energy sources.
Physics	34	Specifications of standards incorporating physics artefacts or processes, such as sensors, optical and electronic components, and spectroscopy.
Energy engineering	30	Technical and infrastructural aspects of the energy sector.
Chemistry	29	Specification of standards incorporating chemical processes. Includes biochemistry.
Metrology/ instruments	28	Standards for quantities and units, measurement processes, and equipment used for the latter.
Civil engineering and transport	26	The standardization of building practices and materials, as well as urban management and smart transportation systems.
Public sector	22	The role of governments and institutions in standardization, with a focus on public procurement, Public-Private Partnerships, public investments and eGovernment.
Biology	22	Specifications of standards in the field of biology and biotechnologies.
CSR	20	Contribution of standards to Corporate Social Responsibility.
Renewable Fuel Standards	19	Standards for renewable fuels for transportation systems.
Supply chain and operations management	19	Standardization supporting (local and global) supply chain management and operations, such as quality management, six-sigma, and enterprise resource planning.
Marketing and consumer behavior	18	The cultural and psychological factors influencing the adoption of standards by humans.
SDGs	17	Relationship between standardization and the 17 U.N. Sustainable Development Goals.
Safety	16	Research on safety standards and physical/environmental risk management.
Image and video processing	15	Standards (protocols) for image and video coding and encryption.
Sports	10	Standardization of rules and regulations in different sports.
Psychology	8	Psychological research on standardization.
International relations	6	Standardization as a tool for global governance.
Geology	5	Standardization for earth sciences and seismology.
Genetics	5	Standard measurements for clinical genetics and genomics.

Table 7-5 – Vertical topics of standardization research

Note: since every paper can be associated with up to two topics, the sum of papers in all rows is higher than the total number of papers in the dataset.

Journal	Papers	Energy and environmental research	Technical and engineering research	Management and policy
Energy Policy	29	✔		
IEEE Communications Magazine	27		✔	
Research Policy	26			✔
IEEE Access	24		✔	
Journal of Cleaner Production	24	✔		
Technological Forecasting and Social Change	16			✔
IEEE Communications Standards Magazine	14		✔	
Telecommunications Policy	14		✔	
Energy Economics	13	✔		
Organization Studies	12			✔

Table 7-6 – Top ten journals for high-impact publications on standardization

Appendix of Chapter 4

Appendix 1 – SSOs' hierarchy

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
1394TA		✔		✔	Working groups focus on IEEE 1394 (FireWire) standards.	1394TA Archive
3GPP		✔			Three Technical Specifications Groups (TSGs) divided into several Working groups (WGs) develop interdependent 3G/4G standards.	3GPP Groups
3GPP2		✔			Similar to 3GPP, focused on CDMA2000 standards.	3GPP2 Archive
AES (Audio Engineering Society)		✔			WGs focus on audio standards (e.g., AES67).	AES
AFEI (Armed Forces Electronics & Intel.)				✔	Merged into NDIA; was an alliance.	NDIA
ASTM	✔	✔	✔		Committees (e.g., Steel, Plastics) with WGs under them. WGs are called "subcommittees".	ASTM
ATIS	✔	✔	✔		Committees (e.g., Network, Security) with WGs. WGs are called "subcommittees".	ATIS
AUTOSAR		✔		✔	WGs develop automotive software standards.	AUTOSAR
Accellera		✔		✔	WGs focus on EDA standards (e.g., SystemVerilog).	Accellera
Advanced Television Systems Committee (ATSC)	✔	✔	✔		Committees (e.g., TG3) with WGs for TV standards.	ATSC
BSF (Broadband Services Forum)				✔	Dissolved; was an alliance.	BSF Archive
BioAPI Consortium		✔		✔	WGs for biometric API standards. It became a subcommittee of JTC1 between ISO and IEC	BioAPI Archive

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
Bluetooth SIG		✔		✔	WGs develop interdependent Bluetooth specs.	Bluetooth
CAMI (Coalition Against Malware)				✔	Defunct; was an informal alliance.	N/A
CDG (CDMA Development Group)		✔		✔	WGs focus on CDMA evolution.	CDG
CDISC (Clinical Data Interchange Standards)	✔	✔	✔		Committees (e.g., SDS) with WGs.	CDISC
CEA (Consumer Electronics Assoc.)	✔	✔	✔		Committees (e.g., Video, Audio) with WGs.	CTA Tech
CENSA (CEN Security Alliance)				✔	Merged into other EU bodies.	CEN Archive
CIPA (Camera & Imaging Products Assoc.)		✔		✔	WGs for camera standards (e.g., EXIF).	CIPA
CableLabs		✔		✔	WGs develop DOCSIS, PacketCable.	CableLabs
CalConnect		✔		✔	WGs for calendaring standards.	CalConnect
CTIA	✔			✔	Committees (e.g., Cybersecurity, IoT).	CTIA
DDEX (Digital Data Exchange)		✔		✔	WGs for digital media standards.	DDEX
DECT Forum		✔		✔	WGs for cordless telecom standards.	DECT Forum
DLNA		✔		✔	WGs for interoperable media devices.	DLNA Archive
DMPF (Digital Media Project)				✔	Dissolved; was an alliance.	N/A
DMTF (Distributed Mgmt Task Force)		✔			WGs for cloud/IT management standards.	DMTF
DRM (Digital Radio Mondiale)		✔		✔	WGs for digital radio standards.	DRM
DVB Project	✔	✔	✔		Committees (e.g., technical module, commercial module) with WGs.	DVB
DVD Forum		✔		✔	WGs for DVD/Blu-ray standards.	DVD Forum Archive
ECMA International	✔	✔	✔		Committees (e.g., TC39 for JavaScript).	ECMA
ECOM (E-Commerce Standards Mgmt)				✔	Defunct; was an alliance.	N/A
ECSS (Space Standardization)		✔			WGs for space engineering standards.	ECSS

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
EDA (Electronic Design Automation)		✔		✔	WGs for chip design standards.	EDA Consortium Archive
EDIFICE (E-Commerce Standards)				✔	Focused on B2B e-commerce.	EDIFICE
EEMBC (Embedded Benchmarks)				✔	Alliance for performance benchmarks.	EEMBC
EIC (Electronics Industry Council)				✔	Merged into other trade groups.	N/A
EIDQ (Enterprise Data Quality)				✔	Defunct; no subdivisions.	N/A
EMF-EMI Control				✔	Informal group; no structure.	N/A
ERTICO (ITS Europe)		✔		✔	WGs for intelligent transport systems.	ERTICO
ETIS (Telco IT Standards)				✔	Alliance for telecom IT best practices.	ETIS
ETP (Energy Technology Platform)				✔	EU energy research alliance.	ETP
ETSI	✔	✔	✔		Committees (e.g., TC Cyber) with WGs.	ETSI Committees
EUROGEOGRAPHIC				✔	Geospatial data alliance.	EUROGEOGRAPHIC
EUROGI (Geographic Info.)				✔	Dissolved; was an alliance.	N/A
Echonet		✔		✔	WGs for smart home standards.	Echonet
Eclipse Foundation		✔		✔	WGs for open-source tools.	Eclipse
Energistics		✔		✔	WGs for energy data standards.	Energistics
Eurogeographic				✔	Same as EUROGEOGRAPHIC.	Eurogeographic
FIPA (Agent Standards)				✔	Defunct; was an alliance.	N/A
Flexray Consortium		✔		✔	WGs for automotive networking.	Flexray Archive
GLOBALPLATFORM		✔		✔	WGs for secure chip standards.	GlobalPlatform
GSDI (Global Spatial Data Infra.)				✔	Alliance for geospatial data.	GSDI
GVF (Global VSAT Forum)				✔	Merged into ESOA.	GVF Archive
GSA (General Services Admin.)	✔				Government body; no WGs.	GSA
Gigabit Ethernet Alliance				✔	Merged into IEEE 802.3.	N/A

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
HAVi (Home Audio/Video Interop.)				✔	Defunct; no subdivisions.	N/A
HDMI Forum		✔		✔	WGs for HDMI specs.	HDMI Forum
HIMSS (Healthcare IT)	✔				Committees for healthcare IT.	HIMSS
HR-XML		✔		✔	WGs for HR data standards.	HR-XML Archive
Home Gateway Initiative		✔		✔	WGs for home gateway specs.	HGI
HomePNA		✔		✔	WGs for home networking.	HomePNA Archive
HomePlug Alliance		✔		✔	WGs for powerline networking.	HomePlug
IBIA (Biometric Industry Assoc.)				✔	Advocacy group; no WGs.	IBIA
IBTA (InfiniBand Trade Assoc.)		✔		✔	WGs for InfiniBand specs.	IBTA
IDEAMA (Industrial Data Exchange)				✔	Defunct; no subdivisions.	N/A
IDEAlliance	✔				Focused on printing/color standards.	IDEAlliance
IDEMA (International Disk Drive)				✔	Dissolved; was an alliance.	N/A
IDPF (Int'l Digital Publishing)				✔	Merged into W3C.	IDPF Archive
IEEE	✔	✔	✔		Societies (e.g., Computer Society) with WGs (e.g., 802.11).	IEEE
IETF		✔			WGs (e.g., HTTP, TLS) develop internet standards.	IETF
IFSF (Fuel Standards Forum)		✔		✔	WGs for fuel retail standards.	IFSF
IIA (Internet Infrastructure Assoc.)				✔	Defunct; no subdivisions.	N/A
IMTC (Multimedia Telecom)		✔		✔	WGs for VoIP/video standards.	IMTC Archive
INC (InterNational Committee)				✔	Now part of INCITS.	INCITS
INEMI (Electronics Manufacturing)		✔		✔	WGs for manufacturing standards.	INEMI
INTERNET2				✔	R&D consortium; no WGs.	Internet2

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
INTUG (Int'l Telecom Users Group)				✔	Advocacy group; no WGs.	INTUG
IPTC (News Metadata)		✔		✔	WGs for news standards (e.g., NewsML).	IPTC
IRDA (Infrared Data Assoc.)				✔	Dissolved; no subdivisions.	N/A
ISC (Infra. Security Consortium)				✔	Defunct; no subdivisions.	N/A
ISMA (Internet Streaming Media)				✔	Merged into other groups.	N/A
IVI (Industrial Volatile Interfaces)				✔	Defunct; no subdivisions.	N/A
IWA (Irrigation Water Assoc.)				✔	No subdivisions.	IWA
INCITS	✔	✔	✔		Committees (e.g., B10 for barcodes) with WGs.	INCITS
IrDA				✔	Dissolved; no subdivisions.	N/A
JCF (Java Community Process)		✔		✔	Expert Groups (like WGs) for Java specs.	JCP
JEDEC	✔	✔	✔		Committees (e.g., JC-42) with WGs.	JEDEC
Khronos Group		✔		✔	WGs (e.g., Vulkan, OpenGL).	Khronos
KNX Association		✔		✔	WGs for smart building standards.	KNX
LONMARK		✔		✔	WGs for LonWorks automation.	LONMARK
LXI (LAN eXtensions for Instruments)		✔		✔	WGs for test/measurement standards.	LXI
Liberty Alliance		✔		✔	WGs for federated identity.	Liberty Archive
MEF (Metro Ethernet Forum)		✔		✔	WGs for carrier Ethernet.	MEF
MIPC (Mobile IPC Alliance)				✔	Defunct; no subdivisions.	N/A
MIPI Alliance		✔		✔	WGs for mobile interface specs.	MIPI
MMA (Mobile Marketing Assoc.)				✔	No subdivisions.	MMA
MPEGIF (MPEG Industry Forum)				✔	Advocacy group; no WGs.	MPEGIF Archive
MSF (Multiservice Switching Forum)				✔	Merged into MEF.	N/A

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
Mobey Forum				✔	Focused on mobile finance.	Mobey
NCOIC (Network-Centric Ops.)				✔	Dissolved; no subdivisions.	N/A
NFC Forum		✔		✔	WGs for NFC standards.	NFC Forum
NIL (National Information Library)				✔	Defunct; no subdivisions.	N/A
NPC Forum (Near Field Communication)				✔	Merged into NFC Forum.	N/A
NISO	✔	✔	✔		Committees (e.g., Z39) with WGs.	NISO
OAGI (Open Applications Group)		✔		✔	WGs for business data standards.	OAGI
OASIS	✔	✔	✔		TCs (like committees) with WGs.	OASIS
OCP-IP (Open Core Protocol)				✔	Merged into Accellera.	N/A
ODVA (DeviceNet/Vendor Assoc.)		✔		✔	WGs for industrial networking.	ODVA
OGC (Open Geospatial Consortium)		✔			WGs for geospatial standards.	OGC
OIF (Optical Internetworking Forum)		✔		✔	WGs for optical networking.	OIF
OMA (Open Mobile Alliance)	✔	✔	✔	✔	Contained both TCs and WGs for mobile service standards.	OMA Web Archive 2017
OMTP (Open Mobile Terminal Platform)				✔	Dissolved; no subdivisions.	N/A
ONFI (Open NAND Flash Interface)		✔		✔	WGs for flash memory standards.	ONFI
OPA (OpenFabrics Alliance)				✔	No subdivisions.	OPA
OPEN AJAX ALLIANCE				✔	Defunct; no subdivisions.	N/A
OPEN FORUM EUROPE				✔	Advocacy group; no WGs.	OFE
OSGI Alliance		✔		✔	WGs for Java modularity.	OSGI
OTA (Open Travel Alliance)		✔		✔	WGs for travel industry standards.	OTA
OW2 (Open Source Middleware)				✔	No subdivisions.	OW2

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
PC104 Consortium				✔	No subdivisions.	PC104
PCCA (Portable Computer Comm. Assoc.)				✔	Defunct; no subdivisions.	N/A
PCI-SIG		✔		✔	WGs for PCI Express standards.	PCI-SIG
PDES (Product Data Exchange Standards)				✔	Merged into other groups.	N/A
PHS MoU Group				✔	Defunct; no subdivisions.	N/A
PICMG (PCI Industrial Computers)		✔		✔	WGs for embedded computing.	PICMG
PIDX (Petroleum Industry Data Exchange)		✔		✔	WGs for oil/gas data standards.	PIDX
PMCIG (Power Management Coalition)				✔	Defunct; no subdivisions.	N/A
PWG (Printer Working Group)		✔		✔	WGs for printing standards.	PWG
Power.org		✔		✔	WGs for Power Architecture.	Power.org Archive
Project MESA (Public Safety Comms.)		✔		✔	WGs for emergency comms.	MESA
RapidIO Trade Assoc.		✔		✔	WGs for interconnect standards.	RapidIO
SA Forum (Service Availability)		✔		✔	WGs for telecom software.	SA Forum
SCSI Trade Assoc.		✔		✔	WGs for storage standards.	SCSI
SDR Forum (Software Defined Radio)		✔		✔	Now Wireless Innovation Forum.	SDR Forum
SEMATECH				✔	R&D consortium; no WGs.	SEMATECH
SIA (Security Industry Assoc.)				✔	Advocacy group; no WGs.	SIA
SIFA (Semiconductor Industry Financial Assoc.)				✔	Defunct; no subdivisions.	N/A
SIM Alliance				✔	Focused on SIM card standards.	SIM Alliance
SIP Forum		✔		✔	WGs for VoIP standards.	SIP Forum
SISO (Simulation Interoperability)		✔		✔	WGs for modeling/simulation.	SISO
SMDG (Shipping Industry Standards)				✔	No subdivisions.	SMDG

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
SNIA (Storage Networking)	✔	✔	✔		Committees (e.g., SSSI) with WGs.	SNIA
SPC (Storage Performance Council)				✔	No subdivisions.	SPC
SSCI (Semiconductor Safety Council)				✔	Defunct; no subdivisions.	N/A
SATA-IO		✔		✔	WGs for SATA standards.	SATA-IO
Smart Card Alliance				✔	Advocacy group; no WGs.	SCA
SMPTE	✔	✔	✔		Committees (e.g., TC-32) with WGs.	SMPTE
Spirit Consortium				✔	Merged into Accellera.	N/A
TAHI Project				✔	IPv6 testing; no subdivisions.	TAHI
TCG (Trusted Computing Group)		✔		✔	WGs for security standards.	TCG
TD-SCDMA Forum				✔	Defunct; no subdivisions.	N/A
TEI (Text Encoding Initiative)				✔	No subdivisions.	TEI
TETRA Assoc.		✔		✔	WGs for critical comms.	TETRA
The Globus Consortium				✔	Dissolved; no subdivisions.	N/A
TIA	✔	✔	✔		Committees (e.g., TR-42) with WGs.	TIA
TM Forum		✔		✔	WGs for telecom management.	TM Forum
TOG (The Open Group)		✔			WGs for enterprise architecture.	TOG
TPC (Transaction Processing Council)				✔	No subdivisions.	TPC
TV Anytime Forum				✔	Merged into other groups.	N/A
TWIST (Financial Messaging)				✔	No subdivisions.	TWIST
The Khronos Group		✔		✔	WGs for graphics/compute.	Khronos
The Linux Foundation		✔		✔	Collaborative projects (like WGs).	Linux Foundation
UMTS Forum				✔	Advocacy group; no WGs.	UMTS Forum
UPnP Forum		✔		✔	WGs for device interoperability.	UPnP
USB-IF		✔		✔	WGs for USB standards.	USB-IF

SSO Name	Includes Committees?	Includes Working Groups?	Includes Both?	Informal SSO?	Notes on hierarchy	Website
USPI (Universal Serial Protocol Initiative)				✔	Defunct; no subdivisions.	N/A
UniForum				✔	Merged into other groups.	N/A
Unicode Consortium		✔			WGs for character encoding.	Unicode
Universal Wireless Comm. Consortium				✔	Defunct; no subdivisions.	N/A
VESA		✔		✔	WGs for display standards.	VESA
VICS (Voluntary Interindustry Comm.)				✔	No subdivisions.	VICS
VITA (VMEbus Trade Assoc.)		✔		✔	WGs for embedded computing.	VITA
VoIPSA (VoIP Security Alliance)				✔	Defunct; no subdivisions.	N/A
VPNC (VPN Consortium)				✔	No subdivisions.	VPNC
VoiceXML Forum				✔	Merged into W3C.	N/A
W3C		✔			WGs (e.g., HTML, CSS) develop web standards.	W3C Process
WEB3D Consortium		✔		✔	WGs for 3D graphics.	Web3D
WEDI (Healthcare IT)				✔	No subdivisions.	WEDI
WFMC (Workflow Management Coalition)				✔	No subdivisions.	WFMC
WorldDAB		✔		✔	WGs for digital radio.	WorldDAB
XBRL International		✔		✔	WGs for financial reporting.	XBRL
ZigBee Alliance		✔		✔	WGs for IoT standards.	ZigBee
ewc (Enhanced Wireless Consortium)				✔	Defunct; no subdivisions.	ewc
i3a (International Imaging Industry Assoc.)				✔	Defunct, merged into IS&T	Wikipedia
Total (191 SSOs)	21	99	17	156		

Table 7-7 – Hierarchy and structure of the 191 SSOs in our dataset

Appendix 2 – Descriptive statistics of FSPs versus non-FSPs

Variable	FSPs	Non-FSPs
Number of employees 25% percentile	67	491
Number of employees 50% percentile	475	3131
Number of employees 75% percentile	3990	20,109
Number of employees mean	10,522	26,594
Annual revenues 25% percentile (thousand $)	13,189	130,501
Annual revenues 50% percentile (thousand $)	110,691	783,386
Annual revenues 75% percentile (thousand $)	988,249	5,502,240
Annual revenues mean (thousand $)	3,284,406	10,000,000

Table 7-8 – Descriptive statistics of focused standardization players (FSPs) and non-focused ones.

FPSs are way smaller on average than non-FSPs, though they cannot be considered "small" on absolute terms. However, the values of FSPs may be amplified by the presence of non-technical large firms, such as Walmart (in some years) and many banks.

Appendix 3 – Extended names of the 20 most recurring SSOs

(ATIS) Alliance for Telecommunications Industry Solutions

(ASTM) American Society for Testing and Materials

(Bluetooth) Bluetooth SIG

(CTIA) Cellular Telecommunications Industry Association

(CTA) Consumer Technology Association (former Consumer Electronics Association)

(ETSI) European Telecommunications Standards Institute

(HIMSS) Healthcare Information and Management Systems Society

IDEAlliance

INTERNET2

(JEDEC) JEDEC Solid State Technology Association

(OASIS) Organization for the Advancement of Structured Information Standards

(PCI) Peripheral Component Interconnect SIG

(TIA) Telecommunications Industry Association

(TM) TM Forum

(TOG) The Open Group

(UPnP) Universal Plug and Play Forum

(VESA) Video Electronics Standards Association

(Wi-Fi) Wi-Fi Alliance

(WiMax) WiMax Forum

(W3C) World Wide Web Consortium

Appendix of Chapter 5

Appendix 1 ─ Limitations

In this exploratory research on the role of standardization for SLR adaptation, we have encountered important aspects that would be beneficial to reduce its limitations and complement this study. Within the first analytical block we deem that the inventory-based research can be expanded to a wider pool of national SSOs. However, this would require specific expertise on each local language. As part of the second analytical block, a higher number of sector-specific interviews could be conducted to deepen the understanding of each single SLR adaptation measure and identify more accurately the individual standards development candidates based on technological maturity. This would also allow us to go beyond the current aggregation into cluster and provide more granular knowledge on specific measures. At the same time, it would enable our study to indicate more precisely knowledge holders and existing clusters of technical expertise that may initiate standards development processes.

Moreover, the pool of interviewees is slightly unbalanced in the global representation between Global North and Global South, with a larger representation of the Global North. However, multiple experts had long-standing hands-on experience in the Global South and could provide comparative insights on both perspectives. Concerning the Q-Method survey design, such a tool could have allowed us to distill more specific perspectives based on the characteristics of respondents, such as their expertise, their role (e.g., academic vs policymaker vs private sector), and geographical scope. However, the anonymity requirements of our sampling strategy did not allow us to create customized links for every respondent, making it impossible to track the cited metadata. Furthermore, although not a proper limitation, the survey surprisingly resulted in "just" two statistically significant perspectives, showing the generally low level of consensus among the experts.

Appendix 2 ─ Coding procedure and full list of adaptation measures

SLR adaptation measures include any *material* (infrastructural, engineering and natural solutions) and *immaterial* (policy, governance, decision-making & support tools) action that have the objective of preparing or protecting coastal communities, their infrastructure and ecosystems for the impacts of climate change on sea levels. Extant literature has also used the *Protect, Accommodate and Retreat* (PAR) model – originally introduced by the IPCC (Dronkers et al., 1990) – to categorize such measures for SLR adaptation. *Protective* examples include beach nourishment and mangroves (Bridges et al., 2022; Furlan et al., 2021). *Accommodate* refers to measures that allow sustained use of vulnerable areas by better coping with impacts, e.g., drainage and sewage systems (Buurman & Babovic, 2016; Porio, 2011). *Retreat* measures involve, for instance, the (temporary) relocation of communities and natural environments (Hellman, 2015; McAdam, 2014). Scholars additionally coined the category of *attack* to refer to measures that 'advance the line' as opposed to 'holding the line' (Nicholls, 2011; RIBA & ICE, 2010). These measures may consist of breakwaters or the extension of piers and groins (Renaud et al., 2016). More recently, Dedekorkut-Howes et al., (2020) made a strong case to also recognize *non-structural* measures, namely those non-technical measures of organizational, procedural, or socio-institutional nature. *Non-structural* measures include, among others, the assessment of risks, impacts, and vulnerabilities of coastal areas (Dawson et al., 2011; Jin et al., 2018; Lal et al., 2012).

To compile an exhaustive list of measures, we opted for scientific literature as our main source. This is due to most of the state-of-the-art technical knowledge on climate adaptation being developed by academic research, particularly regarding sea level rise. Much of this research is funded with sources often linked to political institutions, making this source more complete than, for instance, policy briefs and technical reports. Additionally, we aligned our findings with several renowned policy sources, such as the OECD, the World Economic Forum, and the United Nations, showing that research-based sources effectively capture both scientific and policy-relevant measures. Lastly, we used academic sources for a better replicability of our study. The selection of the keywords relates to the two phenomena we are interested in: sea level rise and climate adaptation. Both of these two terms had to be included in the title, abstract, or keywords of the publications. The string on Web of Science appeared as TS=("climate adaptation" AND "sea level rise"). This search warranted a high precision and recall of our dataset for two reasons. First, we found quite some redundancy in the measures we filtered (262 duplicates spread across 75 coded measures). Second, a comparison with another popular taxonomy in the field by Dedekorkut et al. (2020) showed that we covered all the measures they mention (except for some synonyms that were useful for the inventory of standards), with the addition of some novel ones. Searching for "sea level rise" and "adaptation" would have resulted in roughly 3000 sources, making it impossible to conduct a search of this precision. Including "measures" in the keyword string would have generated more vague results, also omitting many synonyms (e.g., solutions, responses, strategies).

Below, some tables and figures display the results of our search. Figure 7-3 displays the measures divided across the PARA(N) strategies. Table 7-9 shows the list of grouped measures (that is, after completing the axial coding) ranked by their occurrence in our dataset. Table 7-10 contains a description of the two dimensions we use to categorize our measures: the four thematic clusters and the PARA(N) strategies.

Appendix 3 ─ Inventory of existing standards

Based on the results of the literature review on existing SLR adaptation measures, we took the 71 measures, their synonyms and different spelling (e.g., dikes and dykes) as keywords for investigating the presence of existing standards. Results of the keyword-based research revealed a total of 1373 standards. Then, a qualitative assessment of the relation and affinity between the standards identified and the description of SLR adaptation measures has been carried out. This analysis has generated the following results:

- Relevant standards: 82 standards show either direct or indirect potential relevance with SLR adaptation, climate hazards and flooding risks. Most standards in this category cover standardized practices and technical specifications that are currently applied in other emergency situations or water flooding mitigation or prevention.
- Relevant expertise: 198 standards display a potential technical relevance for SLR adaptation practices. Typically, these are standards currently applied in other fields and contexts, whose contents could be partly re-adapted to SLR adaptation practice. This category includes, for example, a large set (~150) of standards for water drainage systems.
- Out of scope: the remaining standards (1093) turned out to be non-related, not even potentially to SLR adaptation. They appear in our dataset mostly due to random occurrences of some generic keywords we used.

Below, we include several information related to our dataset. Table 7-11 describes the SSOs whose databases were used to collect the standards. Table 7-12 describes the most active technical committees in the field by number of relevant standards they developed. Table 7-13 lists all the 83 relevant standards and their metadata, including the SSO that developed them, their technical committee and reference, the associated measures and their thematic cluster.

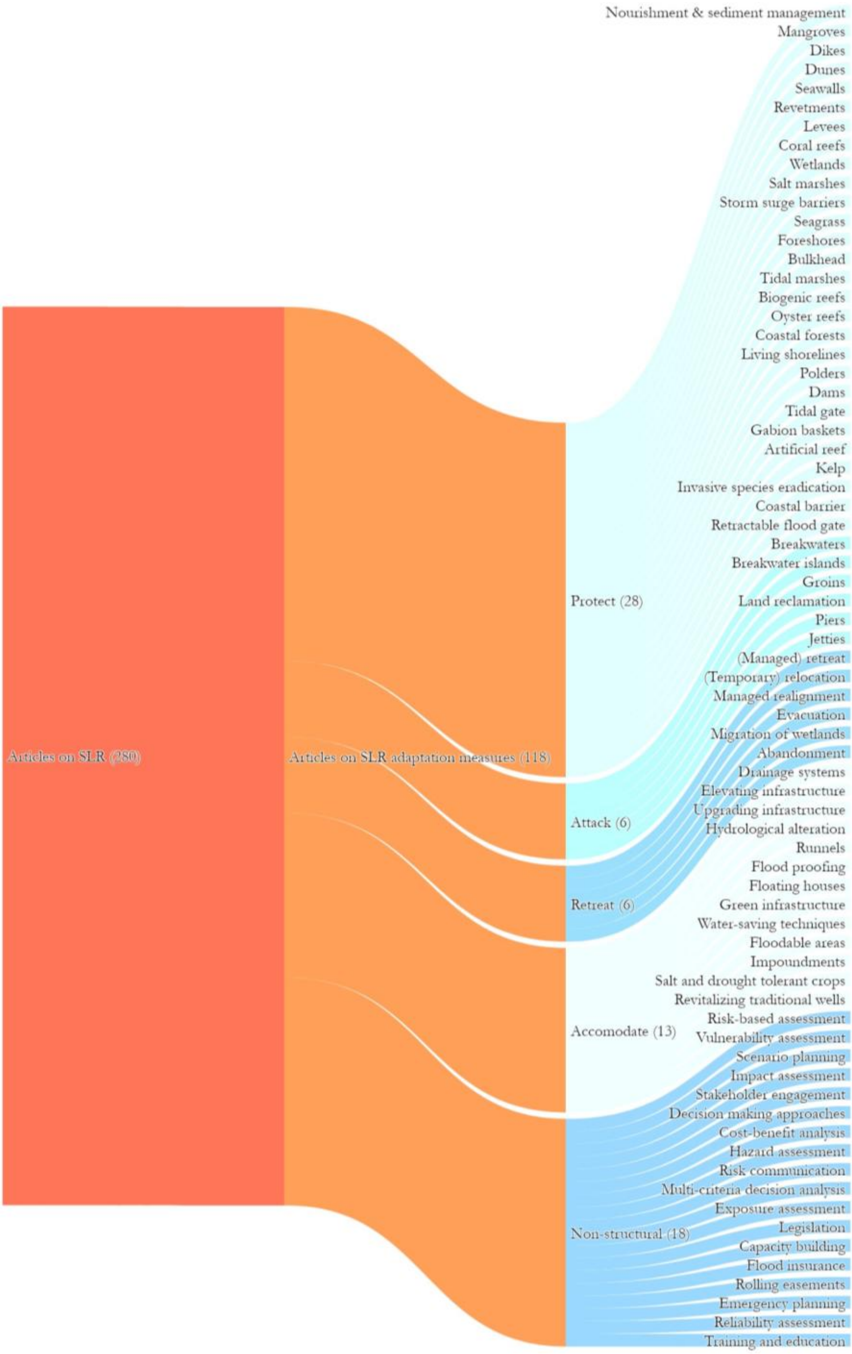


Figure 7-3 – SLR adaptation measures from literature

Axial coded measures (75)	N. of occurrences	% Total occurrences
Risk-based assessment	23	**6,8%**
Nourishment & sediment management	19	**5,6%**
Vulnerability assessment	19	**5,6%**
(Managed) retreat	15	**4,5%**
Scenario planning	15	**4,5%**
Mangroves	12	**3,6%**
(Temporary) relocation	12	**3,6%**
Dikes	11	**3,3%**
Impact assessment	11	**3,3%**
Stakeholder engagement	10	**3,0%**
Dunes (e.g., vegetated or artificial)	9	**2,7%**
Drainage systems	8	**2,4%**
Seawalls	8	**2,4%**
Elevating housing & infrastructure	7	**2,1%**
Revetments	7	**2,1%**
Upgrading/reinforcing infrastructure	7	**2,1%**
Decision support systems	7	**2,1%**
Levees	6	**1,8%**
Coral reefs	6	**1,8%**
Wetlands	6	**1,8%**
Salt marshes	6	**1,8%**
Cost-benefit analysis	6	**1,8%**
Breakwaters	5	**1,5%**
Managed realignment	5	**1,5%**
Hazzard assessment	5	**1,5%**
Storm surge barriers	4	**1,2%**
Evacuation (incl. routes, maps, etc.)	4	**1,2%**
(deployable/temporary) floodwall	3	**0,9%**
Breakwater islands	3	**0,9%**
Risk communication	3	**0,9%**
Seagrass	3	**0,9%**
Multi-criteria decision analysis	3	**0,9%**
Exposure assessment	3	**0,9%**
Hydrological alteration	2	**0,6%**
Groins	2	**0,6%**
Runnels	2	**0,6%**
Land reclamation	2	**0,6%**
Flood proofing	2	**0,6%**
Floating houses	2	**0,6%**
Legislation	2	**0,6%**
Capacity building	2	**0,6%**
Foreshores	2	**0,6%**
Bulkhead	2	**0,6%**
Urban greening & green infrastructure	2	**0,6%**
Water-saving techniques	2	**0,6%**
Migration of wetlands	2	**0,6%**
Tidal marshes	2	**0,6%**
Biogenic reefs	2	**0,6%**
Oyster reefs	2	**0,6%**
Coastal forests	2	**0,6%**
Abandonment	2	**0,6%**
Floodable areas	2	**0,6%**
Living shorelines	2	**0,6%**
Polders	2	**0,6%**
Flood insurance	2	**0,6%**
Dams	2	**0,6%**
Slopes	1	**0,3%**
Tidal gates	2	**0,6%**

Mound structure	1	**0,3%**
Piers	1	**0,3%**
Rolling easements	1	**0,3%**
Jetties	1	**0,3%**
Gabion baskets	1	**0,3%**
Impoundments	1	**0,3%**
Sandbags	1	**0,3%**
Artificial reef	1	**0,3%**
Emergency planning	1	**0,3%**
Kelp	1	**0,3%**
Salt and drought tolerant crops	1	**0,3%**
Revitalizing traditional wells	1	**0,3%**
Invasive species eradication	1	**0,3%**
Reliability assessment	1	**0,3%**
Training and education	1	**0,3%**
Coastal barrier	1	**0,3%**
Retractable flood gate	1	**0,3%**

Table 7-9 – Occurrence of SLR adaptation measures in the literature

Thematic Clusters
Civil Engineering & Infrastructure: Adaptation measures to SLR involve specific interventions and modifications aimed at designing, constructing, and maintaining infrastructure that can withstand SLR (e.g., dykes or natural barriers) or mitigate its impacts (e.g., material requirements). These measures aim to ensure the longevity, resilience, and functionality of buildings and infrastructure in coastal areas.
Risk Assessment Modelling, Safety & Security: SLR adaptation measures encompass a prevention framework aimed at identifying, assessing, and mitigating potential hazards, threats, and vulnerabilities associated with escalating sea levels. These measures may be integral components of a comprehensive approach aimed at ensuring the safety, security, and resiliency of coastal communities and critical infrastructure.
Policy, Governance & Spatial Planning: Adaptation measures are essential to prepare a fertile ground to implement integrated and comprehensive approaches for SLR adaptation. Essential ingredients in this domain are cross-sectoral collaboration, community engagement, adaptive planning, and flexibility both for regulation and for planning.
Nature-Based Solutions: these measures leverage the natural environment to provide adaptation benefits, contributing to the resiliency of coastal communities, ecosystems, and infrastructure. These approaches are pivoted on the inherent resiliency and protective qualities of natural systems to reduce vulnerability and enhance the adaptability of coastal areas. In addition, these measures often offer multiple co-benefits, including habitat restoration, biodiversity conservation, and carbon sequestration, among others.
PARA(N) strategies
Protecting measures are those that physically prevent the encroachment of water. A**ccommodating** measures do not stop water but make structures and systems less vulnerable; **Retreat** involves the displacement of people, assets, and infrastructure away from risk areas; **Attacking** measures are about advancing seawards and reclaiming land; **Non-structural** measures are all those that do not involve physical constructions but rather high-level planning, for example through policies and education.

Table 7-10 – Description of the thematic clusters and PARA(N) strategies

STANDARD-SETTING ORGANIZATION	ACRONYM	SCOPE
International Organization for Standardization	ISO	Global
Comité Européen de Normalisation	CEN	Regional (Europe)
CARICOM Caribbean Regional Organisation for Standards & Quality	CROSQ	Regional (Caribbean)
Royal Netherlands Standardization Institute	NEN	National (the Netherlands)
National Standardization Agency of Indonesia	BSN	National (Indonesia)
Trinidad & Tobago Bureau of Standardization	TTBS	National (Trinidad and Tobago)
Bangladesh Standards and Testing Institution	BSTI	National (Bangladesh)
Bureau of Indian Standards	BSI	National (India)
Saudi Arabia Standards Organisation	SASO	National (Saudi Arabia)

Table 7-11 – Standard Setting Organizations selected for the inventory research phase

TECHNICAL COMMITTEE	COMMITTEE SUBJECT MATTER	ASSOCIATED MEASURE	N. OF STANDARDS
CEN/TC 165	Wastewater engineering	Drainage systems	14
ISO/TC 292	Security and resilience	Emergency planning	12
CEN/TC 341	Geotechnical investigation and testing	Drainage systems	6
NEN 3650	Transport pipelines	Dykes/Abandonment	5
CEN/TC 230	Water analysis	Salt marshes	4
CEN/TC 250	Structural Eurocodes	Dykes	3
CEN/TC 396	Earthworks	Dykes	3
NEN 7024	Elements for block revetments	Revetments	3
ISO/TC 113/SC 8	Ground water	Well	2
CEN/TC 318	Hydrometry	Nourishment & sediment management	2
CEN/TC 189	Geotextiles and geotextile-related products	Drainage systems	2
SNI 7717	Geographic Information/ Geomatics	Mangroves	2

Table 7-12 – Most active technical committees developing "relevant" standards – those connected to SLR adaptation

SSO	Committee	Reference	Document title	Measure	Thematic Cluster
ISO	TC 45/SC 4/WG 2	ISO 23711:2022	Elastomeric seals — Requirements for materials for pipe joint seals used in water and drainage applications — Thermoplastic elastomers	Drainage systems	Civil and materials engineering
ISO	TC 221/WG 6	ISO/TR 18228-4:2022	Design using geosynthetics — Part 4: Drainage	Drainage systems	Civil and materials engineering
ISO	TC 292/WG 5	ISO 22395:2018	Security and resilience — Community resilience — Guidelines for supporting vulnerable persons in an emergency	Emergency planning	Safety standards
ISO	TC 292	ISO/TR 22351:2015	Societal security — Emergency management — Message structure for exchange of information	Emergency planning	Safety standards
ISO	TC 292/WG 3	ISO 22329:2021	Security and resilience — Emergency management — Guidelines for the use of social media in emergencies	Emergency planning	Safety standards
ISO	TC 292/WG 3	ISO 22328-1:2020	Security and resilience — Emergency management — Part 1: General guidelines for the implementation of a community-based disaster early warning system	Emergency planning	Safety standards
ISO	TC 292/WG 3	ISO 22328-3	Security and resilience — Emergency management — Part 3: Guidelines for the implementation of a community-based tsunami early warning system	Emergency planning	Safety standards
ISO	TC 292/WG 3	ISO 22326:2018	Security and resilience — Emergency management — Guidelines for monitoring facilities with identified hazards	Emergency planning	Safety standards
ISO	TC 292	ISO 22324	Security and resilience – Emergency management – Guidelines for colour-coded alert	Emergency planning	Safety standards
ISO	TC 292	ISO 22324:2015	Societal security — Emergency management — Guidelines for colour-coded alerts	Emergency planning	Safety standards
ISO	TC 292	ISO 22322	Security and resilience — Emergency management — Guidelines for public warning	Emergency planning	Safety standards
ISO	TC 292	ISO 22322:2015	Societal security — Emergency management — Guidelines for public warning	Emergency planning	Safety standards
ISO	TC 292/WG 3	ISO 22320:2018	Security and resilience — Emergency management — Guidelines for incident management	Emergency planning	Safety standards
ISO	TC 204/WG 8	ISO/TR 19083-1:2016	Intelligent transport systems — Emergency evacuation and disaster response and recovery — Part 1: Framework and concept of operation	Emergency planning	Safety standards
ISO	TC 292/WG 5	ISO 22315:2014	Societal security — Mass evacuation — Guidelines for planning	Evacuation	Safety standards
ISO	TC 21/SC 3	ISO 8201:2017	Alarm systems — Audible emergency evacuation signal — Requirements	Evacuation	Safety standards
ISO	TC 113/SC 8	ISO/TR 23211:2009	Hydrometry — Measuring the water level in a well using automated pressure transducer methods	Revitalizing traditional wells	Safety standards
ISO	TC 113/SC 8	ISO 21413:2005	Manual methods for the measurement of a groundwater level in a well	Revitalizing traditional wells	Safety standards
CEN/ CENELEC	TC 318	/	Hydrometry - Sedimentation - Measurements required for effective sediment management and control at river structures	Nourishment & sediment management	Safety standards
CEN/ CENELEC	TC 341	EN ISO 22282-1:2012	Geotechnical investigation and testing - Geohydraulic testing - Part 1: General rules (ISO 22282-1:2012)	Drainage systems	Safety standards
CEN/ CENELEC	TC 341	EN ISO 17892-7:2018	Geotechnical investigation and testing - Laboratory testing of soil - Part 7: Unconfined compression test (ISO 17892-7:2017)	Drainage systems	Safety standards
CEN/ CENELEC	TC 341	EN ISO 17892-5:2017	Geotechnical investigation and testing - Laboratory testing of soil - Part 5: Incremental loading oedometer test (ISO 17892-5:2017)	Drainage systems	Safety standards
CEN/ CENELEC	CLC/SR 4	EN IEC 60545:2021	Guidelines for commissioning and operation of hydraulic turbines, pump-turbines and storage pumps	Drainage systems	Civil and materials engineering
CEN/ CENELEC	TC 288	EN 15237:2007	Execution of special geotechnical works - Vertical drainage	Drainage systems	Urban Management and managed retreat
CEN/ CENELEC	TC 165	EN 1433:2002/ AC:2004	Drainage channels for vehicular and pedestrian areas - Classification, design and testing requirements, marking and evaluation of conformity	Drainage systems	Urban Management and managed retreat
CEN/ CENELEC	TC 165	EN 1433:2002/ A1:2005	Drainage channels for vehicular and pedestrian areas - Classification, design and testing requirements, marking and evaluation of conformity	Drainage systems	Urban Management and managed retreat
CEN/ CENELEC	TC 165	EN 1433:2002	Drainage channels for vehicular and pedestrian areas - Classification, design and testing requirements, marking and evaluation of conformity	Drainage systems	Urban Management and managed retreat

SSO	Committee	Reference	Document title	Measure	Thematic Cluster
CEN/ CENELEC	TC 165	EN 13508-2:2003+A1: 2011	Investigation and assessment of drain and sewer systems outside buildings - Part 2: Visual inspection coding system	Drainage systems	Safety standards
CEN/ CENELEC	TC 165	EN 13508-1:2012	Investigation and assessment of drain and sewer systems outside buildings - Part 1: General Requirements	Drainage systems	Safety standards
CEN/ CENELEC	TC 189	EN 13252:2016	Geotextiles and geotextile-related products - Characteristics required for use in drainage systems	Drainage systems	Safety standards
CEN/ CENELEC	TC 165	EN 12109:1999	Vacuum drainage systems inside buildings	Drainage systems	Civil and materials engineering
CEN/ CENELEC	TC 165	EN 12056-5:2000	Gravity drainage systems inside buildings - Part 5: Installation and testing, instructions for operation, maintenance and use	Drainage systems	Civil and materials engineering
CEN/ CENELEC	TC 165	EN 12056-4:2000	Gravity drainage systems inside buildings - Part 4: Wastewater lifting plants - Layout and calculation	Drainage systems	Civil and materials engineering
CEN/ CENELEC	TC 165	EN 12056-3:2000	Gravity drainage systems inside buildings - Part 3: Roof drainage, layout and calculation	Drainage systems	Civil and materials engineering
CEN/ CENELEC	TC 165	EN 12056-2:2000	Gravity drainage systems inside buildings - Part 2: Sanitary pipework, layout and calculation	Drainage systems	Civil and materials engineering
CEN/ CENELEC	TC 165	EN 12056-1:2000	Gravity drainage systems inside buildings - Part 1: General and performance requirements	Drainage systems	Civil and materials engineering
CEN/ CENELEC	TC 250	prEN 1991-1-8	Eurocode 1 - Actions on structures - Part 1-8 General actions - Actions from waves and currents on coastal structures	Dikes	Urban Management and managed retreat
CEN/ CENELEC	TC 396	EN 16907-4:2018	Earthworks - Part 4: Soil treatment with lime and/or hydraulic binders	Dikes	Urban Management and managed retreat
CEN/ CENELEC	TC 396	EN 16907-1:2018	Earthworks - Part 1: Principles and general rules	Dikes	Urban Management and managed retreat
CEN/ CENELEC	TC 218	EN ISO 28017:2018	Rubber hoses and hose assemblies, wire or textile reinforced, for dredging applications - Specification (ISO 28017:2018)	Coral reefs	Civil and materials engineering
CEN/ CENELEC	WS ARCH	CWA 17727:2022	City Resilience Development - Guide to combine disaster risk management and climate change adaptation - Historic areas	Vulnerability assessment	Urban Management and managed retreat
CEN/ CENELEC	TC 250	prEN 1991-1-7 rev	Eurocode 1 — Actions on structures - Part 1-7: General actions - Accidental actions	Elevating housing & infrastructure	Urban Management and managed retreat
CEN/ CENELEC	TC 250	EN 1998-2:2005/A2: 2011	Eurocode 8: Design of structures for earthquake resistance - Part 2: Bridges	Elevating housing & infrastructure	Civil and materials engineering
CEN/ CENELEC	TC 254	CEN/TS 17659:2021	Design guideline for mechanically fastened roof waterproofing systems	Elevating housing & infrastructure	Civil and materials engineering
CEN/ CENELEC	TC 189	EN 13253:2016	Geotextiles and geotextile-related products - Characteristics required for use in erosion control works (coastal protection, bank revetments)	Revetments	Civil and materials engineering
CEN/ CENELEC	TC 341	EN ISO 18674-4:2020	Geotechnical investigation and testing - Geotechnical monitoring by field instrumentation - Part 4: Measurement of pore water pressure: Piezometers (ISO 18674-4:2020)	Revetments	Safety standards
CEN/ CENELEC	TC 341	EN ISO 18674-3:2017	Geotechnical investigation and testing - Geotechnical monitoring by field instrumentation - Part 3: Measurement of displacements across a line: Inclinometers (ISO 18674-3:2017)	Revetments	Safety standards
CEN/ CENELEC	TC 341	EN ISO 18674-2:2016	Geotechnical investigation and testing - Geotechnical monitoring by field instrumentation - Part 2: Measurement of displacements along a line: Extensometers (ISO 18674-2:2016)	Revetments	Safety standards
CEN/ CENELEC	TC 230	EN 17218:2019	Water quality - Guidance on sampling of mesozooplankton from marine and brackish water using mesh	Salt marshes	Safety standards
CEN/ CENELEC	TC 229	EN 15258:2008	Precast concrete products - Retaining wall elements	Bulkhead	Civil and materials engineering

SSO	Committee	Reference	Document title	Measure	Thematic Cluster
CEN/ CENELEC	TC 177	EN 1520:2011	Prefabricated reinforced components of lightweight aggregate concrete with open structure with structural or non-structural reinforcement	Bulkhead	Civil and materials engineering
CEN/ CENELEC	TC 230	EN 16503:2014	Water quality - Guidance standard on assessing the hydromorphological features of transitional and coastal waters	Biogenic reefs	Urban Management and managed retreat
CEN/ CENELEC	TC 219	EN ISO 13174:2012	Cathodic protection of harbour installations (ISO 13174:2012)	Tidal gate	Civil and materials engineering
CEN/ CENELEC	TC 391	EN ISO 22315:2018	Societal security - Mass evacuation - Guidelines for planning (ISO 22315:2014)	Evacuation	Safety standards
CEN/ CENELEC	TC 203	EN 877:2021	Cast iron pipe systems and their components for the evacuation of water from works - characteristics and test methods	Evacuation	Civil and materials engineering
CEN/ CENELEC	TC 396	EN 16907-6:2018	Earthworks - Part 6: Land reclamation earthworks using dredged hydraulic fill	Land reclamation	Urban Management and managed retreat
CEN/ CENELEC	TC 308	CEN/TR 13983:2003	Characterization of sludges - Good practice for sludge utilisation in land reclamation	Land reclamation	Urban Management and managed retreat
CEN/ CENELEC	TC 230	EN 15843:2010	Water quality - Guidance standard on determining the degree of modification of river hydromorphology	Flood proofing	Safety standards
CEN/ CENELEC	TC 165	EN 13564-3:2003	Anti-flooding devices for buildings - Part 3: Quality assurance	Flood proofing	Civil and materials engineering
CEN/ CENELEC	TC 165	EN 13564-2:2002	Anti-flooding devices for buildings - Part 2: Test methods	Flood proofing	Civil and materials engineering
CEN/ CENELEC	TC 165	EN 13564-1:2002	Anti-flooding devices for buildings - Part 1: Requirements	Flood proofing	Civil and materials engineering
CEN/ CENELEC	TC 230	NA	Guidelines for the installation and operational implementation of continuous measuring systems	Flood proofing	Safety standards
CEN/ CENELEC	TC 318	CEN/TS 17171:2018	Management of observed hydrometric data - Guidance	Floodable areas	Safety standards
BSN	06-6597-2001	SNI 06-6597-2001	Statistical testing for acid mine drainage identification	Drainage systems	Safety standards
BSN	7717:2020	SNI 7717:2020	Spesifikasi informasi geospasial – Mangrove skala 1:25.000 dan 1:50.000	Mangroves	Nature based solutions
BSN	7717:2011	SNI 7717:2011	Survei dan pemetaan mangrove	Mangroves	Nature based solutions
BSN	7513:2008	SNI 7513:2008	Mangrove seeds handling	Mangroves	Nature based solutions
BSN	ISO 21110:2019	SNI ISO 21110:2019	Information and Documentation — Emergency preparedness and response	Emergency planning	Safety standards
NEN	3651	NEN 3651	Additional requirements for pipelines in or nearby important public works	Dikes	Civil and materials engineering
NEN	3650-1	NEN 3650-1	Requirements for pipeline systems - Part 1: General requirements	Dikes	Civil and materials engineering
NEN	3650-2	NEN 3650-2	Requirements for pipeline systems - Part 2: Additional specifications for steel pipelines	Dikes	Civil and materials engineering
NEN	3650-3	NEN 3650-3	Requirements for pipeline systems - Part 3: Additional specifications for plastic pipelines	Abandonment	Civil and materials engineering
NEN	3650-4	NEN 3650-4	Requirements for pipeline systems - Part 4: Additional specifications for concrete pipelines	Abandonment	Civil and materials engineering
NEN	3650-5	NEN 3650-5	Requirements for pipeline systems - Part 5: Additional specifications for cast iron pipelines	Abandonment	Civil and materials engineering
NEN	3656	NEN 3656	Requirements for submarine steel pipeline systems	Dikes	Civil and materials engineering
NEN	NPR 9998	NPR 9998	Assessment of structural safety of buildings in case of erection, reconstruction and disapproval - Induced earthquakes - Basis of design, actions and resistances	Elevating housing & infrastructure	Safety standards

SSO	Committee	Reference	Document title	Measure	Thematic Cluster
NEN	7024-1	NEN 7024-1	Elements for block revetments - Part 1: General requirements	Revetments	Civil and materials engineering
NEN	7024-2	NEN 7024-2	Elements for block revetments - Part 2: Elements made of cement concrete, without interlocking and without reinforcement	Revetments	Civil and materials engineering
NEN	7024-3	NEN 7024-3	Elements for block revetments - Part 3: Elements made of cement concrete, with interlocking and without reinforcement	Revetments	Civil and materials engineering
NEN	NTA 8111	NTA 8111	Floating constructions	Floating houses	Civil and materials engineering
NEN	NTA 8287	NTA 8287	Safety Cube Method for design, engineering and integration of systems and products	Risk communication	Safety standards
NEN	NPR 7201	NPR 7201	Geotechnics - Determination of the axial bearing capacity of foundation piles by pile load testing	Biogenic reefs	Safety standards

Table 7-13 – Full list of relevant standards and their main features

Appendix 4 ─ Semi-structured interviews

This appendix complements section 5.3.2 of the *Methods* section by providing details on the experts' interview process. Table 7-14 gives the complete overview of the 20 interviewees while complying with the anonymity principles laid out for this research. The table displays information on their professional background and experience, their geographical focus of expertise between Global South and Global North (or both), their expertise according to the thematic clusters set by our study and a more specific thematic focus of the interview. Table 7-15 provides an indicative sample of an interview structure for thematic SLR experts. However, due to the multi-disciplinarity of the fields covered, and the significant variety of SLR adaptation measures even within the same cluster, each interview required a dedicated thematic preparation and a tailored set of questions to stimulate to steer the conversation. As a result, the sample should be read as guidance framework that we followed to prepare each interview.

Appendix 5 ─ Q-Method

Our study uses the Q-method to identify the two main perspectives of the experts and the statements that reached a level of consensus that is statistically significant for our research. The experts (i.e., the respondents of the survey) had to be kept fully anonymous, to comply with the privacy requirements on which the study was conducted. Thus, we do not have data on the survey's sample representativeness in terms of thematic expertise and geographical distribution. However, to obtain a balanced and diverse sample across the four thematic clusters and the different geographical areas affected by the problem, our purposive sampling calibrated the geographical and thematic representativity of potential respondents through two channels: the authors of the papers included in the dataset of our review, and the standardization practitioners of ISO's committees and national SSOs. In contacting the latter, we have reached out to the same number of national SSOs from countries in the Global North and the Global South.

In Table 7-16 we have included the factor loadings of each respondent for both perspectives. We have marked the so-called "defining" respondents, namely the ones whose highest factor loading (i.e., the most fitting perspective) exceeded 0.36. This shows a correlation with a significance level of $p<0.05$. This level of significance is established in Equation 7-1 (Brown, 1980; McKeown & Thomas, 1988). We obtained 10 and 11 defining respondents in perspective 1 and 2 respectively.

$$\textbf{\textit{Factor loading}} > \mathbf{1.96} \times \frac{\mathbf{1}}{\sqrt{\textbf{\textit{N statements}}}} > \mathbf{0.36}$$

Equation 7-1 – Formula to derive factors with significance level of p<0.05

Table 7-17, instead, reports the z-scores of each statement for the two perspectives and their difference. A difference in z-scores between 0.4 and -0.4 resulted in a "consensus" statement. For more information on the technical process behind the z-scores see Brown (1980). These consensus statements were used as a baseline for our analysis and discussion.

N°	Professional background and experience	Geographical Expertise	Thematic Expertise*	Thematic Focus
1	Policy Making and Academia	Global North	CL1 & CL4	Coastal barriers, infrastructural interventions, beach nourishments, dune stabilization.
2	Academia and Standard-Setting Organization	Global North	STR	Standards development processes, technical committees setup and composition, type and function of standards.
3	Standard-Setting Organization	Global North	STR	Standards development processes, technical committees setup and composition, type and function of standards, global cooperation.
4	Standard-Setting Organization	Global North & South	STR	Standards development processes, technical committees setup and composition, type and function of standards, global cooperation.
5	Academia	Global South	CL4	Mangroves, coastal wetland restoration and coral reefs.
6	Academia	Global North	CL2 & STR	Risk based assessment tools, impact simulation emergency preparedness, warning systems, data requirements and uniformity.
7	Policy Advice and Academia	Global North	CL2 & CL3	Risk based assessment tools, impact simulation, response plans, critical infrastructure protection.
8	Academia	Global North	CL3 & STR	Policies, Spatial Planning, Governance of Standardization processes and technological maturity
9	Policy Advice and Academia	Global North	CL3 & CL4	Adaptive policy making, spatial planning frameworks, multi-stakeholder governance, building with nature.
10	Policy Advice	Global South	CL1 & CL3	Adaptive policy making, spatial planning frameworks, capacity building, global cooperation, grey vs green infrastructure.
11	Academia	Global South	CL4	Mangroves, wetland restoration, living shorelines, awareness and capacity building programmes.
12	Academia	Global North	CL1 & CL4	Dykes, coastal barriers, sediment management, dune restoration, wetlands, salt marshes, building with nature.
13	Industry and Academia	Global South	CL1	Floating construction, maintenance and material requirements, coastal barriers.
14	Policy Making	Global South	CL3 & CL4	Managed retreat, spatial and urban planning, living shorelines, mangroves and coral reefs.
15	Academia	Global North & South	CL2	Impact simulation, risk-based assessment methods, emergency preparedness, alarms, decision support tools
16	Policy Advice and Academia	Global South	CL1 & CL2	Material requirements and maintenance, decision support tools, dynamic assessment methods, data uniformity requirements.
17	Standard-Setting Organization	Global North	STR	Standardization for climate change adaptation, technical committees composition, standards flexibility.
18	Policy Advice and Academia	Global South	CL1 & CL3	Waterfront infrastructures, coastal engineering, spatial design and planning, capacity building, global cooperation.
19	Academia	Global North	STR	Standards development processes, technical committee setup and composition, type and function of standards.
20	Policy Advice and Academia	Global North & South	CL3	Participatory governance structures, community-based decision making, capacity building, global cooperation.

Table 7-14 – Overview of the professional, geographical and thematic expertise of the interviewees

***CL 1: Civil Engineering & Infrastructure; CL 2: Risk Assessment Modelling, Safety & Security; CL 3: Policy, Governance & Spatial Planning; CL 4: Nature-Based Solutions; STR: Standardization**

Interview objectives: each interview aimed at collecting data and knowledge on the role that standardization can play in the field of SLR adaptation. The interviews investigated both descriptive and technical information to provide experts perspectives to discuss the following aspects: a) the priorities and most concrete opportunities for local and global SSOs in the field of SLR adaptation; b) the role of geographical specificities for the standardization of specific SLR adaptation measures; c) the level of (technical/technological) maturity of specific SLR adaptation measures; d) the challenges and blocking factors for the standardization of SLR adaptation measures	
Interview duration: 60 minutes on average	
Interview - First stage (Unstructured) In the first part of the interview, the interviewee was stimulated to reflect first on the impact of SLR in his specific fields of expertise and then on the challenges and concrete opportunities that standardization may address to support for SLR adaptation practice and a broader uptake of SLR adaptation measures globally. The discussion is purposedly unstructured in this phase, thus no inputs will be provided except for the basic context of reference. A main teasing question will guide the open discussion. The question will only be slightly adapted to the field of expertise and of the interviewee.	
Teasing questions	▪ What is the state of the art for SLR adaptation in your field? ▪ Can you describe the SLR adaptation measures you are working with both from a functional and technical standpoint? ▪ What is the role of local geographical specificities for the SLR adaptation measures you are working with? ▪ Do you see opportunities for developing standardization for SLR adaptation in your field?
Interview - Second stage (Semi-Structured) In the second part of the interview, the interviewee has been stimulated with inputs from the interviewers' side concerning the specific field of expertise and thematic focus of the interview. In particular, we aimed at discussing existing or hypothetical ideas for standards and collecting their expert opinion on the feasibility and impact of potential standards development. Moreover, this second part will also evolve and be characterized based on what has emerged in the first unstructured stage of the interview.	
Questions and inputs	These questions were elaborated based on the thematic expertise of the interviewee and calibrated with the inventory outcomes and other inputs that are relevant to his/her field of expertise. This part of the conversation has always dynamic and adaptive to what emerged in the first, unstructured, part of the interview. Follow-up questions emerged naturally from the conversation in accordance with the Semi-Structured approach of the interview. Yet, most of the interviews zoomed in the following aspects: ▪ Role of geographical specificities for potential standard development processes ▪ Different approaches between Global North and Global South ▪ Level of technological maturity (different stages) of the SLR adaptation measure ▪ Recommendations for potential standardization processes e.g., priorities, specific aspects, challenges, controversies.

Table 7-15 – Guidance framework for preparing and conducting interviews with thematic experts

Respondents	Perspective 1	Perspective 2
R1	0.4301 (X)	0.27485
R2	-0.07577	0.38388 (X)
R3	0.35488	0.12848
R4	0.5292 (X)	-0.11982
R5	0.69455 (X)	-0.02944
R6	-0.00429	0.27825
R7	0.09385	0.78136 (X)
R8	0.62895 (X)	0.42961
R9	0.51852 (X)	-0.05273
R10	0.35759	0.17588
R11	0.20969	0.50223 (X)
R12	0.6204 (X)	0.00881
R13	0.24781	0.18952
R14	0.62889 (X)	-0.08373
R15	0.38659	0.63946 (X)
R16	0.35019	0.52029 (X)
R17	0.34029	0.23354
R18	0.36412 (X)	0.22205
R19	0.03087	0.54038 (X)
R20	0.22456	0.18755
R21	0.12197	0.17424
R22	0.51816 (X)	0.23662
R23	0.30765	0.3959 (X)
R24	0.11001	0.38711 (X)
R25	0.09222	0.36057 (X)
R26	0.11568	0.58663 (X)
R27	0.29702	0.02838
R28	0.07522	0.4518 (X)
R29	-0.11857	0.35516
R30	0.74391 (X)	0.14574
Total significant respondents	**10**	**11**

Table 7-16 – Respondents' factor loadings. (X) denotes if the respondent Q-sort correlates with the factor at a significance level of $p < 0.05$

N.	Statement	Z-score Perspective 1	Z-score Perspective 2	Difference
1	Global Standardization for SLR adaptation should focus on a set of guidelines that pave the way for local standardization practice.	0.68	-0.31	0.98
2	The level of risk (probability and impact) of SLR climate hazards is still too high to provide globally standardized solutions.	-0.63	-1.82	1.18
3	Short-termism in decision-making and planning is among the biggest limiting factors for standardizing SLR adaptation measures.	-0.31	0.03	-0.34 (C)
4	The lack of standards for data collection, processing and use challenges both the implementation and standardization of SLR adaptation measures.	-0.89	-0.44	-0.46
5	Global Standardization should start from providing a framework specifically for developing SLR adaptation measures.	-0.12	-0.56	0.43
6	Global Standardization should be initiated bottom-up by local standardization bodies (interests of stakeholders).	-0.89	-0.71	-0.19 (C)
7	SLR adaptation measures are so heavily reliant on case-by-case and place-specific inputs that cannot be standardized globally	-2.00	0.29	-2.28
8	Global standardization should engage with international organizations (e.g., IPCC, UN, OECD) to leverage expertise and promote collective action.	0.39	-0.06	0.45
9	Any standardization process should embed a protocol (e.g., a questionnaire) to explicitly consider its relationship with climate adaptation.	-1.10	-0.09	-1.01
10	Prototypes and practices for floating construction are mature enough for standardizing its principles	-0.69	-1.67	0.98
11	Some existing standards in the field of construction and civil engineering could also be used in SLR adaptation contexts.	0.91	0.04	0.88
12	Civil engineering practices adopted in flood-prone urban areas seem ready to be standardized.	0.36	-1.29	1.65
13	Standardization should not neglect monitoring and maintenance requirements for civil engineering and infrastructural interventions	1.47	1.42	0.05 (C)
14	Infrastructural interventions such as dykes and barriers are often overprotective solutions for SLR adaptation.	-1.44	-1.84	0.40 (C)
15	Risk-based assessments should be a preliminary step to enable any possible SLR adaptation strategy and measure.	2.10	1.14	0.96

16	Standardization should focus on data requirements, harmonization, and validity at a global scale to enable implementation of existing risk-based assessment models.	0.73	-0.12	0.85
17	Standardization should primarily focus on estimating the risks because thresholds for risk acceptance and SLR adaptation strategies are primarily political choices	0.00	0.33	-0.33 (C)
18	Due to the strong local dependency of evacuation plans, global standardization should focus on evacuation preparedness and predisposition.	-0.62	0.12	-0.74
19	Global standardization for SLR risk assessment should target not only public sector (policy guidelines) but also industry and SMEs.	1.04	1.33	-0.28 (C)
20	The high risk (probability and impact) embedded in climate hazards suggests that SLR policies must follow adaptive planning approaches.	1.74	1.63	0.10 (C)
21	Multi-sectorial stakeholder engagement should be standardized as a key support tool to pursue participatory decision making for SLR adaptation measures.	0.73	0.14	0.59
22	Local governance schemes for SLR adaptation cannot be standardized at a global scale because of cultural factors	-1.36	1.80	-3.16
23	Tools and protocols that support decision-making for SLR adaption should be a priority for standardization.	1.14	1.51	-0.37 (C)
24	The standardization of adaptive policy approaches to coastal management must target a strong reliance on Nature-Based Solutions .	0.59	-0.29	0.88
25	Nature Based Solutions (NBS) requirements (e.g., conditions for healthy flora growth) should be standardized first.	0.38	-1.13	1.51
26	Guidelines on the policy & governance of ecosystems should be standardized first to deal with conflicting visions for land use	-0.61	-0.14	-0.47
27	The material and dynamic requirements of some NBS such as sand nourishment and wetlands can be standardized globally (as a function of coastal features)	-0.32	-0.50	0.18 (C)
28	NBS can only be a part of adaptation strategies as they rarely represent a standalone solution for SLR scenarios.	-0.43	0.68	-1.11
29	The adoption and standardization of NBS is challenging due to conflicting visions and interests on the use of land	-1.00	0.97	-1.97
30	Spatial Planning standards for SLR risk-prone areas should focus on solutions that prevent the need for emergency planning	0.21	-0.47	0.68

Table 7-17 – Statements' z-scores and their difference between the two perspectives. (C) denotes consensus statements

Bibliography

Abdelkafi, N., Bekkers, R., Bolla, R., Rodriguez-Ascaso, A., & Wetterwald, M. (2021). *Understanding ICT Standardization* (2nd ed.). ETSI.

Abediasl, H., & Hashemi, H. (2015). Monolithic optical phased-array transceiver in a standard SOI CMOS process. *Optics Express*, *23*(5), 6509. https://doi.org/10.1364/oe.23.006509

Aboelela, S. W., Larson, E., Bakken, S., Carrasquillo, O., Formicola, A., Glied, S. A., Haas, J., & Gebbie, K. M. (2007). Defining interdisciplinary research: Conclusions from a critical review of the literature. *Health Services Research*, *42*(1 I), 329–346. https://doi.org/10.1111/j.1475-6773.2006.00621.x

Abou-zeid, H., Pervez, F., Adinoyi, A., Aljlayl, M., & Yanikomeroglu, H. (2019). Cellular V2X Transmission for Connected and Autonomous Vehicles Standardization, Applications, and Enabling Technologies. *IEEE Consumer Electronics Magazine*, *8*(6), 91–98. https://doi.org/10.1109/MCE.2019.2941467

Abrahamson, E., & Rosenkopf, L. (1997). Social Network Effects on the Extent of Innovation Diffusion: A Computer Simulation. *Organization Science*, 8(3), 289–309. https://doi.org/10.1287/orsc.8.3.289

Acemoglu, D., Gancia, G., & Zilibotti, F. (2012). Competing engines of growth: Innovation and standardization. *Journal of Economic Theory*, *147*(2), 570-601 https://doi.org/10.1016/j.jet.2010.09.001

Addey, C. (2017). Golden relics & historical standards: how the OECD is expanding global education governance through PISA for Development. *Critical Studies in Education*, *58*(3), 311–325. https://doi.org/10.1080/17508487.2017.1352006

Adger, W. N. (2003). Social capital, collective action, and adaptation to climate change. *Economic Geography*, *79*(4), 387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x

Adler, P. S. (2001). Market, Hierarchy, and Trust: The Knowledge Economy and the Future of Capitalism. *Organization Science*, *12*(2), 215–234. https://doi.org/10.1287/orsc.12.2.215.10117

Afuah, A. (2012). Are network effects really about size? The role of structure and conduct. *Strategic Management Journal*, 1154(March), 1–43. https://doi.org/10.1002/smj

Agarwal, S., Miller, C. D., & Ganco, M. (2023). Growing platforms within platforms: How platforms manage the adoption of complementor products in the presence of network effects? *Strategic Management Journal*, *January*, 1–32. https://doi.org/10.1002/smj.3487

Aggarwal, N., Dai, Q., & Walden, E. A. (2011). The More, the Merrier? How the Number of Partners in a Standard-Setting Initiative Affects Shareholder's Risk and Return. *MIS Quarterly*, *35*(2), 445–462.

Aghbashlo, M., Tabatabaei, M., Hosseini, S. S., B. Dashti, B., & Mojarab Soufiyan, M. (2018). Performance assessment of a wind power plant using standard exergy and extended exergy accounting (EEA) approaches. *Journal of Cleaner Production*, *171*, 127–136. https://doi.org/10.1016/j.jclepro.2017.09.263

Ahuja, G. (2000). Collaboration networks, structural holes and innovation: A longitudinal study. *Academy of Management Proceedings*, 246, 1–70.

Ahuja, G., Lampert, C. M., & Novelli, E. (2013). The second face of appropriability: generative appropriability and its determinants. *Academy of Management Review*, *38*(2), 248–269.

Albu, C. N., Albu, N., & Alexander, D. (2014). When global accounting standards meet the local context-Insights from an emerging economy. *Critical Perspectives on Accounting*, *25*(6), 489–510. https://doi.org/10.1016/j.cpa.2013.03.005

Alfraih, M. M. (2016). The effectiveness of board of directors' characteristics in mandatory disclosure compliance. *Journal of Financial Regulation and Compliance*, *24*(2), 154–176. https://doi.org/10.1108/JFRC-07-2015-0035

Ali, F., Yigang, H., Shi, G., Sui, Y., & Yuang, H. (2020). Future Generation Spectrum Standardization for 5G and Internet of Things. *Journal of Communications*, 276–282. https://doi.org/10.12720/jcm.15.3.276-282

Alizada, K. (2018). Rethinking the diffusion of renewable energy policies: A global assessment of feed-in tariffs and renewable portfolio standards. *Energy Research and Social Science*, *44*(May), 346–361. https://doi.org/10.1016/j.erss.2018.05.033

Alkraiji, A. I., Jackson, T., & Murray, I. (2016). Factors impacting the adoption decision of health data standards in tertiary healthcare organisations in Saudi Arabia. *Journal of Enterprise Information Management*, *29*(5), 650–676. https://doi.org/10.1108/JEIM-11-2014-0111

Al-Taie, M. Z., & Kadry, S. (2017). *Python for Graph and Network Analysis*. In Springer. http://www.springer.com/series/4738

Anderson, E. G., Bhargava, H. K., Boehm, J., & Parker, G. (2022). Electric Vehicles Are a Platform Business: What Firms Need to Know. *California Management Review,* 64(4), 135–154. https://doi.org/10.1177/00081256221107420

Armstrong, M. (2006). Competition in two-sided markets. *RAND Journal of Economics*, 37(3), 668–691.

Arnold, N., & Loconto, A. (2021). Serving Magically Perfect Fruit Globally: Local nesting in translating multiple standards. *Organization Studies*, *42*(2), 327–349. https://doi.org/10.1177/0170840620935858

Arora, A., Alderman, J. E., Palmer, J., Ganapathi, S., Laws, E., McCradden, M. D., Oakden-Rayner, L., Pfohl, S. R., Ghassemi, M., McKay, F., Treanor, D., Rostamzadeh, N., Mateen, B., Gath, J., Adebajo, A. O., Kuku, S., Matin, R., Heller, K., Sapey, E., … Liu, X. (2023). The value of standards for health datasets in artificial intelligence-based applications. *Nature Medicine*, *29*(11), 2929–2938. https://doi.org/10.1038/s41591-023-02608-w

Arthur, W. B. (1989). Competing Technologies, Increasing Returns, and Lock-In by Historical Events. *The Economic Journal*, 99(394), 116. https://doi.org/10.2307/2234208

Atinafu, D. G., Jin Chang, S., Kim, K.-H., & Kim, S. (2020). Tuning surface functionality of standard biochars and the resulting uplift capacity of loading/energy storage for organic phase change materials. *Chemical Engineering Journal*, *394*, 125049. https://doi.org/10.1016/j.cej.2020.125049

Austin, M. T., & Milner, H. V. (2001). Strategies of European standardization. *Journal of European Public Policy*, *8*(3), 411–431. https://doi.org/10.1080/13501760110056040

Axelrod, R., Mitchell, W., Thomas, R. E., Bennett, D. S., & Bruderer, E. (1995). Coalition Formation in Standard-Setting Alliances. *Management Science*, *41*(9), 1493–1508. https://doi.org/10.1287/mnsc.41.9.1493

Ayoub, W., Samhat, A. E., Nouvel, F., Mroue, M., & Prevotet, J.-C. (2019). Internet of Mobile Things: Overview of LoRaWAN, DASH7, and NB-IoT in LPWANs Standards and Supported Mobility. *IEEE Communications Surveys and Tutorials*, *21*(2), 1561–1581. https://doi.org/10.1109/COMST.2018.2877382

Bakos, Y., & Halaburda, H. (2020). Platform competition with multihoming on both sides: Subsidize or not? *Management Science*, 66(12), 5599–5607. https://doi.org/10.1287/mnsc.2020.3636

Baldwin, C. Y., Bogers, M. L. A. M., Kapoor, R., & West, J. (2024). Focusing the ecosystem lens on innovation studies. *Research* Policy, 53(3). https://doi.org/10.1016/j.respol.2023.104949

Balland, P. A., Boschma, R., & Frenken, K. (2015). Proximity and Innovation: From Statics to Dynamics. *Regional Studies*, *49*(6), 907–920. https://doi.org/10.1080/00343404.2014.883598

Balzarova, M. A., & Castka, P. (2012). Stakeholders' Influence and Contribution to Social Standards Development: The Case of Multiple Stakeholder Approach to ISO 26000 Development. *Journal of Business Ethics*, *111*(2), 265–279. https://doi.org/10.1007/s10551-012-1206-9

Bamber, M., & McMeeking, K. (2016). An examination of international accounting standard-setting due process and the implications for legitimacy. *British Accounting Review*, *48*(1), 59–73. https://doi.org/10.1016/j.bar.2015.03.003

Banken, R., & Wubs, B. (2017). *The Rhine: A Transnational Economic History*. Nomos Verlagsgesellschaft mbH & Co. KG. https://doi.org/10.5771/9783845284736

Bao, X., Zhao, W., Wang, X., & Tan, Z. (2019). Impact of policy mix concerning renewable portfolio standards and emissions trading on electricity market. *Renewable Energy*, *135*, 761–774. https://doi.org/10.1016/j.renene.2018.12.005

Bar, T., & Leiponen, A. (2014). Committee composition and networking in standard setting: The case of wireless telecommunications. *Journal of Economics and Management Strategy*, *23*(1), 1–23. https://doi.org/10.1111/jems.12044

Barabási, A. L. (2012). The network takeover. *Nature Physics*, 8(1), 14–16. https://doi.org/10.1038/nphys2188

Barbose, G., Bird, L., Heeter, J., Flores-Espino, F., & Wiser, R. (2015). Costs and benefits of renewables portfolio standards in the United States. *Renewable and Sustainable Energy Reviews*, *52*, 523–533. https://doi.org/10.1016/j.rser.2015.07.175

Barca, F., McCann, P., & Rodríguez-Pose, A. (2012). The Case for Regional Development Intervention: Place-based versus Place-neutral Approaches. *Journal of Regional Science*, *52*(1), 134–152. https://doi.org/10.1111/j.1467-9787.2011.00756.x

Barlow, M. A., Verhaal, J. C., & Angus, R. W. (2019). Optimal distinctiveness, strategic categorization, and product market entry on the Google Play app platform. *Strategic Management Journal*, 40(8), 1219–1242. https://doi.org/10.1002/smj.3019

Baron, J., & Kanevskaia, O. (2023). Wearing multiple hats—The role of working group chairs' affiliation in standards development. *Research Policy*, *52*(9), 104822. https://doi.org/10.1016/j.respol.2023.104822

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., & Spulber, D. F. (2018). Technology Standards and Standard Setting Organizations: Introduction to the Searle Center Database. *Journal of Economics and Management Strategy*, *27*(3), 462–503. https://doi.org/10.1111/jems.12257

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

Baron, J., Pohlmann, T., & Blind, K. (2016). Essential patents and standard dynamics. *Research Policy*, *45*(9), 1762–1773. https://doi.org/10.1016/j.respol.2016.05.004

Bartelsman, E., Haltiwanger, J., & Scarpetta, S. (2013). Cross-country differences in productivity: The role of allocation and selection. *American Economic Review*, *103*(1), 305–334. https://doi.org/10.1257/aer.103.1.305

Bass, F. M. (1969). A New Product Growth for Model Consumer Durables. *Management Science*, 15(5), 215–227. https://doi.org/10.1287/mnsc.15.5.215

Bathelt, H., Buchholz, M., & Storper, M. (2024). The nature, causes, and consequences of inter-regional inequality. *Journal of Economic Geography, 24(3),* 353–374. https://doi.org/10.1093/jeg/lbae005

Battistella, C., Colucci, K., De Toni, A. F., & Nonino, F. (2013). Methodology of business ecosystems network analysis: A case study in telecom italia future centre. *Technological Forecasting and Social Change, 80(6),* 1194–1210. https://doi.org/10.1016/j.techfore.2012.11.002

Baum, J. A. C., Shipilov, A. V, & Rowley, T. J. (2003). Where do small worlds come from? *Industrial and Corporate Change*, *12*(4), 697–725.

Baumann-Pauly, D., Nolan, J., van Heerden, A., & Samway, M. (2017). Industry-Specific Multi-Stakeholder Initiatives That Govern Corporate Human Rights Standards: Legitimacy assessments of the Fair Labor Association and the Global Network Initiative. *Journal of Business Ethics*, *143*(4), 771–787. https://doi.org/10.1007/s10551-016-3076-z

Baumol, W. J., & Oates, W. E. (1971). The Use of Standards and Prices for Protection of the Environment. *The Scandinavian Journal of Economics*, *73*(1), 42–54.

Baynard, E. C. (1982). The nature of the voluntary industrial standards concept. *Computers and Standards*, *1*(2–3), 145–159. https://doi.org/10.1016/0167-8051(82)90024-9

Bekkers, R. (2001). *Mobile Telecommunications Standards: GSM,UMTS,TETRA and ERMES*. Boston, MA: Artech House.

Bekkers, R., & Lazaj, E. (2025). Voting or consensus? An empirical study of decision-making in the European standards body ETSI. *Innovation: The European Journal of Social Science Research*. https://doi.org/10.1080/13511610.2024.2442948

Bekkers, R., & Martinelli, A. (2012). Knowledge positions in high-tech markets: Trajectories, standards, strategies and true innovators. *Technological Forecasting and Social Change*, *79*(7), 1192–1216. https://doi.org/10.1016/j.techfore.2012.01.009

Bekkers, R., Bongard, R., & Nuvolari, A. (2011). An empirical study on the determinants of essential patent claims in compatibility standards. *Research Policy*, *40*(7), 1001–1015. https://doi.org/10.1016/j.respol.2011.05.004

Bekkers, R., Catalini, C., Martinelli, A., Righi, C., & Simcoe, T. (2023). Disclosure rules and declared essential patents. *Research Policy, 52(1),* 104618. https://doi.org/10.1016/j.respol.2022.104618

Bekkers, R., Duysters, G., & Verspagen, B. (2002). Intellectual property rights, strategic technology agreements and market structure. *Research Policy*, *31*(7), 1141–1161. https://doi.org/10.1016/S0048-7333(01)00189-5

Bekkers, R., Iversen, E., & Blind, K. (2012). Emerging ways to address the reemerging conflict between patenting and technological standardization. *Industrial and Corporate Change*, *21*(4), 901–931. https://doi.org/10.1093/icc/dtr067

Bekkers, R., Tur, E. M., Henkel, J., van der Vorst, T., Driesse, M., & Contreras, J. L. (2022). Overcoming inefficiencies in patent licensing: A method to assess patent essentiality for technical standards. *Research Policy*, *51*(10), 104590. https://doi.org/10.1016/j.respol.2022.104590

Bellandi, M., Biagi, B., Faggian, A., Marrocu, E., & Usai, S. (2018). *Regional Development Trajectories Beyond the Crisis*. FrancoAngeli s.r.l. http://bit.ly/francoangeli-oa

Bellemare, M. F., Masaki, T., & Pepinsky, T. B. (2015). *Lagged Explanatory Variables and the Estimation of Causal Effects* (62350; MPRA Paper). https://mpra.ub.uni-muenchen.de/62350/

Benner, M. J., & Tripsas, M. (2012). The influence of prior industry affiliation on framing in nascent industries: The evolution of digital cameras. *Strategic Management Journal*, *33*(3), 277–302. https://doi.org/10.1002/smj.950

Bennett, E. A., & College, C. (2017). Who Governs Socially-Oriented Voluntary Sustainability Standards ? Not the Producers of Certified Products. *World Development*, *91*, 53–69. https://doi.org/10.1016/j.worlddev.2016.10.010

Bento, A. M., Garg, T., & Kaffine, D. (2018). Emissions reductions or green booms? General equilibrium effects of a renewable portfolio standard. *Journal of Environmental Economics and Management*, *90*, 78–100. https://doi.org/10.1016/j.jeem.2018.05.006

Berends, H., van Burg, E., & van Raaij, E. M. (2011). Contacts and Contracts: Cross-Level Network Dynamics in the Development of an Aircraft Material. *Organization Science*, *22*(4), 940–960. https://doi.org/10.1287/orsc.1100.0578

Besen, S. M., & Farrell, J. (1994). Choosing How to Compete: Strategies and Tactics in Standardization. *Journal of Economic Perspectives*, *8*(*2*), 117–131. https://doi.org/10.1257/jep.8.2.117

Bhardwaj, A., & Kumar, V. (2021). Electronic Healthcare Records. *International Journal of Service Science, Management, Engineering, and Technology*, *12*(2), 44–58. https://doi.org/10.4018/IJSSMET.2021030103

Bijlmakers, S. (2022). No ISO-fix for human rights: a critical perspective on ISO 26000 Guidance on social responsibility. In A. Henriques (Ed.), Research Handbook on Global Governance, Business and Human Rights (Vol. 1, Issue 1). Edward Elgar Publishing. https://doi.org/10.4337/9781788979832

Bilby, K. (1986). *The General: David Sarnoff and the Rise of the Communications Industry*. Harpercollins.

Bitzer, V., & Bijman, J. (2014). Old Oranges in New Boxes? Strategic Partnerships between Emerging Farmers and Agribusinesses in South Africa.

Journal of Southern African Studies, *40*(1), 167–183. https://doi.org/10.1080/03057070.2014.877647

Bitzer, V., & Glasbergen, P. (2015). NGO partnerships in global value chains : part of the solution or part of the problem of sustainable change ? *Current Opinion in Environmental Sustainability*, *12*, 35–40. https://doi.org/10.1016/j.cosust.2014.08.012

Björkegren, D., & Farronato, C. (2021). Network-Based Platforms Must Be Regulated. But How? *Harvard Business Review*. https://hbr.org/2021/10/network-based-platforms-must-be-regulated-but-how

Blind, K. (2004). *The Economics of Standards*. Edward Elgar Publishing. https://doi.org/10.4337/9781035305155

Blind, K. (2006). Explanatory factors for participation in formal standardisation processes: Empirical evidence at firm level. *Economics of Innovation and New Technology*, *15*(2), 157–170. https://doi.org/10.1080/10438590500143970

Blind, K., & Fenton, A. (2021). Standard-relevant publications: evidence, processes and influencing factors. *Scientometrics*, *0123456789*. https://doi.org/10.1007/s11192-021-04210-8

Blind, K., & Gauch, S. (2009). Research and standardisation in nanotechnology: evidence from Germany. *The Journal of Technology Transfer*, *34*(3), 320–342. https://doi.org/10.1007/s10961-008-9089-8

Blind, K., & Jungmittag, A. (2008). The impact of patents and standards on macroeconomic growth: a panel approach covering four countries and 12 sectors. *Journal of Productivity Analysis*, *29*(1), 51–60. https://doi.org/10.1007/s11123-007-0060-8

Blind, K., & Mangelsdorf, A. (2013). Alliance formation of SMEs: Empirical evidence from standardization committees. *IEEE Transactions on Engineering Management*, *60*(1), 148–156. https://doi.org/10.1109/TEM.2012.2192935

Blind, K., & Mangelsdorf, A. (2016). Motives to standardize : Empirical evidence from Germany. *Technovation*, *48–49*, 13–24. https://doi.org/10.1016/j.technovation.2016.01.001

Blind, K., Jungmittag, A., & Mangelsdorf, A. (2011). *The Economic Benefits of Standardization*. DIN German Institute for Standardization. https://www.din.de/resource/blob/89552/68849fab0eeeaafb56c5a3ffee9959c5/economic-benefits-of-standardization-en-data.pdf

Blind, K., Kenney, M., Leiponen, A., & Simcoe, T. (2023). Standards and innovation: A review and introduction to the special issue. *Research Policy*, *52(8),* 104830. https://doi.org/10.1016/j.respol.2023.104830

Blind, K., Petersen, S. S., & Riillo, C. A. F. (2017). The impact of standards and regulation on innovation in uncertain markets. *Research Policy*, *46*(1), 249–264. https://doi.org/10.1016/j.respol.2016.11.003

Boccaletti, S., Bianconi, G., Criado, R., del Genio, C. I., Gómez-Gardeñes, J., Romance, M., Sendiña-Nadal, I., Wang, Z., & Zanin, M. (2014). The structure and dynamics of multilayer networks. *Physics Reports*, *544(1),* 1–122. https://doi.org/10.1016/j.physrep.2014.07.001

Bogers, M., Sims, J., & West, J. (2019). What Is an Ecosystem? Incorporating 25 Years of Ecosystem Research. *Academy of Management Proceedings*, *2019*(1), 11080. https://doi.org/10.5465/AMBPP.2019.11080abstract

Boiral, O. (2007). Corporate Greening Through ISO 14001: A Rational Myth? *Organization Science*, *18*(1), 127–146. https://doi.org/10.1287/orsc.1060.0224

Boiral, O., Guillaumie, L., Heras-Saizarbitoria, I., & Tayo Tene, C. V. (2018). Adoption and Outcomes of ISO 14001: A Systematic Review. *International Journal of Management Reviews*, *20*(2), 411–432. https://doi.org/10.1111/ijmr.12139

Borgatti, S. P., Everett, M., & Johnson, J. C. (2018). *Analyzing Social Networks*. Sage.

Borgatti, S. P., Mehra, A., Brass, D. J., & Labianca, G. (2009). Network analysis in the social sciences. *Science*, 323(5916), 892–895. https://doi.org/10.1126/science.1165821

Borner, K., Berends, H., Deken, F., & Feldberg, F. (2023). Another pathway to complementarity: How users and intermediaries identify and create new combinations in innovation ecosystems. *Research Policy*, 52(7). https://doi.org/10.1016/j.respol.2023.104788

Boschma, R. A., & Frenken, K. (2006). Why is economic geography not an evolutionary science? Towards an evolutionary economic geography. *Journal of Economic Geography, 6(3),* 273–302. https://doi.org/10.1093/jeg/lbi022

Boström, M., & Tamm Hallström, K. (2013). Global multi-stakeholder standard setters: how fragile are they? *Journal of Global Ethics*, *9*(1), 93–110. https://doi.org/10.1080/17449626.2013.773180

Boström, M., Jönsson, A. M., Lockie, S., Mol, A. P. J., & Oosterveer, P. (2015). Sustainable and responsible supply chain governance: Challenges and opportunities. *Journal of Cleaner Production*, *107*, 1–7. https://doi.org/10.1016/j.jclepro.2014.11.050

Bott, E. (1958). *Family and Social Network*. Tavistock Press.

Botzem, S. (2014). Transnational standard setting in accounting: Organizing expertise-based self-regulation in times of crises. *Accounting, Auditing and Accountability Journal*, *27*(6), 933–955. https://doi.org/10.1108/AAAJ-04-2013-1301

Botzem, S., & Dobusch, L. (2012). Standardization Cycles: A Process Perspective on the Formation and Diffusion of Transnational Standards. *Organization Studies*, *33*(5–6), 737–762. https://doi.org/10.1177/0170840612443626

Braa, J., Hanseth, O., Heywood, A., Mohammed, W., & Shaw, V. (2007). Developing health information systems in developing countries: The flexible standards strategy. *MIS Quarterly: Management Information Systems*, *31*(2), 381–402. https://doi.org/10.2307/25148796

Brady, R. A. (1929). *Industrial Standardization*. New York, National industrial conference board. https://catalog.hathitrust.org/Record/001321667

Brako, D. E., Richard, A., & Alexandros, G. (2021). Do voluntary certification standards improve yields and wellbeing? Evidence from oil palm and cocoa smallholders in Ghana. *International Journal of Agricultural Sustainability*, *19*(1), 16–39. https://doi.org/10.1080/14735903.2020.1807893

Brandi, C. A. (2017). Sustainability Standards and Sustainable Development – Synergies and Trade-Offs of Transnational Governance. *Sustainable Development*, *25*(1), 25–34. https://doi.org/10.1002/sd.1639

Breeman, M. P., Grillo, F., & van de Kaa, G. (2022). Battles in space: De-facto standardization of Global Navigation Satellite Systems. *Journal of Engineering and Technology Management* – 65 (June 2021). https://doi.org/10.1016/j.jengtecman.2022.101693

Brem, A., & Nylund, P. A. (2021). Maneuvering the bumps in the New Silk Road: Open innovation, technological complexity, dominant design, and the international impact of Chinese innovation. *R&D Management*, *51*(3), 293–308. https://doi.org/10.1111/radm.12451

Bresnahan, T. F., & Greenstein, S. (1999). Technological competition and the structure of the computer industry. *Journal of Industrial Economics*, *47*(1), 1–40. https://doi.org/10.1111/1467-6451.00088

Bridges, T. S., Smith, J. M., King, J. K., Simm, J. D., Dillard, M., deVries, J., Reed, D., Piercy, C. D., van Zanten, B., Arkema, K., Swannack, T., de Looff, H., Lodder, Q., Jeuken, C., Ponte, N., Gailani, J. Z., Whitfield, P., Murphy, E., Lowe, R. J., … Naylor, L. A. (2022). Coastal Natural and Nature-Based Features: International Guidelines for Flood Risk Management. *Frontiers in Built Environment*, *8*(May), 1–9. https://doi.org/10.3389/fbuil.2022.904483

Brown, S. R. (1980). *Political Subjectivity: Applications of Q Methodology in Political Science*. Yale University Press. https://doi.org/10.2307/3151542

Brunsson, N., Rasche, A., & Seidl, D. (2012). The dynamics of standardization : Three perspectives on standards in organization studies. *Organization Studies*, *33*, 613–632.

Bulbulia, J. (2012). Spreading order: religion, cooperative niche construction, and risky coordination problems. *Biology & Philosophy*, *27*(1), 1–27. https://doi.org/10.1007/s10539-011-9295-x

Burasa, P., Djerafi, T., & Wu, K. (2021). A 28 GHz and 60 GHz Dual-Band On-Chip Antenna for 5G-Compatible IoT-Served Sensors in Standard CMOS Process. *IEEE Transactions on Antennas and Propagation*, *69*(5), 2940–2945. https://doi.org/10.1109/TAP.2020.3025236

Busch, L. (2011). *Standards*. The MIT Press. https://doi.org/10.7551/mitpress/8962.001.0001

Bushee, B. J., Keusch, T., & Kim-Gina, J. (2023). Co-Opetition and the Firm's Information Environment. *Management Science*. https://doi.org/10.1287/mnsc.2021.03152

Büthe, T., & Mattli, W. (2010). International Standards and Standard-Setting Bodies. In Oxford University Press (Ed.), *The Oxford Handbook of Business and Government* (Issue July, pp. 440–471). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199214273.003.0020

Büthe, T., & Mattli, W. (2011). *The New Global Rulers: The Privatization of Regulation in the World Economy*. Princeton University Press.

Butts, D., & Adams, H. (2020). Weather Contracts: Capturing a sense of weather for place-based adaptation to climate change. *Global Environmental Change*, *63*(December 2019), 102052. https://doi.org/10.1016/j.gloenvcha.2020.102052

Buurman, J., & Babovic, V. (2016). Adaptation Pathways and Real Options Analysis: An approach to deep uncertainty in climate change adaptation policies. *Policy and Society*, *35*(2), 137–150. https://doi.org/10.1016/j.polsoc.2016.05.002

Cailean, A.-M., & Dimian, M. (2017). Impact of IEEE 802.15.7 Standard on Visible Light Communications Usage in Automotive Applications. *IEEE Communications Magazine*, *55*(4), 169–175. https://doi.org/10.1109/MCOM.2017.1600206

Campos, P., Álvarez, A., Oviedo, J. L., Mesa, B., Caparrós, A., & Ovando, P. (2020). Environmental incomes: Refined standard and extended accounts applied to cork oak open woodlands in Andalusia, Spain. *Ecological Indicators*, *117*, 106551. https://doi.org/10.1016/j.ecolind.2020.106551

Carse, A., & Lewis, J. A. (2017). *Toward a political ecology of infrastructure standards : Or , how to think about ships , waterways , sediment , and communities together*. https://doi.org/10.1177/0308518X16663015

Casey, A. J., & Niblett, A. (2017). The death of rules and standards. *Indiana Law Journal*, *92*(4), 1401–1447. https://doi.org/10.2139/ssrn.2693826

CEN and CENELEC. (2016). *Guide for addressing climate change adaptation in standards*. https://www.cencenelec.eu/media/Guides/CEN-CLC/cenclcguide32.pdf

CEN and CENELEC. (2021). *Strategy 2030*. https://www.cencenelec.eu/european-standardization/strategy-2030/

Cenamor, J., & Frishammar, J. (2021). Openness in platform ecosystems: Innovation strategies for complementary products. *Research Policy*, 50(1), 104148. https://doi.org/10.1016/j.respol.2020.104148

Cennamo, C. (2021). Competing in digital markets: A platform-based perspective. *Academy of Management Perspectives*, 35(2), 265–291.

Chavinskaia, L., & Loconto, A. M. (2020). Keep Diversity—Make Standards! Spaces of Standardization for Diversity Analyzed through Cattle Breeding Industry. *Engaging Science, Technology, and Society*, *6*, 193. https://doi.org/10.17351/ests2020.287

Chen, P., & Forman, C. (2006). Can Vendors Influence Switching Costs and Compatibility in an Environment with Open Standards? *MIS Quarterly*, *30*, 541. https://doi.org/10.2307/25148772

Chen, H., Mehra, A., Tasselli, S., & Borgatti, S. P. (2022). Network Dynamics and Organizations: A Review and Research Agenda. *Journal of Management*, *48*(6), 1602–1660. https://doi.org/10.1177/01492063211063218

Chen, M., Wan, J., & Li, F. (2012). Machine-to-machine communications: Architectures, standards and applications. *KSII Transactions on Internet and Information Systems*, *6*(2), 480–497. https://doi.org/10.3837/tiis.2012.02.002

Chen, T., Qian, L., & Narayanan, V. (2017). Battle on the Wrong Field? Entrant Type, Dominant Designs, and Technology Exit. *Strategic Management Journal*, *38*(13), 2579–2598. https://doi.org/10.1002/smj.2669

Chen, Y., & Wang, L. (2013). Renewable Portfolio Standards in the Presence of Green Consumers and Emissions Trading. *Networks and Spatial Economics*, *13*(2), 149–181. https://doi.org/10.1007/s11067-012-9176-0

Cheng, Y., Sokol, D. D., & Cennamo, C. (2025). Rethinking the Traditional M&A Motivations within the Platform Acquisitions Context. In *Handbook on Digital Platforms. Cambridge University Press.*

Chiao, B., Lerner, J., & Tirole, J. (2007). The rules of standard-setting organizations: An empirical analysis. RAND Journal of Economics, *38(4),* 905–930. https://doi.org/10.1111/j.0741-6261.2007.00118.x

Chien, C.-F., Hsu, C.-Y., & Chang, K.-H. (2013). Overall Wafer Effectiveness (OWE): A novel industry standard for semiconductor ecosystem as a whole. *Computers & Industrial Engineering*, *65*(1), 117–127. https://doi.org/10.1016/j.cie.2011.11.024

Chien, H. K., & Chu, C. Y. C. (2008). Sale or lease? Durable-goods monopoly with network effects. *Marketing Science*, *27(6)*, 1012–1019. https://doi.org/10.1287/mksc.1070.0356

Chinosi, M., & Trombetta, A. (2012). BPMN: An introduction to the standard. *Computer Standards and Interfaces*, *34*(1), 124–134. https://doi.org/10.1016/j.csi.2011.06.002

Choi, B. C. K., & Pak, A. W. P. (2006). Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: Definitions, objectives, and evidence of effectiveness. *Clinical and Investigative Medicine*, *29*(6), 351–364.

Choi, D. G., Lee, H., & Sung, T. (2011). Research profiling for 'standardization and innovation.' *Scientometrics*, *88*(1), 259–278. https://doi.org/10.1007/s11192-011-0344-7

Christensen, A., & Hobbs, B. (2016). A model of state and federal biofuel policy: Feasibility assessment of the California Low Carbon Fuel Standard. *Applied Energy*, *169*, 799–812. https://doi.org/10.1016/j.apenergy.2016.01.121

Christensen, L. T., Morsing, M., & Thyssen, O. (2017). License to Critique: A Communication Perspective on Sustainability Standards. *Business Ethics Quarterly*, *27*(2), 239–262. https://doi.org/10.1017/beq.2016.66

Christin, A. (2018). *Counting Clicks : Quantification and Variation in Web Journalism in the United States*. *123*(5), 1382–1415.

Church, J., & Gandal, N. (1992). Network Effects, Software Provision, and Standardization. *The Journal of Industrial Economics*, *40*(1), 85. https://doi.org/10.2307/2950628

Ciborra, C. U. (1996). The Platform Organization: Recombining Strategies, Structures, and Surprises. *Organization Science*, *7*(2), 103–118. https://doi.org/10.1287/orsc.7.2.103

Clements, M. T. (2004). Direct and indirect network effects: Are they equivalent? International *Journal of Industrial Organization*, *22*(5), 633–645. https://doi.org/10.1016/j.ijindorg.2004.01.003

CMA. (2023). Anticipated acquisition by Microsoft of Activision Blizzard, Inc. - Final report (Issue April). https://www.gov.uk/cma-cases/microsoft-slash-activision-blizzard-merger-inquiry

Coase, R. H. (1937). The Nature of the Firm. *Economica*, *4*(16), 386–405. https://doi.org/10.1111/j.1468-0335.1937.tb00002.x

Cohen, S. K., Hsu, S. T., & Dahlin, K. B. (2016). With whom do technology sponsors partner during technology battles? Social networking strategies for unproven (and proven) technologies. *Organization Science*, *27*(4), 846–872. https://doi.org/10.1287/orsc.2016.1063

Coleman, J. S. (1988). Social Capital in the Creation of Human Capital. *American Journal of Sociology*, 94(1988), S95–S120.

Condit, K. H. (1928). The Economic Aspects of Standardization. *The Annals of the American Academy of Political and Social Science*, *137*, 39–42.

Constantinides, P., & Barrett, M. (2015). Information Infrastructure Development and Governance as Collective Action. *Information Systems Research*, *26*(1), 40–56. https://doi.org/10.1287/isre.2014.0542

Conte, B., Desmet, K., Nagy, D. K., & Rossi-Hansberg, E. (2021). Local sectoral specialization in a warming world. *Journal of Economic Geography*, *21*(4), 493–530. https://doi.org/10.1093/jeg/lbab008

Cooper, M. H. (2015). Measure for measure? Commensuration, commodification, and metrology in emissions markets and beyond. *Environment and Planning A*, *47*(9), 1787–1804. https://doi.org/10.1068/a130275p

Corbin, J. M., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative Sociology*, *13*(1), 3–21. https://doi.org/10.1007/BF00988593

Corradini, C., & Vanino, E. (2022). Path dependency, regional variety and the dynamics of new firm creation in rooted and pioneering industries. *Journal of Economic Geography*, *22*(3), 631–651. https://doi.org/10.1093/jeg/lbab021

Cortés Arbués, I., Chatzivasileiadis, T., Ivanova, O., Storm, S., Bosello, F., & Filatova, T. (2024). Distribution of economic damages due to climate-driven sea-level rise across European regions and sectors. *Scientific Reports*, *14*(1), 126. https://doi.org/10.1038/s41598-023-48136-y

Corus, D., & Oliveto, P. S. (2018). Standard Steady State Genetic Algorithms Can Hillclimb Faster Than Mutation-Only Evolutionary Algorithms. *IEEE Transactions on Evolutionary Computation*, *22*(5), 720–732. https://doi.org/10.1109/TEVC.2017.2745715

Cuppen, E., Breukers, S., Hisschemöller, M., & Bergsma, E. (2010). Q methodology to select participants for a stakeholder dialogue on energy options from biomass in the Netherlands. *Ecological Economics*, *69*(3), 579–591. https://doi.org/10.1016/j.ecolecon.2009.09.005

Cusumano, M. (2020). The Evolution of Research on Industry Platforms. *Academy of Management Discoveries*, *8*(1), 7–14. https://doi.org/10.5465/amd.2020.0091

Cusumano, M. A., Kahl, S. J., & Suarez, F. F. (2014). Services, Industry Evolution, and the Competitive Strategies of Product Firms. *Strategic Management Journal*, *920*(October), 1–43. https://doi.org/10.1002/smj

Cusumano, M. A., Mylonadis, Y., & Rosenbloom, R. S. (1992). Strategic Maneuvering and Mass-Market Dynamics: The Triumph of VHS over Beta. *Business History Review*, *66*(1), 51–94. https://doi.org/10.2307/3117053

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global Environmental Change, *18*(4), 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013

Dabbicco, G., & Steccolini, I. (2019). Building legitimacy for European public sector accounting standards (EPSAS). *International Journal of Public Sector Management*, *33*(2/3), 229–245. https://doi.org/10.1108/IJPSM-12-2018-0264

Dai, H., Qualls, W. J., & Zhu, Y. (2024). Win, lose, or draw? Forecasting the outcome of a race toward a dominant formal standard with machine learning. *Technological Forecasting and Social Change*, *205*(June), 123499. https://doi.org/10.1016/j.techfore.2024.123499

Das, H. S., Rahman, M. M., Li, S., & Tan, C. W. (2020). Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. *Renewable and Sustainable Energy Reviews*, *120*, 109618. https://doi.org/10.1016/j.rser.2019.109618

Dattée, B., Alexy, O., & Autio, E. (2018). Maneuvering in poor visibility: How firms play the ecosystem game when uncertainty is high. *Academy of Management Journal*, *61*(2), 466–498. https://doi.org/10.5465/amj.2015.0869

Davey, S. S., & Richards, C. (2013). Supermarkets and private standards: unintended consequences of the audit ritual. *Agriculture and Human Values*, *30*(2), 271–281. https://doi.org/10.1007/s10460-012-9414-6

David, P. A. (2001). Path dependence, its critics and the quest for 'historical economics.' In *Evolution and Path Dependence in Economic Ideas* (pp. 15–40). Edward Elgar Publishing. https://doi.org/10.4337/9781781950227.00006

David, P. A., & Greenstein, S. (1990). The economics of compatibility standards: An introduction to recent research. *Economics of Innovation and New Technology*, *1*(1–2), 3–41. https://doi.org/10.1080/10438599000000002

Davies, R. B., & Vadlamannati, K. C. (2013). A race to the bottom in labor standards? An empirical investigation. *Journal of Development Economics*, *103*(1), 1–14. https://doi.org/10.1016/j.jdeveco.2013.01.003

Dawson, R. J., Ball, T., Werritty, J., Werritty, A., Hall, J. W., & Roche, N. (2011). Assessing the effectiveness of non-structural flood management measures in the Thames Estuary under conditions of socio-economic and environmental change. *Global Environmental Change*, *21*(2), 628–646. https://doi.org/10.1016/j.gloenvcha.2011.01.013

de la Plaza Esteban, C., Visseren-Hamakers, I. J., & de Jong, W. (2014). The Legitimacy of Certification Standards in Climate Change Governance. *Sustainable Development*, *22*(6), 420–432. https://doi.org/10.1002/sd.1568

De Lajudie, P. M., Andrews, M., Ardley, J., Eardly, B., Jumas-Bilak, E., Kuzmanović, N., Lassalle, F., Lindström, K., Mhamdi, R., Martínez-Romero, E., Moulin, L., Mousavi, S. A., Nesme, X., Peix, A., Puławska, J., Steenkamp, E., Stępkowski, T., Tian, C. F., Vinuesa, P., … Young, P. (2019). Minimal standards for the description of new genera and species of rhizobia and agrobacteria. *International Journal of Systematic and Evolutionary Microbiology*, *69*(7), 1852–1863. https://doi.org/10.1099/ijsem.0.003426

de Lorenzo, V., & Schmidt, M. (2018). Biological standards for the Knowledge-Based BioEconomy: What is at stake. *New Biotechnology*, *40*, 170–180. https://doi.org/10.1016/j.nbt.2017.05.001

de Vries, H. J. (1997). Standardization: What's in a Name? *Terminology. International Journal of Theoretical and Applied Issues in Specialized Communication*, *4*(1), 55–83. https://dx.doi.org/10.1075/term.4.1.05vri

de Vries, H. J. (1998). The Classification of Standards. *Knowledge Organization*, *25*(3), 79–89.

de Vries, H. J. (1999). *Standardization: A Business Approach to the Role of National Standardization Organizations*. Springer US.

de Vries, H. J. (2000). Achieving Best Practices in National Standardization: A Benchmarking Study of the National Standardization System of Finland, Sweden, Denmark and Italy. A Book Review. *Homo Oeconomicus*, *17*(345–346).

de Vries, H. J. (2001). Standardization - a new discipline? *Proceedings from the 2nd IEEE Conference on Standardization and Innovation in Information Technology (Cat. No.01EX530)*, 91–105. https://doi.org/10.1109/SIIT.2001.968558

de Vries, H. J. (2006). Standards for Business-How companies can profit from participation in international standards setting. In *Standardization as a strategic tool*. IEC. https://www.researchgate.net/publication/306038425 de Vries, H. J. (2010). Fundamentals of Standards and Standardization. In W. Hesser, A. J. Feilzer, & H. J. de Vries (Eds.), *Standardisation in Companies and Markets*. Helmut Schmidt University Hamburg.

de Vries, H. J. (2015). Standardisation - A developing field for research. In P. Delimatsis (Ed.), *The law, economics and politics of international standardisation* (pp. 19–41). Cambridge International Trade and Economics Law.

de Vries, H. J., & El Osrouti, F. (2019). Impact studies on standards and standardisation – Looking back and moving forward. *Proceedings 24th EURAS Annual Standardisation Conference – Standards for a Bio-Based Economy*.

de Vries, H. J., & Veurink, J. L. (2017). Cost-Benefit analysis of participation in standardization: Developing a calculation tool. *International Journal of Standardization Research*, *15*(1), 1–15. https://doi.org/10.4018/IJSR.2017010101

de Vries, H. J., & Wiegmann, P. M. (2017). Impact of service standardization on service innovation. In R. Hawkins, K. Blind, & R. Page (Eds.), *Handbook of Standards and Innovation* (pp. 187–211). Edward Elgar.

de Vries, H. J., Blind, K., Mangelsdorf, A., Verheul, H., & van der Zwan, J. (2009). *SME access to European standardization. Enabling small and medium-sized enterprises to achieve greater benefit from standards and from involvement in standardization*. Rotterdam School of Management, Erasmus University.

Dedekorkut-Howes, A., Torabi, E., & Howes, M. (2020). When the tide gets high: a review of adaptive responses to sea level rise and coastal flooding. *Journal of Environmental Planning and Management*, *63*(12), 2102–2143. https://doi.org/10.1080/09640568.2019.1708709

Delcamp, H., & Leiponen, A. (2014). Innovating standards through informal consortia: The case of wireless telecommunications. *International Journal of Industrial Organization*, *36*, 36–47. https://doi.org/10.1016/j.ijindorg.2013.07.004

Delimatsis, P. (2015). *The Law, Economics and Politics of International Standardisation*. Cambridge University Press. https://doi.org/10.1017/CBO9781316423240

Dell'Ariccia, G., Igan, D., & Laeven, L. (2012). Credit booms and lending standards: evidence from the subprime mortgage market. *Journal of Money, Credit and Banking*, *44*(2/3), 367–384.

Demange, G., & Wooders, M. (2005). *Group Formation in Economics: Networks, Clubs, and Coalitions*. Cambridge University Press.

den Uijl, S. (2015). The Emergence of De-facto Standards. In *Doctoral Dissertation, Erasmus Research Institute of Management (ERIM).*

den Uijl, S., & de Vries, H. J. (2013). Pushing technological progress by strategic manoeuvring: the triumph of Blu-ray over HD-DVD. Business History, 55(8), 1361–1384. https://doi.org/10.1080/00076791.2013.771332

Deng, X., Li, Q. C., & Mateut, S. (2022). Participation in setting technology standards and the implied cost of equity. *Research Policy*, *51*(5). https://doi.org/10.1016/j.respol.2022.104497

Derkx, B., & Glasbergen, P. (2014). Elaborating global private meta-governance: An inventory in the realm of voluntary sustainability standards. *Global Environmental Change*, *27*(1), 41–50. https://doi.org/10.1016/j.gloenvcha.2014.04.016

Domenico, M. di, Hofman, E., & Schiele, H. (2024). A Bibliometric Review of the Business Platforming Literature: Theoretical Cornerstones and Research Trends. *IEEE Transactions on Engineering Management*, *71*, 6812–6829. https://doi.org/10.1109/TEM.2023.3240300

Dietz, T., Grabs, J., & Chong, A. E. (2021). Mainstreamed voluntary sustainability standards and their effectiveness: Evidence from the Honduran coffee sector. *Regulation and Governance*, *15*(2). https://doi.org/https://doi.org/10.1111/rego.12239

Diodato, V. (1994). *Dictionary of Bibliometrics*. Haworth Press, Inc.

Dobusch, L., & Quack, S. (2013). Framing standards, mobilizing users: Copyright versus fair use in transnational regulation. *Review of International Political Economy*, *20*(1), 52–88. https://doi.org/10.1080/09692290.2012.662909

Dokko, G., & Rosenkopf, L. (2010). Social capital for hire? Mobility of technical professionals and firm influence in wireless standards committees. *Organization Science*, *21*(3), 677–695. https://doi.org/10.1287/orsc.1090.0470

Dokko, G., Nigam, A., & Rosenkopf, L. (2012). Keeping Steady as She Goes: A Negotiated Order Perspective on Technological Evolution. *Organization Studies*, *33*(5–6), 681–703. https://doi.org/10.1177/0170840612443624

Dong, C. G. (2012). Feed-in tariff vs. renewable portfolio standard: An empirical test of their relative effectiveness in promoting wind capacity development. *Energy Policy*, *42*, 476–485. https://doi.org/10.1016/j.enpol.2011.12.014

Dong, F., Shi, L., Ding, X., Li, Y., & Shi, Y. (2019). Study on China's Renewable Energy Policy Reform and Improved Design of Renewable Portfolio Standard. *Energies*, *12*(11), 2147. https://doi.org/10.3390/en12112147

Donner, P., Rimmert, C., & van Eck, N. J. (2020). Comparing institutional-level bibliometric research performance indicator values based on different affiliation disambiguation systems. *Quantitative Science Studies*, *1*(1), 150–170. https://doi.org/10.1162/qss_a_00013

Dosi, G., & Nelson, R. R. (2013). The Evolution of Technologies: An Assessment of the State-of-the-Art. *Eurasian Business Review*, *3*(1), 3–46. https://doi.org/10.14208/BF03353816

Dronkers, J., Gilbert, J. T. E., Butler, L. W., Carey, J. J., Campbell, J., James, E., Mckenzie, C., Misdorp, R., Quin, N., Ries, K. L., Schroder, P. C., Spradley, J. R., Titus, J. G., Vallianos, L., & Von Dadelszen, J. (1990). *Strategies for Adaptation to Sea Level Rise*. Intergovernmental Panel on Climate Change (IPCC)

Dunne, J. A., Williams, R. J., & Martinez, N. D. (2002). Food-web structure and network theory: The role of connectance and size. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(20), 12917–12922. https://doi.org/10.1073/pnas.192407699

Durán-García, E., Santos-Ramos, B., Puigventos-Latorre, F., & Ortega, A. (2011). Literature review on the structure and operation of Pharmacy and Therapeutics Committees. *International Journal of Clinical Pharmacy 33*(3), 475–483. https://doi.org/10.1007/s11096-011-9501-6

Durocher, S., Fortin, A., Allini, A., & Zagaria, C. (2019). Users' legitimacy perceptions about standard-setting processes. *Accounting and Business Research*, *49*(2), 206–243. https://doi.org/10.1080/00014788.2018.1526664

Dyck, B., & Silvestre, B. S. (2019). A Novel NGO Approach to Facilitate the Adoption of Sustainable Innovations in Low-Income Countries: Lessons from Small-scale Farms in Nicaragua. *Organization Studies*, *40*(3), 443–461. https://doi.org/10.1177/0170840617747921

Economides, N. (1996). The economics of networks. *International Journal of Industrial Organization*, *14*(6), 673–699. https://doi.org/10.1016/0167-7187(96)01015-6

Economides, N., & Katsamakas, E. (2006). Two-sided competition of proprietary vs. open source technology platforms and the implications for the software industry. *Management Science*, *52*(7), 1057–1071. https://doi.org/10.1287/mnsc.1060.0549

Egyedi, T. M., & Hashem Sherif, M. (2008). Standards' dynamics through an innovation lens: next generation ethernet networks. *Proceedings of the First ITU-T Kaleido- Scope Academic Conference, 'Innovations in NGN,' May*, 127–134.

Egyedi, T., & Blind, K. (2008). *The Dynamics of Standards*. Edward Elgar Publishing.

Eichengreen, B. (2019). *Globalizing Capital: A History of the International Monetary System*. Princeton University Press.

Einwiller, S., Ruppel, C., & Schnauber, A. (2016). Harmonization and differences in CSR reporting of US and German companies. *Corporate Communications: An International Journal*, *21*(2), 230–245. https://doi.org/10.1108/CCIJ-09-2014-0062

Eisenman, M. (2013). Understanding Aesthetic Innovation in the Context of Technological Evolution. *Academy of Management Review*, *38*(3), 332–351. https://doi.org/10.5465/amr.2011.0262

Eliantonio, M., & Cauffman, C. (2020). The Legitimacy of Standardisation as a Regulatory Technique in the EU – A Cross-disciplinary and Multi-level Analysis: An Introduction. In *The Legitimacy of Standardisation as a Regulatory*

Technique in the EU – A Cross-disciplinary and Multi-level Analysis (Vol. 56, pp. 1–18). Edward Elgar Publishing.

Eliantonio, M., & Medzmariashvili, M. (2017). Hybridity under scrutiny: How European standardization shakes the foundations of EU constitutional and internal market law. *Legal Issues of Economic Integration*, *44*(4), 323–335. https://doi.org/10.54648/leie2017017

Elton-Chalcraft, S., Lander, V., Revell, L., Warner, D., & Whitworth, L. (2017). To promote, or not to promote fundamental British values? Teachers' standards, diversity and teacher education. *British Educational Research Journal*, *43*(1), 29–48. https://doi.org/10.1002/berj.3253

Erlinghagen, S., Lichtensteiger, B., & Markard, J. (2015). Smart meter communication standards in Europe - A comparison. *Renewable and Sustainable Energy Reviews*, *43*, 1249–1262. https://doi.org/10.1016/j.rser.2014.11.065

Ertug, G., Brennecke, J., & Tasselli, S. (2023). Theorizing about the Implications of Multiplexity. *Academy of Management Annals 17*(2), 626-654

European Commission. (2006). *SMEs and standardisation in Europe*. http://ec.europa.eu/enterprise/entrepreneurship/craft/craft-

European Commission. (2014). *Competition policy brief: Standard-essential patents* (Issue 8).

European Commission. (2020). *Regulation of the European Parliament and of the Council on contestable and fair markets in the digital sector (Digital Markets Act)*

European Commission. (2021). *Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change. COM(2021) 82 final.*

European Commission. (2021). *Harmonisation of the laws of the Member States relating to the making available on the market of radio equipment* (Vol. 0291).

European Commission. (2021). *The EU Artificial Intelligence Act. COM/2021/206 final.*

European Commission. (2022). *An EU Strategy on Standardisation Setting global standards in support of a resilient, green and digital EU single market. COM/2022/31 final.*

European Commission. (2023). *Guidelines on the applicability of Article 101 of the Treaty on the Functioning of the European Union to horizontal co-operation agreements.*

European Commission. (2023). *On standard essential patents and amending Regulation (EU)2017/1001: Vol. COM(2023).*

European Commission. (2023). *On standard essential patents and amending Regulation (EU)2017/1001: Vol. COM(2023).*

European Council. (1985). *Council Resolution of 7 May 1985 on a new approach to technical harmonization and standards (85/C 136/01) (Issue C).*

European Parliament, & European Council. (2016). *Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation).* https://eur-lex.europa.eu/eli/reg/2016/679/oj

European Parliament. (2024). *European Parliament legislative resolution of 28 February 2024 on the proposal for a regulation of the European Parliament and of the Council on standard essential patents and amending Regulation (EU) 2017/1001 (COM(2023)0232 – C9-0147/2023 – 2023/0133(COD))*

Evans, D. S., & Schmalensee, R. (2010). Failure to launch: Critical mass in platform businesses. *Review of Network Economics*, *9*(4). https://doi.org/10.2202/1446-9022.1256

Evans, D. S., Schmalensee, R., Noel, M. D., Chang, H. H., & Garcia-Swartz, D. D. (2011). Platform economics: Essays on multi-sided businesses. *Competition Policy International*, 459.

Everett, M., & Borgatti, S. P. (2005). Ego network betweenness. *Social Networks*, *27*(1), 31–38. https://doi.org/10.1016/j.socnet.2004.11.007

Fan, Z., Kulkarni, P., Gormus, S., Efthymiou, C., Kalogridis, G., Sooriyabandara, M., Zhu, Z., Lambotharan, S., & Chin, W. H. (2013). Smart grid communications: Overview of research challenges, solutions, and standardization activities. *IEEE Communications Surveys and Tutorials*, *15*(1), 21–38. https://doi.org/10.1109/SURV.2011.122211.00021

Farrell, J. (1989). Standardization and Intellectual Property. *Jurimetrics*, *30*(1), 35–50.

Farrell, J., & Klemperer, P. (2011). Coordination and Lock-In: Competition with Switching Costs and Network Effects. *SSRN Electronic Journal*, May, 1–129. https://doi.org/10.2139/ssrn.917785

Farrell, J., & Saloner, G. (1985). Standardization, compatibility, and innovation. *The RAND Journal of Economics*, *16*(1), 70–83.

Farrell, J., & Saloner, G. (1988). Coordination Through Committees and Markets. *The RAND Journal of Economics*, *19*(2), 235. https://doi.org/10.2307/2555702

Farrell, J., & Simcoe, T. (2012). Choosing the rules for consensus standardization. *RAND Journal of Economics*, *43*(2), 235–252. https://doi.org/10.1111/j.1756-2171.2012.00164.x

Farris, P., Pfeifer, P. E., & Johnson, R. R. (2021). The Value of Networks. *SSRN Electronic Journal*, July. https://doi.org/10.2139/ssrn.1420578

Farronato, C., Fong, J., & Fradkin, A. (2023). Dog Eat Dog: Measuring Network Effects Using a Digital Platform Merger. *Management Science*. https://doi.org/10.2139/ssrn.3727123

Fearnley, C. J., McGuire, W. J., Davies, G., & Twigg, J. (2012). Standardisation of the USGS Volcano Alert Level System (VALS): analysis and ramifications. *Bulletin of Volcanology*, *74*(9), 2023–2036. https://doi.org/10.1007/s00445-012-0645-6

Federal Trade Commission. (2002). *FTC Issues Complaint Against Rambus, Inc.* https://doi.org/10.1016/S0140-6736(00)94402-7

Fenech, M., Giugni, M., & Bown, K. (2012). A Critical Analysis of the National Quality Framework: Mobilising for a Vision for Children Beyond Minimum Standards. *Australasian Journal of Early Childhood*, *37*(4), 5–14. https://doi.org/10.1177/183693911203700402

Festag, A. (2015). Standards for vehicular communication—from IEEE 802.11p to 5G. *Elektrotechnik Und Informationstechnik*, *132*(7), 409–416. https://doi.org/10.1007/s00502-015-0343-0

Fine, J. (2017). Enforcing Labor Standards in Partnership with Civil Society: Can Co-enforcement Succeed Where the State Alone Has Failed? *Politics & Society*, *45*(3), 359–388. https://doi.org/10.1177/0032329217702603

Finkbeiner, M., Inaba, A., Tan, R. B. H., Christiansen, K., & Klüppel, H. J. (2006). The new international standards for life cycle assessment: ISO 14040 and ISO 14044. In *International Journal of Life Cycle Assessment* (Vol. 11, Issue 2, pp. 80–85). Springer Verlag. https://doi.org/10.1065/lca2006.02.002

Flynn, A., & Hacking, N. (2019). Setting standards for a circular economy: A challenge too far for neoliberal environmental governance? *Journal of Cleaner Production*, *212*, 1256–1267. https://doi.org/10.1016/j.jclepro.2018.11.257

Fontagné, L., Orefice, G., Piermartini, R., & Rocha, N. (2015). Product standards and margins of trade: Firm-level evidence. *Journal of International Economics*, *97*(1), 29–44. https://doi.org/10.1016/j.jinteco.2015.04.008

Fontana, R., & Greenstein, S. (2021). Platform leadership and supply chains: Intel, Centrino, and the restructuring of Wi-Fi supply. *Journal of Economics and Management Strategy*, *30*(2), 259–286. https://doi.org/10.1111/jems.12409

Fortunato, S., Bergstrom, C. T., Börner, K., Evans, J. A., Helbing, D., Milojević, S., Petersen, A. M., Radicchi, F., Sinatra, R., Uzzi, B., Vespignani, A., Waltman, L., Wang, D., & Barabási, A. L. (2018). Science of science. *Science*, *359*(6379). https://doi.org/10.1126/science.aao0185

Foster, R. (1986). *Innovation: The Attacker's advantage*. Summit Books.

Fotouhi, A., Qiang, H., Ding, M., Hassan, M., Giordano, L. G., Garcia-Rodriguez, A., & Yuan, J. (2019). Survey on UAV Cellular Communications: Practical Aspects, Standardization Advancements, Regulation, and Security Challenges. *IEEE Communications Surveys and Tutorials*, *21*(4), 3417–3442. https://doi.org/10.1109/COMST.2019.2906228

Foucart, R., & Li, Q. C. (2021). The role of technology standards in product innovation: Theory and evidence from UK manufacturing firms. *Research Policy*, *50*(2), 104157. https://doi.org/10.1016/j.respol.2020.104157

Framling, K., Kubler, S., & Buda, A. (2014). Universal Messaging Standards for the IoT From a Lifecycle Management Perspective. *IEEE Internet of Things Journal*, *1*(4), 319–327. https://doi.org/10.1109/JIOT.2014.2332005

Fransen, L. W., & Kolk, A. (2007). Global Rule-Setting for Business: A Critical Analysis of Multi-Stakeholder Standards. *Organization*, *14*(5), 667–684. https://doi.org/10.1177/1350508407080305

Fransen, L., Kolk, A., & Rivera-Santos, M. (2019). The multiplicity of international corporate social responsibility standards. *Multinational Business Review*, *27*(4), 397–426. https://doi.org/10.1108/MBR-08-2019-0083

Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy*, *93*(October 2018), 101–111. https://doi.org/10.1016/j.envsci.2018.12.033

Frazier, T. G., Thompson, C. M., Dezzani, R. J., & Butsick, D. (2013). Spatial and temporal quantification of resilience at the community scale. *Applied Geography*, *42*, 95–107. https://doi.org/10.1016/j.apgeog.2013.05.004

Freeman, L. C. (1982). Centered graphs and the structure of ego networks. *Mathematical Social Sciences*, 3(3), 291–304. https://doi.org/10.1016/0165-4896(82)90076-2

Funk, J. L., & Methe, D. T. (2001). Market- and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication. *Research Policy*, *30*(4), 589–610. https://doi.org/10.1016/S0048-7333(00)00095-0

Furlan, E., Pozza, P. D., Michetti, M., Torresan, S., Critto, A., & Marcomini, A. (2021). Development of a Multi-Dimensional Coastal Vulnerability Index: Assessing vulnerability to inundation scenarios in the Italian coast. *Science of the Total Environment*, *772*, 144650. https://doi.org/10.1016/j.scitotenv.2020.144650

Gaillard, J. (1934). *Industrial standardization, its principles and application*. New York, The H. W. Wilson company. https://catalog.hathitrust.org/Record/006595248

Gallagher, S. (2012). The battle of the blue laser DVDs: The significance of corporate strategy in standards battles. *Technovation*, *32*(2), 90–98. https://doi.org/10.1016/j.technovation.2011.10.004

Gandal, N., Gantman, N., & Genesove, D. (2004). *Intellectual Property and Standardization Committee Participation in the US Modem Industry*. www.cepr.org

Ganti, A. R., & Lazzara, C. J. (2022). *Concentration within Sectors and Its Implications for Equal Weighting*.

Gao, P. (2015). Government in the catching-up of technology innovation: Case of administrative intervention in China. *Technological Forecasting and Social Change*, *96*, 4–14. https://doi.org/10.1016/j.techfore.2015.01.014

Gao, P., Gao, X., & Liu, G. (2021). Government-Controlled Enterprises in Standardization in the Catching-Up Context: Case of TD-SCDMA in China. *IEEE Transactions on Engineering Management*, *68*(1), 45–58. https://doi.org/10.1109/TEM.2020.3005274

Gao, P., Yu, J., & Lyytinen, K. (2014). Government in standardization in the catching-up context: Case of China's mobile system. *Telecommunications Policy*, *38*(2), 200–209. https://doi.org/10.1016/j.telpol.2013.10.002

Gao, X., & Liu, J. (2012). Catching up through the development of technology standard: The case of TD-SCDMA in China. *Telecommunications Policy*, *36*(7), 531–545. https://doi.org/10.1016/j.telpol.2012.01.006

Garud, R., Jain, S., & Kumaraswamy, A. (2002). Institutional Entrepreneurship in the Sponsorship of Common Technological Standards: The Case of Sun Microsystems and Java. *Academy of Management Journal*, *45*(1), 196–214. https://doi.org/10.2307/3069292

Gaubert, C., Hanson, G. H., & Neumark, D. (2024). *Economics of Place-Based Policies*. National Bureau of Economic Research. https://www.nber.org/conferences/economics-place-based-policies-fall-2024

Gauch, S., & Blind, K. (2015). Technological convergence and the absorptive capacity of standardisation. *Technological Forecasting and Social Change*, *91*, 236–249. https://doi.org/10.1016/j.techfore.2014.02.022

Gawer, A. (2014). Bridging differing perspectives on technological platforms: Toward an integrative framework. *Research Policy*, 43(7), 1239–1249. https://doi.org/10.1016/j.respol.2014.03.006

Gawer, A. (2021). Digital platforms and ecosystems: remarks on the dominant organizational forms of the digital age. *Innovation*, 24(1), 1–15. https://doi.org/10.1080/14479338.2021.1965888

Gawer, A., & Cusumano, M. A. (2014). Industry platforms and ecosystem innovation. *Journal of Product Innovation Management*, *31*(3), 417–433. https://doi.org/10.1111/jpim.12105

Gazis, V. (2017). A Survey of Standards for Machine-to-Machine and the Internet of Things. *IEEE Communications Surveys and Tutorials*, *19*(1), 482–511. https://doi.org/10.1109/COMST.2016.2592948

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, *31*(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems. *Research Policy*, *33*(6–7), 897–920. https://doi.org/10.1016/j.respol.2004.01.015

Gehanno, J. F., Rollin, L., Le Jean, T., Louvel, A., Darmoni, S., & Shaw, W. (2009). Precision and recall of search strategies for identifying studies on return-to-work in medline. *Journal of Occupational Rehabilitation*, *19*(3), 223–230. https://doi.org/10.1007/s10926-009-9177-0

Ghanem, A., & Wang, C. (2018). Enantioselective separation of racemates using CHIRALPAK IG amylose-based chiral stationary phase under normal standard, non-standard and reversed phase high performance liquid chromatography. *Journal of Chromatography A*, *1532*, 89–97. https://doi.org/10.1016/j.chroma.2017.11.049

Giddens, A. (1984). *The Constitution of Society: Outline of the Theory of Structuration*. University of California Press.

Gilbert, D. U., Rasche, A., & Waddock, S. (2011). Accountability In A Global Economy: The Emergence of International Accountability Standards. *Business Ethics Quarterly*, *21*(1), 23–44. https://doi.org/10.1017/s1052150x00013038

Gilder, G. (1993). Telecosm: "Metcalfe's law and legacy." Forbes ASAP.

Gilsing, V., Nooteboom, B., Vanhaverbeke, W., Duysters, G., & van den Oord, A. (2008). Network embeddedness and the exploration of novel technologies: Technological distance, betweenness centrality and density. *Research Policy*, *37*(10), 1717–1731. https://doi.org/10.1016/j.respol.2008.08.010

Glaeser, E. L., & Gottlieb, J. D. (2008). The Economics of Place-Making Policies. In *Source: Brookings Papers on Economic Activity* (Issue Spring). https://www.jstor.org/stable/27561617

Glazebrook, R. (1931). Standards of Measurement : Their History and Development.*. *Nature*, *3218*(3218).

González-Pampillón, N., Jofre-Monseny, J., & Viladecans-Marsal, E. (2019). Can urban renewal policies reverse neighborhood ethnic dynamics? *Journal of Economic Geography*. https://doi.org/10.1093/jeg/lbz011

Gordon, J.-S., & Fomin, V. V. (2019). Ethics and Standardization. In *Corporate Standardization Management and Innovation* (pp. 177–192). https://doi.org/10.4018/978-1-5225-9008-8.ch009

Government of India. (2018). *Indian National Strategy for Standardization (INSS) - Evolving a Quality Ecosystem*. https://commerce.gov.in/wp-content/uploads/2020/02/NTESCL636655457105693409_INSS_Booklet_2018.pdf

Granovetter, M. (1985). Economic Action and Social Structure: the Problem of Embeddedness. *Journal of Economic Sociology*, *91*(3). https://doi.org/10.17323/1726-3247-2002-3-44-58

Granstrand, O., Patel, P., & Pavitt, K. (1997). Multi-technology corporations: Why they have "distributed" rather than "distinctive core" competencies. *California Management Review*, *39*(4), 8–25. https://doi.org/10.2307/41165908

Greenleaf, G. (2012). The influence of European data privacy standards outside Europe: Implications for globalisation of Convention 108? In *Research Paper*

Series (2012/12; Vol. 38, Issue 988). https://doi.org/10.1016/S0140-6736(02)85470-8

Greenstein, S. (2012). Economic experiments and the development of Wi-Fi. In *Advances in Strategic Management* (Vol. 29, Issue 2012). Emerald Group Publishing Ltd. https://doi.org/10.1108/S0742-3322(2012)0000029005

Griliches, Z. (1957). Hybrid Corn: An Exploration in the Economics of Technological Change. *Econometrica*, 25(4), 501. https://doi.org/10.2307/1905380

Griliches, Z. (1986). Productivity, R&D, and Basic Research at the Firm Level in the 1970's. *The American Economic Review*, *76*(1), 141–154. https://about.jstor.org/terms

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*, July, 788–830. https://doi.org/10.5465/annals.2023.0072

Grisot, M., & Vassilakopoulou, P. (2013). Infrastructures in healthcare: The interplay between generativity and standardization. *International Journal of Medical Informatics*, *82*(5), e170–e179. https://doi.org/10.1016/j.ijmedinf.2012.08.010

Guerreiro, M. S., Rodrigues, L. L., & Craig, R. (2012). Voluntary adoption of International Financial Reporting Standards by large unlisted companies in Portugal - Institutional logics and strategic responses. *Accounting, Organizations and Society*, *37*(7), 482–499. https://doi.org/10.1016/j.aos.2012.05.003

Gulati, R., & Singh, H. (1998). The Architecture of Cooperation: Managing Coordination Costs and Appropriation Concerns in Strategic Alliances. *Administrative Science Quarterly*, *43*(4), 781. https://doi.org/10.2307/2393616

Gulati, R., Nohria, N., & Zaheer, A. (2000). Strategic Networks. *Strategic Entrepreneurship Journal*, 21(3), 1–23.

Gustafsson, R., Jääskeläinen, M., Maula, M., & Uotila, J. (2016). Emergence of Industries: A Review and Future Directions. *International Journal of Management Reviews*, *18*(1), 28–50. https://doi.org/10.1111/ijmr.12057

Haack, P., Schoeneborn, D., & Wickert, C. (2012). Talking the Talk, Moral Entrapment, Creeping Commitment? Exploring Narrative Dynamics in Corporate Responsibility Standardization. *Organization Studies*, *33*(5–6), 815–845. https://doi.org/10.1177/0170840612443630

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, *23*(2), 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Hagiu, A., & Wright, J. (2015). Multi-Sided Platforms. *International Journal of Industrial Organization.*

Han, S., Xie, T., Chih-Lin, I., Chai, L., Liu, Z., Yuan, Y., & Cui, C. (2020). Artificial-Intelligence-Enabled Air Interface for 6G: Solutions, Challenges, and Standardization Impacts. *IEEE Communications Magazine*, *58*(10), 73–79. https://doi.org/10.1109/MCOM.001.2000218

Han, Y. J. (2015). Analysis of essential patent portfolios via bibliometric mapping: an illustration of leading firms in the 4G era. *Technology Analysis and Strategic Management*, *27*(7), 809–839. https://doi.org/10.1080/09537325.2015.1019850

Hanseth, O., Jacucci, E., Grisot, M., & Aanestad, M. (2006). Reflexive Standardization: Side Effects and Complexity in Standard Making. *MIS Quarterly*, *30*, 563–581.

Harounabadi, M., Soleymani, D. M., Bhadauria, S., Leyh, M., & Roth-Mandutz, E. (2021). V2X in 3GPP Standardization: NR Sidelink in Release-16 and Beyond. *IEEE Communications Standards Magazine*, *5*(1), 12–21. https://doi.org/10.1109/MCOMSTD.001.2000070

Hassan, M. K., Miglietta, F., Paltrinieri, A., & Floreani, J. (2018). The effects of Shariah board composition on Islamic equity indices' performance. *Business Ethics*, *27*(3), 248–259. https://doi.org/10.1111/beer.12185

Heikkilä, J., Rissanen, J., & Ali-Vehmas, T. (2023). Coopetition, Standardization and General Purpose Technologies: A Framework and an Application. *Telecommunications Policy*, 47. https://doi.org/10.2139/ssrn.4108419

Heinrich, T. (2014). Standard wars, tied standards, and network externality induced path dependence in the ICT sector. *Technological Forecasting and Social Change*, *81*(1), 309–320. https://doi.org/10.1016/j.techfore.2013.04.015

Hellman, J. (2015). Living with floods and coping with vulnerability. *Disaster Prevention and Management: An International Journal*, *24*(4), 468–483. https://doi.org/10.1108/DPM-04-2014-0061

Henfridsson, O., Mathiassen, L., & Svahn, F. (2014). Managing technological change in the digital age: The role of architectural frames. *Journal of Information Technology*, *29*(1), 27–43. https://doi.org/10.1057/jit.2013.30

Henriksen, L. F. (2015). The global network of biofuel sustainability standards-setters. *Environmental Politics*, *24*(1), 115–137. https://doi.org/10.1080/09644016.2014.955680

Henshel, R. L., & Johnston, W. (1987). The Emergence of Bandwagon Effects: A Theory. *The Sociological Quarterly*, 28(4), 493–511. https://doi.org/10.1111/j.1533-8525.1987.tb00308.x

Heß, P., & Blind, K. (2023). The Effect of the COVID-19 Pandemic on Standardization. *IEEE Transactions on Engineering Management*, *X*(X), 1–13. https://doi.org/10.1109/TEM.2023.3331973

Hesser, W. (1997). *The Need for Interdisciplinary Research on Standardization* (Vol. 49, Issue 0).

Hesser, W., Feilzer, A., & de Vries, H. J. (2010). *Standardisation in Companies and Markets*. Helmut-Schmidt-University Hamburg, Erasmus University Rotterdam.

Higgins, V., & Richards, C. (2019). Framing sustainability: Alternative standards schemes for sustainable palm oil and South-South trade. *Journal of Rural Studies*, *65*, 126–134. https://doi.org/10.1016/j.jrurstud.2018.11.001

Hinings, B., Gegenhuber, T., & Greenwood, R. (2018). Digital innovation and transformation: An institutional perspective. *Information and Organization*, *28*(1), 52–61. https://doi.org/10.1016/j.infoandorg.2018.02.004

Hirschman, D., & Bosk, E. A. (2020). Standardizing Biases: Selection Devices and the Quantification of Race. *Sociology of Race and Ethnicity*, *6*(3), 348–364. https://doi.org/10.1177/2332649219844797

Ho, J. Y., & O'Sullivan, E. (2017). Strategic standardisation of smart systems: A roadmapping process in support of innovation. *Technological Forecasting and Social Change*, *115*, 301–312. https://doi.org/10.1016/j.techfore.2016.04.014

Hoffman, A. J. (1999). Institutional evolution and change: Environmentalism and the U.S. chemical industry. *Academy of Management Journal*, *42*(4), 351–371. https://doi.org/10.2307/257008

Hoffmann, A. A., & Sgró, C. M. (2011). Climate change and evolutionary adaptation. *Nature*, *470*(7335), 479–485. https://doi.org/10.1038/nature09670

Holland, S. P. (2012). Emissions taxes versus intensity standards: Second-best environmental policies with incomplete regulation. *Journal of Environmental Economics and Management*, *63*(3), 375–387. https://doi.org/10.1016/j.jeem.2011.12.002

Hospes, O. (2014). Marking the success or end of global multi-stakeholder governance? The rise of national sustainability standards in Indonesia and Brazil for palm oil and soy. *Agriculture and Human Values*, *31*(3), 425–437. https://doi.org/10.1007/s10460-014-9511-9

Houghton, K. A., Kend, M., & Jubb, C. (2013). The CLERP 9 Audit Reforms: Benefits and Costs Through the Eyes of Regulators, Standard Setters and Audit Service Suppliers. *Abacus*, *49*(2), 139–160. https://doi.org/10.1111/abac.12002

Hu, Y., Wang, Z., & Deng, T. (2021). Expansion in the shrinking cities: Does place-based policy help to curb urban shrinkage in China? *Cities*, *113*. https://doi.org/10.1016/j.cities.2021.103188

Huang, H., Khanna, M., Önal, H., & Chen, X. (2013). Stacking low carbon policies on the renewable fuels standard: Economic and greenhouse gas implications. *Energy Policy*, *56*, 5–15. https://doi.org/10.1016/j.enpol.2012.06.002

Hughes-Morgan, M., & Yao, B. E. (2016). Rent Appropriation in Strategic Alliances: A Study of Technical Alliances in Pharmaceutical Industry. *Long Range Planning*, 49(2), 186–195. https://doi.org/10.1016/j.lrp.2015.12.016

Huovila, A., Bosch, P., & Airaksinen, M. (2019). Comparative analysis of standardized indicators for Smart sustainable cities: What indicators and standards to use and when? *Cities*, *89*(June 2019), 141–153. https://doi.org/10.1016/j.cities.2019.01.029

Hussinger, K., & Schwiebacher, F. (2015). The Market Value of Technology Disclosures to Standard Setting Organizations. *Industry and Innovation*, *22*(4), 321–344. https://doi.org/10.1080/13662716.2015.1049866

Husted, B. W., Montiel, I., & Christmann, P. (2016). Effects of local legitimacy on certification decisions to global and national CSR standards by multinational subsidiaries and domestic firms. *Journal of International Business Studies*, *47*(3), 382–397. https://doi.org/10.1057/jibs.2016.3

Hwang, S., Kim, E., Lee, I., & Marcotte, E. M. (2015). Systematic comparison of variant calling pipelines using gold standard personal exome variants. *Scientific Reports*, *5*(1), 17875. https://doi.org/10.1038/srep17875

Iammarino, S. (2005). An evolutionary integrated view of regional systems of innovation: Concepts, measures and historical perspectives. *European Planning Studies*, *13*(4), 497–519. https://doi.org/10.1080/09654310500107084

Iansiti, M. (2021). Assessing the Strength of Network Effects in Social Network Platforms. Harvard Business School Working Paper.

IEEE Standards Association. (2023). Emerging technology, standards and sustainability.

Inoue, Y. (2021). Indirect innovation management by platform ecosystem governance and positioning: Toward collective ambidexterity in the ecosystems. *Technological Forecasting and Social Change*, 166. https://doi.org/10.1016/j.techfore.2021.120652

IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental

Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. https://doi.org/10.59327/IPCC/AR6-9789291691647

Isaksen, A. (2015). Industrial development in thin regions: Trapped in path extension? *Journal of Economic Geography*, *15*(3), 585–600. https://doi.org/10.1093/jeg/lbu026

ISO. (2019). Guidance on the Systematic Review process in ISO.

ISO. (2022). *Climate change adaptation*. https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100449.pdf

ISO/IEC. (2004). *ISO/IEC Guide 2:2004 - Standardization and related activities: General vocabulary*. https://www.iso.org/standard/39976.html

ISO/IEC. (2005). Regional or national adoption of International Standards and other International Deliverables.

Jackson, M. O. (2010). Social and Economic Networks. *Social and Economic Networks*, 1–504. https://doi.org/10.1093/acprof:oso/9780199591756.003.0019

Jacobides, M. G., Cennamo, C., & Gawer, A. (2018). Towards a theory of ecosystems. *Strategic Management Journal*, *39*(8), 2255–2276. https://doi.org/10.1002/smj.2904

Jacobides, M. G., Cennamo, C., & Gawer, A. (2024). Externalities and complementarities in platforms and ecosystems : From structural solutions to endogenous failures. *Research Policy*, *53*(1), 104906. https://doi.org/10.1016/j.respol.2023.104906

Jacobides, M. G., Knudsen, T., & Augier, M. (2006). Benefiting from innovation: Value creation, value appropriation and the role of industry architectures. *Research Policy*, 35(8 SPEC. ISS.), 1200–1221. https://doi.org/10.1016/j.respol.2006.09.005

Jacomy, M., Venturini, T., Heymann, S., & Bastian, M. (2014). ForceAtlas2, a Continuous Graph Layout Algorithm for Handy Network Visualization Designed for the Gephi Software. *PLoS ONE*, *9*(6), e98679. https://doi.org/10.1371/journal.pone.0098679

Jain, S. (2012). Pragmatic agency in technology standards setting: The case of Ethernet. *Research Policy*, *41*(9), 1643–1654. https://doi.org/10.1016/j.respol.2012.03.025

Jakobs, K. (2023). *ICT Standardisation Management – A multidimensional perspective on company participation in standardisation committees*. RSM PhD Series "Research in Management."

Jantsch, E. (1967). Technological Forecasting in Perspective.

Jha, A. V., Appasani, B., Ghazali, A. N., Pattanayak, P., Gurjar, D. S., Kabalci, E., & Mohanta, D. K. (2021). Smart grid cyber-physical systems: communication technologies, standards and challenges. *Wireless Networks*, *27*(4), 2595–2613. https://doi.org/10.1007/s11276-021-02579-1

Jin, L., Whitehead, P. G., Rodda, H., Macadam, I., & Sarkar, S. (2018). Simulating climate change and socio-economic change impacts on flows and water quality in the Mahanadi River system, India. *Science of the Total Environment*, *637–638*, 907–917. https://doi.org/10.1016/j.scitotenv.2018.04.349

Johansson, M., Kärreman, M., & Foukaki, A. (2019). Research and development resources, coopetitive performance and cooperation: The case of standardization in 3GPP, 2004–2013. *Technovation*, *88*(May), 102074. https://doi.org/10.1016/j.technovation.2019.04.001

Johnson, A. (2019). The Roundtable on Sustainable Palm Oil's national interpretation process in Ecuador: 'Fitting' global standards into local contexts. *Journal of Rural Studies*, *71*, 125–133. https://doi.org/10.1016/j.jrurstud.2019.02.013

Jones, A. (2014). Standard-essential patents: Frand commitments, injunctions and the smartphone wars. *European Competition Journal*, *10*(1), 1–36. https://doi.org/10.5235/17441056.10.1.1

Jones, L., Jaspers, S., Pavanello, S., Ludi, E., Slater, R., Arnall, A., Grist, N., & Mtisi, S. (2010). Responding to a changing climate: Exploring how disaster risk reduction, social protection and livelihoods approaches promote features of adaptive capacity.

Jones, S. L., Leiponen, A., & Vasudeva, G. (2021). The evolution of cooperation in the face of conflict: Evidence from the innovation ecosystem for mobile telecom standards development. *Strategic Management Journal*, *42*(4), 710–740. https://doi.org/10.1002/smj.3244

Jorissen, A., Lybaert, N., Orens, R., & van der Tas, L. (2013). A geographic analysis of constituents' formal participation in the process of international accounting standard setting: Do we have a level playing field? *Journal of Accounting and Public Policy*, *32*(4), 237–270. https://doi.org/10.1016/j.jaccpubpol.2013.04.005

Jullien, B., Pavan, A., & Rysman, M. (2021). Two-sided Markets , Pricing , and Network Effects (1238, Issue July).

Kafle, V. P., Fukushima, Y., & Harai, H. (2016). Internet of things standardization in ITU and prospective networking technologies. *IEEE Communications Magazine*, *54*(9), 43–49. https://doi.org/10.1109/MCOM.2016.7565271

Kalyani, A., Bloom, N., Carvalho, M., Hassan, T., Lerner, J., & Tahoun, A. (2025). The Diffusion of New Technologies. *The Quarterly Journal of Economics*. https://doi.org/10.1093/qje/qjaf002

Kamara, I. (2017). Co-regulation in EU personal data protection: the case of technical standards and the privacy by design standardisation 'mandate. In *European Journal of Law and Technology* (Vol. 8, Issue 1).

Kamps, X., de Vries, H. J., & van de Kaa, G. (2017). Exploring standards consortium survival in high tech industries: The effects of commitment and internal competition. *Computer Standards and Interfaces*, *52*(October 2016), 105–113. https://doi.org/10.1016/j.csi.2017.02.002

Kanevskaia, O. (2023). The Law and Practice of Global ICT Standardization. In *The Law and Practice of Global ICT Standardization*. Cambridge University Press. https://doi.org/10.1017/9781009300551

Kang, B., & Bekkers, R. (2015). Just-in-time patents and the development of standards. *Research Policy*, *44*(10), 1948–1961. https://doi.org/10.1016/j.respol.2015.07.001

Kang, B., & Motohashi, K. (2015). Essential intellectual property rights and inventors' involvement in standardization. *Research Policy*, *44*(2), 483–492. https://doi.org/10.1016/j.respol.2014.10.012

Karanović, J., Berends, H., & Engel, Y. (2021). Regulated Dependence: Platform Workers' Responses to New Forms of Organizing. *Journal of Management Studies*, 58(4), 1070–1106. https://doi.org/10.1111/joms.12577

Karhu, K., Heiskala, M., Ritala, P., & Thomas, L. D. W. (2024). Positive, Negative, and Amplified Network Externalities in Platform Markets. *Academy of Management Perspectives*.

Katz, M. L., & Shapiro, C. (1985). Network Externalities, Competition and Compatibility. *The American Economic Review*, *77*(3), 402–420.

Katz, M. L., & Shapiro, C. (1986). Technology Adoption in the Presence of Network Externalities. *Journal of Political Economy*, 94(4), 822–841.

Katz, M. L., & Shapiro, C. (1994). Systems Competition and Network Effects. *Journal of Economic Perspectives*, *8*(2), 93–115. https://doi.org/10.1257/jep.8.2.93

Kauffman, R. J., McAndrews, J., & Wang, Y. M. (2000). Opening the "Black Box" of Network Externalities in Network Adoption. *Information Systems Research*, *11*(1), 61–82. https://doi.org/10.1287/isre.11.1.61.11783

Keoh, S. L., Kumar, S. S., & Tschofenig, H. (2014). Securing the Internet of Things: A Standardization Perspective. *IEEE Internet of Things*, *1*(3), 265–273.

Kerwer, D. (2005). Rules that Many Use: Standards and Global Regulation. *Governance*, *18*(4), 611–632. https://doi.org/10.1111/j.1468-0491.2005.00294.x

Kester, J., Noel, L., Lin, X., Zarazua de Rubens, G., & Sovacool, B. K. (2019). The coproduction of electric mobility: Selectivity, conformity and fragmentation in the sociotechnical acceptance of vehicle-to-grid (V2G) standards. *Journal of Cleaner Production*, *207*, 400–410. https://doi.org/10.1016/j.jclepro.2018.10.018

Kilduff, M., & Brass, D. J. (2010). Organizational social network research: Core ideas and key debates. *Academy of Management Annals*, 4(1), 317–357. https://doi.org/10.1080/19416520.2010.494827

Kim, D. (2024). The paradox of standards and innovation: Reconceptualising standards and standardisation with the help of Niklas Luhmann. *Systems Research and Behavioral Science*, *December 2023*, 1–10. https://doi.org/10.1002/sres.3068

Kim, J., Yun, J., Choi, S.-C., Seed, D. N., Lu, G., Bauer, M., Al-Hezmi, A., Campowsky, K., & Song, J. (2016). Standard-based IoT platforms interworking: implementation, experiences, and lessons learned. *IEEE Communications Magazine*, *54*(7), 48–54. https://doi.org/10.1109/MCOM.2016.7514163

Kim, Y.-H., & Kim, K.-H. (2012). Novel Approach to Test the Relative Recovery of Liquid-Phase Standard in Sorbent-Tube Analysis of Gaseous Volatile Organic Compounds. *Analytical Chemistry*, *84*(9), 4126–4139. https://doi.org/10.1021/ac300334b

Kirton, J. J., & Trebilcock, M. J. (2004). Hard Choices, Soft Law: Voluntary Standards in Global Trade, Environment and Social Governance. In *NBER Working Papers*. Routledge. http://www.nber.org/papers/w16019

Kivelä, M., Arenas, A., Barthelemy, M., Gleeson, J. P., Moreno, Y., & Porter, M. A. (2014). Multilayer networks. *Journal of Complex Networks*, 2(3), 203–271. https://doi.org/10.1093/comnet/cnu016

Knoke, D., & Kuklinski, J. H. (1988). *Network Analysis*. SAGE Publications.

Kok, M., & Maroun, W. (2021). Not all experts are equal in the eyes of the International Auditing and Assurance Standards Board: On the application of ISA510 and ISA620 by South African registered auditors. *South African Journal of Economic and Management Sciences*, *24*(1). https://doi.org/10.4102/sajems.v24i1.3784

Kraatz, M. S. (1998). Learning by association? Interorganizational networks and adaptation to environmental change. *Academy of Management Journal*, *41*(6), 621–643. https://doi.org/10.2307/256961

Kraus, S., Meier, F., Eggers, F., Bouncken, R. B., & Schuessler, F. (2016). Standardisation vs. adaption: a conjoint experiment on the influence of psychic, cultural and geographical distance on international marketing mix decisions. *European Journal of International Management*, *10*(2), 127. https://doi.org/10.1504/EJIM.2016.074468

Kuhn, T. (1962). *The structure of scientific revolutions*. University of Chicago Press; 3rd edition. https://doi.org/10.5840/philstudies196413082

Kumar, D., Zare, F., & Ghosh, A. (2017). DC Microgrid Technology: System Architectures, AC Grid Interfaces, Grounding Schemes, Power Quality, Communication Networks, Applications, and Standardizations Aspects. *IEEE Access*, *5*, 12230–12256. https://doi.org/10.1109/ACCESS.2017.2705914

Kumar, P., Debele, S. E., Sahani, J., Aragão, L., Barisani, F., Basu, B., Bucchignani, E., Charizopoulos, N., Di Sabatino, S., Domeneghetti, A., Edo, A. S., Finér, L., Gallotti, G., Juch, S., Leo, L. S., Loupis, M., Mickovski, S. B., Panga, D., Pavlova, I., … Zieher, T. (2020). Towards an operationalisation of nature-based solutions for natural hazards. Science of the Total Environment, 731, 138855. https://doi.org/10.1016/j.scitotenv.2020.138855

Kürner, T., & Priebe, S. (2014). Towards THz communications - Status in research, standardization and regulation. *Journal of Infrared, Millimeter, and Terahertz Waves*, *35*(1), 53–62. https://doi.org/10.1007/s10762-013-0014-3

Kwak, J. Y., Lee, H., & Chung, D. B. (2012). The evolution of alliance structure in China's mobile telecommunication industry and implications for international standardization. *Telecommunications Policy*, *36*(10–11), 966–976. https://doi.org/10.1016/j.telpol.2012.07.017

Kwon, T. (2015). Rent and rent-seeking in renewable energy support policies: Feed-in tariff vs. renewable portfolio standard. *Renewable and Sustainable Energy Reviews*, *44*, 676–681. https://doi.org/10.1016/j.rser.2015.01.036

Ladu, L., & Blind, K. (2017). Overview of policies, standards and certifications supporting the European bio-based economy. *Current Opinion in Green and Sustainable Chemistry*, *8*, 30–35. https://doi.org/10.1016/j.cogsc.2017.09.002

Lafortezza, R., & Sanesi, G. (2019). Nature-based solutions: Settling the issue of sustainable urbanization. Environmental Research, 172(August 2018), 394–398. https://doi.org/10.1016/j.envres.2018.12.063

Lakatos, I. (1970). Falsification and the Methodology of Scientific Research Programmes. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the Growth of*

Knowledge (pp. 91–196). Cambridge University Press. https://doi.org/10.1017/CBO9781139171434.009

Lakatos, I. (1978). *Mathematics, Science and Epistemology* (J. Worrall & G. Currie (eds.)). Cambridge University Press. https://doi.org/10.1017/CBO9780511624926

Lakatos, I., & Musgrave, A. (1970). Criticism and the Growth of Knowledge. *Proceedings of the International Colloquium in the Philosophy of Science,*. https://doi.org/10.1017/cbo9781139171434

Lal, P. N., Mitchell, T., Aldunce, P., Auld, H., Mechler, R., Miyan, A., Romano, L. E., Zakaria, S., Dlugolecki, A., Masumoto, T., Ash, N., Hochrainer, S., Hodgson, R., Islam, T. U., Mc Cormick, S., Neri, C., Pulwarty, R., Rahman, A., Ramalingam, B., … Wilby, R. (2012). National systems for managing the risks from climate extremes and disasters. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change* (Vol. 9781107025). IPCC, Geneva, Switzerland. https://doi.org/10.1017/CBO9781139177245.009

Lamont, M., Beljean, S., & Clair, M. (2014). What is missing? Cultural processes and causal pathways to inequality. *Socio-Economic Review*, *12*(3), 573–608. https://doi.org/10.1093/ser/mwu011

Larivière, V., Haustein, S., & Börner, K. (2015). Long-distance interdisciplinarity leads to higher scientific impact. *PLoS ONE*, *10*(3). https://doi.org/10.1371/journal.pone.0122565

Larouche, P., & De Streel, A. (2021). The European Digital Markets Act: A Revolution Grounded on Traditions. *Journal of European Competition Law and Practice*, 12(7), 542–560. https://doi.org/10.1093/jeclap/lpab066

Lee, D. K., & Choi, M. S. (2018). Standard reference materials for cement paste, Part I: Suggestion of constituent materials based on rheological analysis. *Materials*, *11*(4). https://doi.org/10.3390/ma11040624

Lee, H., Harindranath, G., Oh, S., & Kim, D.-J. (2015). Provision of mobile banking services from an actor–network perspective: Implications for convergence and standardization. *Technological Forecasting and Social Change*, *90*, 551–561. https://doi.org/10.1016/j.techfore.2014.02.007

Lee, J. M., & Kapoor, R. (2017). Complementarities and coordination: Implications for governance mode and performance of multiproduct firms. *Organization Science*, *28*(5), 931–946. https://doi.org/10.1287/orsc.2017.1150

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

Lemley, M. A. (2003). Intellectual Property Rights and Standard-Setting Organizations. *SSRN Electronic Journal*, *57*(2), 515–540. https://doi.org/10.2139/ssrn.310122

Lemstra, W. ., Hayes, Vic., & Groenewegen, John. (2011). *The innovation journey of Wi-Fi : the road to global success*. Cambridge University Press.

Lerner, J., & Tirole, J. (2006). A Model of Forum Shopping. *American Economic Review*, *96*(4), 1091–1113. https://doi.org/10.1257/aer.96.4.1091

Lerner, J., & Tirole, J. (2015). Standard-Essential Patents. *Journal of Political Economy*, *123*(3), 547–586. https://doi.org/10.1086/680995

Leskovec, J., & Krevl, A. (2014). SNAP Datasets: Stanford Large Network Dataset Collection.

Li, H., Shen, Q., & Bart, Y. (2018). Local market characteristics and online-to-offline commerce: An empirical analysis of Groupon. *Management Science*, 64(4), 1860–1878. https://doi.org/10.1287/mnsc.2016.2666

Li, Y., Zhan, C., de Jong, M., & Lukszo, Z. (2016). Business innovation and government regulation for the promotion of electric vehicle use: lessons from Shenzhen, China. *Journal of Cleaner Production*, *134*, 371–383. https://doi.org/10.1016/j.jclepro.2015.10.013

Liebowitz, S. J., & Margolis, S. E. (1995). Path dependence, lock-in, and history. *Journal of Law, Economics, and Organization*, 11(1), 205–226. https://doi.org/10.2139/ssrn.1706450

Liguori, K., Keenum, I., Davis, B. C., Calarco, J., Milligan, E., Harwood, V. J., & Pruden, A. (2022). Antimicrobial Resistance Monitoring of Water Environments: A Framework for Standardized Methods and Quality Control.

Environmental Science and Technology, *56*(13), 9149–9160. https://doi.org/10.1021/acs.est.1c08918

Lin, T. C., & Huang, S. L. (2014). Understanding the determinants of consumers' switching intentions in a standards war. *International Journal of Electronic Commerce*, *19*(1), 163–189. https://doi.org/10.2753/JEC1086-4415190105

Lindgren, R., Mathiassen, L., & Schultze, U. (2021). The Dialectics of Technology Standardization. *MIS Quarterly*, *45*(3), 1187–1212. https://doi.org/10.25300/MISQ/2021/12860

Lindsey, R. (2022). *Climate Change: Global Sea Level*. https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level#:~:text=In 2020%2C global sea level,per year from 2006–2015.

Liu, H., Li, X., & Wang, S. (2021). A bibliometric analysis of 30 years of platform research : Developing the research agenda for platform, the associated technologies and social impacts. *Technological Forecasting & Social Change*, 169(April), 120827. https://doi.org/10.1016/j.techfore.2021.120827

Lodder, Q. J., Slinger, J. H., Wang, Z. B., van der Spek, A. J. F., Hijma, M. P., Taal, M., van Gelder-Maas, C., de Looff, H., Litjens, J., Schipper, C. A., Löffler, M., Nolte, A. J., van Oeveren, C., van der Werf, J. J., Grasmeijer, B. T., Elias, E. P. L., Holzhauer, H., & Tonnon, P. K. (2023). The Coastal Genesis 2 research programme: Outputs, Outcomes and Impact. *Ocean and Coastal Management*, *237*(January). https://doi.org/10.1016/j.ocecoaman.2023.106499

Lorenz, A., Raven, M., & Blind, K. (2019). The role of standardization at the interface of product and process development in biotechnology. *J Technol Transf*, *44*, 1097–1133. https://doi.org/10.1007/s10961-017

Lou, Z., Yao, S., & Zhang, X. (2022). The Optimal Patent Portfolio of The Technology Standards Alliances in Innovation Competition. *Emerging Markets Finance and Trade*, *58*(6), 1794–1805. https://doi.org/10.1080/1540496X.2021.1918544

Lu, X., Wang, P., Niyato, D., Kim, D. I., & Han, Z. (2016). Wireless Charging Technologies: Fundamentals, Standards, and Network Applications. *IEEE*

Communications Surveys and Tutorials, *18*(2), 1413–1452. https://doi.org/10.1109/COMST.2015.2499783

Lutfallah, S., & Buchanan, L. (2019). Quantifying subjective data using online Q-methodology software. *The Mental Lexicon*, *14*(3), 415–423. https://doi.org/10.1075/ml.20002.lut

MacDonald, G., & Ryall, M. D. (2004). How do value creation and competition determine whether a firm appropriates value? *Management Science*, 50(10), 1319–1333. https://doi.org/10.1287/mnsc.1030.0152

Macdonald, K. (2020). Private sustainability standards as tools for empowering southern pro-regulatory coalitions? Collaboration, conflict and the pursuit of sustainable palm oil. *Ecological Economics*, *167*, 106439. https://doi.org/10.1016/j.ecolecon.2019.106439

Mainetti, L., Patrono, L., Stefanizzi, M. L., & Vergallo, R. (2013). An innovative and low-cost gapless traceability system of fresh vegetable products using RF technologies and EPCglobal standard. *Computers and Electronics in Agriculture*, *98*, 146–157. https://doi.org/10.1016/j.compag.2013.07.015

Malets, O. (2015). When Transnational Standards Hit the Ground: Domestic Regulations, Compliance Assessment and Forest Certification in Russia. *Journal of Environmental Policy & Planning*, *17*(3), 332–359. https://doi.org/10.1080/1523908X.2014.947922

Manders, B. (2015). *Implementation and Impact of ISO 9001*. ERIM PhD Series in Research in Management. https://repub.eur.nl/pub/12679/PhD Thesis_Curran_May 2008.pdf

Manders, B., de Vries, H. J., & Blind, K. (2016). ISO 9001 and product innovation: A literature review and research framework. *Technovation*, *48–49*, 41–55. https://doi.org/10.1016/j.technovation.2015.11.004

Manning, S., & Reinecke, J. (2016). A modular governance architecture in-the-making: How transnational standard-setters govern sustainability transitions. *Research Policy*, *45*(3), 618–633. https://doi.org/10.1016/j.respol.2015.11.007

Manning, S., Boons, F., von Hagen, O., & Reinecke, J. (2012). National contexts matter: The co-evolution of sustainability standards in global value chains.

Ecological Economics, *83*, 197–209. https://doi.org/10.1016/j.ecolecon.2011.08.029

March, J. G., & Simons, H. A. (1958). *Organizations*. New. York: John Wiley and Sons, Inc.

Markus, M. L., Steinfield, C. W., & Wigand, R. T. (2006). Industry-Wide Information Systems Standardization as Collective Action: The Case of the U.S. Residential Mortgage Industry. In Source: *MIS Quarterly* (Vol. 30).

Martin, R., & Sunley, P. (2006). Path dependence and regional economic evolution. *Journal of Economic Geography*, *6*(4), 395–437. https://doi.org/10.1093/jeg/lbl012

Martinez, J. I., & Jarillo, J. C. (1989). The Evolution of Research on Coordination Mechanisms in Multinational Corporations. *Journal of International Business Studies*, *20*(3), 489–514. https://doi.org/10.1057/palgrave.jibs.8490370

Maskus, K., Bekkers, R., Block, M.S., Contreras, J., Gilbert, R. J., Goodman, D. J., Marasco, A., Simcoe, T., Smoot, O., Suttmeier, R., Updegrove, A. (2013). *Patent Challenges for Standard-Setting in the Global Economy*. National Research Council. https://doi.org/10.17226/18510

Matutes, C., & Regibeau, P. (1988). "Mix and Match": Product Compatibility without Network Externalities. *The RAND Journal of Economics*, *19*(2), 221. https://doi.org/10.2307/2555701

McAdam, J. (2014). Historical cross-border relocations in the pacific: Lessons for planned relocations in the context of climate change. *Journal of Pacific History*, *49*(3), 301–327. https://doi.org/10.1080/00223344.2014.953317

McClean, K., Greer, D., & Jurek-Loughrey, A. (2021). Social network analysis of open source software: A review and categorisation. *Information and Software Technology*, 130. https://doi.org/10.1016/j.infsof.2020.106442

Mcintyre, D. P., & Srinivasan, A. (2016). Networks, platforms, and strategy: emerging views and next steps. *Strategic Management Journal*, 1154(March), 1–43. https://doi.org/10.1002/smj

Mcintyre, D. P., Srinivasan, A., Afuah, A., Gawer, A., & Kretschmer, T. (2020). Multi-sided platforms as new organizational forms. *Academy of Management Journal*, 148, 148–162.

McKeown, B., & Thomas, D. (1988). *Q Methodology*. SAGE Publications.

McWilliam, R. C. (2001). Introduction: 100 years of raising standards. In *BSI: THE FIRST HUNDRED YEARS 1901–2001 A century of achievement* (pp. 1–10). Thomas Telford Publishing. https://doi.org/10.1680/btfhy.30206.0001

Meemken, E.-M. (2020). Do smallholder farmers benefit from sustainability standards? A systematic review and meta-analysis. *Global Food Security*, *26*, 100373. https://doi.org/10.1016/j.gfs.2020.100373

Meijer, A., Wiarda, M., Doorn, N., & van de Kaa, G. (2023). Towards responsible standardisation: investigating the importance of responsible innovation for standards development. *Technology Analysis and Strategic Management*, 1–15. https://doi.org/10.1080/09537325.2023.2225108

Melnitsky, B. (1953). *Profiting From Industrial Standardization*. https://catalog.hathitrust.org/Record/002569728?type%5B%5D=all&lookfor%5B%5D=Profiting%20From%20Industrial%20Standardization&ft=

Memon, M., Wagner, S. R., Pedersen, C. F., Aysha Beevi, F. H., & Hansen, F. O. (2014). Ambient Assisted Living healthcare frameworks, platforms, standards, and quality attributes. *Sensors (Switzerland)*, *14*(3), 4312–4341. https://doi.org/10.3390/s140304312

Mercado, G., Hjortsø, C. N., & Honig, B. (2018). Decoupling from international food safety standards: how small-scale indigenous farmers cope with conflicting institutions to ensure market participation. *Agriculture and Human Values*, *35*(3), 651–669. https://doi.org/10.1007/s10460-018-9860-x

Metcalfe, B. (2013). Metcalfe's law after 40 years of ethernet. *Computer*, 46(12), 26–31. https://doi.org/10.1109/MC.2013.374

Meyer, N. (2012). *Public Intervention in Private Rule Making: The Role of the European Commission in Industry Standardization* (Issue March 2012). London School of Economics. http://etheses.lse.ac.uk/236/

Milgram, S. (1967). The Small-World Problem. *Psychology Today*, *1*(1), 61–67.

Miller, C. D., & Toh, P. K. (2020). Complementary components and returns from coordination within ecosystems via standard setting. *Strategic Management Journal*, February 2018, 1–36. https://doi.org/10.1002/smj.3143

Mintzberg, H. (1980). Structure in 5's: a Synthesis of the Research on Organization Design. *Management Science*, *26*(3).

Mirtsch, M., Kinne, J., & Blind, K. (2021). Exploring the Adoption of the International Information Security Management System Standard ISO/IEC 27001: A Web Mining-Based Analysis. *IEEE Transactions on Engineering Management*, *68*(1), 87–100. https://doi.org/10.1109/TEM.2020.2977815

Mitchell, J. C. (1969). Social networks in urban situations. Manchester University Press for the Institute for African Studies in the University of Zambia.

Mohan, S. (2019). Private standards and producer risk: a framework for analysis of development implications**. *European Review of Agricultural Economics*. https://doi.org/10.1093/erae/jbz005

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine*, *6*(7).

Moreira, S., Klueter, T. M., & Tasselli, S. (2020). Competition, Technology Licensing-in, and Innovation. *Organization Science*, *31*(4), 1012–1036. https://doi.org/10.1287/orsc.2019.1337

Morris, L. A., & Miller, D. W. (2002). The regulation of patient-reported outcome claims: Need for a flexible standard. *Value in Health*, *5*(4), 372–381. https://doi.org/10.1046/j.1524-4733.2002.54073.x

Müller, K. M., & Arndt, K. M. (2012). Standardization in Synthetic Biology. In *Methods in Molecular Biology* (Vol. 813, pp. 23–43). https://doi.org/10.1007/978-1-61779-412-4_2

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

Nadvi, K. (2008). Global standards, global governance and the organization of global value chains. *Journal of Economic Geography*, *8*(3), 323–343. https://doi.org/10.1093/jeg/lbn003

Nadvi, K., & Wältring, F. (2004). Making sense of global standards. In *Local Enterprises in the Global Economy* (Issue February 2004, pp. 53–94). Edward Elgar Publishing. https://doi.org/10.4337/9781843769743.00010

Nakamura, S. (1993). *The New Standardization: Keystone of Continuous Improvement in Manufacturing*. Productivity Press.

Nam, W., Zhao, Y., Song, J., Ali Safiabadi Tali, S., Kang, S., Zhu, W., Lezec, H. J., Agrawal, A., Vikesland, P. J., & Zhou, W. (2020). Plasmonic Electronic Raman Scattering as Internal Standard for Spatial and Temporal Calibration in Quantitative Surface-Enhanced Raman Spectroscopy. *The Journal of Physical Chemistry Letters*, *11*(22), 9543–9551. https://doi.org/10.1021/acs.jpclett.0c03056

Narayanan, V. K., & Chen, T. (2012). Research on technology standards: Accomplishment and challenges. *Research Policy*, *41*(8), 1375–1406. https://doi.org/10.1016/j.respol.2012.02.006

Narula, R. (2019). Enforcing higher labor standards within developing country value chains: Consequences for MNEs and informal actors in a dual economy. *Journal of International Business Studies*, *50*(9), 1622–1635. https://doi.org/10.1057/s41267-019-00265-1

Narula, S., Puppala, H., Kumar, A., Frederico, G. F., Dwivedy, M., Prakash, S., & Talwar, V. (2021). Applicability of industry 4.0 technologies in the adoption of global reporting initiative standards for achieving sustainability. *Journal of Cleaner Production*, *305*, 127141. https://doi.org/10.1016/j.jclepro.2021.127141

Nasrallah, A., Thyagaturu, A. S., Alharbi, Z., Wang, C., Shao, X., Reisslein, M., & ElBakoury, H. (2019). Ultra-low latency (ULL) networks: The IEEE TSN and IETF DetNet standards and related 5G Ull research. *IEEE Communications Surveys and Tutorials*, *21*(1), 88–145. https://doi.org/10.1109/COMST.2018.2869350

Naumann, A., Bielchev, I., Voropai, N., & Styczynski, Z. (2014). Smart grid automation using IEC 61850 and CIM standards. *Control Engineering Practice*, *25*(1), 102–111. https://doi.org/10.1016/j.conengprac.2013.12.001

Nguyen, T., Islam, A., Yamazato, T., & Jang, Y. M. (2018). Technical Issues on IEEE 802.15.7m Image Sensor Communication Standardization. *IEEE Communications Magazine*, *56*(2), 213–218. https://doi.org/10.1109/MCOM.2018.1700134

Nicholls, R. J. (2011). Planning for the impacts of sea level rise. *Oceanography*, *24*(2), 144–157. https://doi.org/10.5670/oceanog.2011.34

Nickell, S. J. (1996). Competition and Corporate Performance. *Journal of Political Economy*, *104*(4), 724–746. https://about.jstor.org/terms

Nikoukar, A., Raza, S., Poole, A., Gunes, M., & Dezfouli, B. (2018). Low-Power Wireless for the Internet of Things: Standards and Applications. *IEEE Access*, *6*, 67893–67926. https://doi.org/10.1109/ACCESS.2018.2879189

Nilsen, T., Grillitsch, M., & Hauge, A. (2023). Varieties of periphery and local agency in regional development. *Regional Studies*, *57*(4), 749–762. https://doi.org/10.1080/00343404.2022.2106364

NIST. (2019). *U.S. LEADERSHIP IN AI: A Plan for Federal Engagement in Developing Technical Standards and Related Tools*. https://dx.plos.org/10.1371/journal.pone.0098679

NIST. (2024). *A Plan for Global Engagement on AI Standards*. https://doi.org/10.6028/NIST.AI.100-5

Nonaka, I., & Takeuchi, H. (1995). The knowledge creating company: how Japanese companies create the dynamics of innovation. Oxford University Press.

Novacheck, J., & Johnson, J. X. (2015). The environmental and cost implications of solar energy preferences in Renewable Portfolio Standards. *Energy Policy*, *86*, 250–261. https://doi.org/10.1016/j.enpol.2015.06.039

Nurunnabi, M. (2015). The impact of cultural factors on the implementation of global accounting standards (IFRS) in a developing country. *Advances in Accounting*, *31*(1), 136–149. https://doi.org/10.1016/j.adiac.2015.03.015

O'Neill, S. J., & Graham, S. (2016). (En) visioning place-based adaptation to sea-level rise. *Geo-Geography and Environment*, *3*(2). https://doi.org/10.1002/geo2.v3.2

O'Sullivan, S., Nevejans, N., Allen, C., Blyth, A., Leonard, S., Pagallo, U., Holzinger, K., Holzinger, A., Sajid, M. I., & Ashrafian, H. (2019). Legal, regulatory, and ethical frameworks for development of standards in artificial intelligence (AI) and autonomous robotic surgery. *The International Journal of Medical Robotics and Computer Assisted Surgery*, *15*(1). https://doi.org/10.1002/rcs.1968

Odlyzko, A., & Tilly, B. (2005). A refutation of Metcalfe's Law and a better estimate for the value of networks and network interconnections. *Technology*, 1–11.

OECD. (2018). Rethinking Antitrust Tools for Multi-Sided Platforms. Rethinking Antitrust Tools for Multi-Sided Platforms, 230. www.oecd.org/competition/rethinking-antitrust-tools-for-multi-sided-platforms.htm

OECD. (2019). Responding to Rising Seas: OECD Country Approaches to Tackling Coastal Risks,. In *OECD Publishing*. https://doi.org/10.1787/9789264312487-en

OECD. (2021). *Methodologies to Measure Market Competition*. https: //oe.cd/mmmc

Oliva, T. D. (2020). Content moderation technologies: Applying human rights standards to protect freedom of expression. *Human Rights Law Review*, *20*(4), 607–640. https://doi.org/10.1093/hrlr/ngaa032

Ong, E. K., & Glantz, S. A. (2001). Constructing "Sound Science" and "Good Epidemiology": Tobacco, Lawyers, and Public Relations Firms. Tobacco, Lawyers, and Public Health, 91(11).

Oren, S. S., Smith, S. A., & Wilson, R. B. (1982). Nonlinear Pricing in Markets with Interdependent Demand. *Marketing Science*, 1(3), 287–313. https://doi.org/10.1287/mksc.1.3.287

Øverby, H., & Audestad, J. A. (2021). *Introduction to Digital Economics: Foundations, Business Models and Case Studies*. Springer. https://doi.org/10.1007/978-3-030-78237-5_4

Oya, C., Schaefer, F., & Skalidou, D. (2018). The effectiveness of agricultural certification in developing countries: A systematic review. *World Development*, *112*, 282–312. https://doi.org/10.1016/j.worlddev.2018.08.001

Panico, C., & Cennamo, C. (2020). User preferences and strategic interactions in platform ecosystems. *Strategic Management Journal*, February 2018, 1–23. https://doi.org/10.1002/smj.3149

Panofsky, A., & Bliss, C. (2017). Ambiguity and Scientific Authority. *American Sociological Review*, *82*(1), 59–87. https://doi.org/10.1177/0003122416685812

Papachristos, G. (2020). Platform competition: A research outline for modelling and simulation research. *Journal of Engineering and Technology Management* - JET-M, 56(February), 101567. https://doi.org/10.1016/j.jengtecman.2020.101567

Papp, S., Kozma, J., Lindfors, T., & Gyurcsányi, R. E. (2020). Lipophilic Multi-walled Carbon Nanotube-based Solid Contact Potassium Ion-selective Electrodes with Reproducible Standard Potentials. A Comparative Study. *Electroanalysis*, *32*(4), 867–873. https://doi.org/10.1002/elan.202000045

Parker, G. G., & Van Alstyne, M. W. (2005). Two-sided network effects: A theory of information product design. *Management Science*, 51(10), 1494–1504. https://doi.org/10.1287/mnsc.1050.0400

Phala, K. S. E., Kumar, A., & Hancke, G. P. (2016). Air Quality Monitoring System Based on ISO/IEC/IEEE 21451 Standards. *IEEE Sensors Journal*, *16*(12), 5037–5045. https://doi.org/10.1109/JSEN.2016.2555935

Phelps, C. C. (2010). A Longitudinal Study of the Influence of Alliance Network Structure and Composition on Firm Exploratory Innovation. *Academy of Management Journal*, *53*(4), 890–913. https://doi.org/10.5465/amj.2010.52814627

Ploog, J. N., & Rietveld, J. (2024). Rolling the Dice: Resolving Demand Uncertainty in Markets with Partial Network Effects. *Academy of Management Journal*. https://doi.org/10.5465/amj.2023.0133

Ploog, J., & Rietveld, J. (2023). Network effects by choice: Evidence from the board games industry. *Working Paper*, *February*. https://doi.org/10.13140/RG.2.2.29002.85442

Ponte, S., & Cheyns, E. (2013). Voluntary standards, expert knowledge and the governance of sustainability networks. *Global Networks*, *13*(4), 459–477. https://doi.org/10.1111/glob.12011

Popper, K. (1934). The Logic of Scientific Discovery. In *Mind: Vol. LXXVII* (Issue 305). https://doi.org/10.1093/mind/lxxvii.305.133

Poret, S. (2019). Label wars: Competition among NGOs as sustainability standard setters. *Journal of Economic Behavior & Organization*, *160*, 1–18. https://doi.org/10.1016/j.jebo.2019.02.015

Porio, E. (2011). Vulnerability , Adaptation , and Resilience to Floods and Climate Change-Related Risks among Marginal , Riverine Communities in Metro Manila. *Asian Journal of Social Science*, *39*, 425–445. https://doi.org/10.1163/156853111X597260

Porter, J., & Demeritt, D. (2012). Flood-risk management, mapping, and planning: The institutional politics of decision support in England. *Environment and Planning A*, *44*(10), 2359–2378. https://doi.org/10.1068/a44660

Pourazad, M. T., Doutre, C., Azimi, M., & Nasiopoulos, P. (2012). HEVC: The New Gold Standard for Video Compression: How Does HEVC Compare with H.264/AVC? *IEEE Consumer Electronics Magazine*, *1*(3), 36–46. https://doi.org/10.1109/MCE.2012.2192754

Pritchard, A. (1969). Statistical bibliography or bibliometrics? *Journal of Documentation*, *24*, 348–349.

Prodanoff, Z., White-Williams, C., & Chi, H. (2021). Regulations and Standards Aware Framework for Recording of mHealth App Vulnerabilities. *International Journal of E-Health and Medical Communications*, *12*(3), 1–16. https://doi.org/10.4018/IJEHMC.20210501.oa1

Provan, K. G., & Kenis, P. (2007). Modes of Network Governance: Structure, Management, and Effectiveness. *Journal of Public Administration Research and Theory*, *18*(2), 229–252. https://doi.org/10.1093/jopart/mum015

Provan, K. G., & Milward, H. B. (1995). A Preliminary Theory of Interorganizational Network Effectiveness: A Comparative Study of Four Community Mental Health Systems. *Administrative Science Quarterly*, 40(1), 1. https://doi.org/10.2307/2393698

Provan, K. G., Fish, A., & Sydow, J. (2007). Interorganizational networks at the network level: A review of the empirical literature on whole networks. *Journal of Management*, *33*(3), 479–516. https://doi.org/10.1177/0149206307302554

Puffert, D. J. (2000). The Standardization of Track Gauge on North American Railways, 1830–1890. *The Journal of Economic History*, *60*(4), 933–960. https://doi.org/10.1017/S0022050700026322

Radanliev, P., De Roure, D. C., Nurse, J. R. C., Mantilla Montalvo, R., Cannady, S., Santos, O., Maddox, L., Burnap, P., & Maple, C. (2020). Future developments in standardisation of cyber risk in the Internet of Things (IoT). *SN Applied Sciences*, *2*(2), 169. https://doi.org/10.1007/s42452-019-1931-0

Raffaelli, R. (2019). Technology Reemergence: Creating New Value for Old Technologies in Swiss Mechanical Watchmaking, 1970–2008. *Administrative Science Quarterly*, *64*(3), 576–618. https://doi.org/10.1177/0001839218778505

Raghavan, M., Barocas, S., Kleinberg, J., & Levy, K. (2020). Mitigating bias in algorithmic hiring. *Proceedings of the 2020 Conference on Fairness, Accountability, and Transparency*, 469–481. https://doi.org/10.1145/3351095.3372828

Ramlo, S. (2021). The Coronavirus and Higher Education: Faculty Viewpoints about Universities Moving Online during a Worldwide Pandemic. *Innovative Higher Education*, *46*(3), 241–259. https://doi.org/10.1007/s10755-020-09532-8

Ranganathan, R., & Rosenkopf, L. (2014). Do Ties Really Bind? The Effect of Knowledge and Commercialization Networks on Opposition to Standards. *Academy of Management Journal*, *57*(2), 515–540. https://doi.org/10.5465/amj.2011.1064

Ranganathan, R., Ghosh, A., & Rosenkopf, L. (2018). Competition–cooperation interplay during multifirm technology coordination: The effect of firm heterogeneity on conflict and consensus in a technology standards organization. *Strategic Management Journal*, *39*(12), 3193–3221. https://doi.org/10.1002/smj.2786

Rao, N. D., & Pachauri, S. (2017). Energy access and living standards: Some observations on recent trends. *Environmental Research Letters*, *12*(2). https://doi.org/10.1088/1748-9326/aa5b0d

Raynolds, L. T. (2002). Consumer/producer links in Fair Trade coffee networks. *Sociologia Ruralis*, *42*(4), 404–424. https://doi.org/10.1111/1467-9523.00224

Reed, D. P. (2003). That Sneaky Exponential — Beyond Metcalfe's Law to the Power of Community Building. *Context*, Winter, 1–8.

Reid, H., & Huq, S. (2007). Community-based adaptation: A vital approach to the threat climate change poses to the poor (Issue May). https://hdl.handle.net/10535/6228%0A

Reinecke, J., Manning, S., & von Hagen, O. (2012). The Emergence of a Standards Market: Multiplicity of Sustainability Standards in the Global Coffee Industry. *Organization Studies*, *33*(5–6), 791–814. https://doi.org/10.1177/0170840612443629

Renaud, F. G., Sudmeier-Rieux, K., Estrella, M., & Nehren, U. (2016). Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice. In *Springer International Publishing* (Vol. 42, Issue December).

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega* (United Kingdom), 53, 49–57. https://doi.org/10.1016/j.omega.2014.11.009

RIBA & ICE. (2010). Facing Up to Rising Sea Levels: Retreat? Defend? Attack?

Rietveld, J., & Schilling, M. A. (2020). Platform Competition : A Systematic and Interdisciplinary Review of the Literature. *Journal of Management*, XX(X), 1–36. https://doi.org/10.1177/0149206320969791

Riillo, C. A. F., Allamano-Kessler, R., Asnafi, N., Fomin, V. V., & van de Kaa, G. (2022). Technological Uncertainty and Standardization Strategies: A Coopetition Framework. *IEEE Transactions on Engineering Management*, PP, 1–14. https://doi.org/10.1109/tem.2022.3145240

Ritala, P., & Hurmelinna-Laukkanen, P. (2009). What's in it for me? Creating and appropriating value in innovation-related coopetition. *Technovation*, 29(12), 819–828. https://doi.org/10.1016/j.technovation.2009.07.002

Ritzer, G. (1993). *The McDonaldization of Society*. Pine Forge Press, Thousand Oaks, California.

Roberts, T. (2014). When Bigger Is Better: A Critique of the Herfindahl-Hirschman Index's Use to Evaluate Mergers in Network Industries. *Pace Law Review*, *34*(2), 894. https://doi.org/10.58948/2331-3528.1863

Robertson, D., & Ulrich, K. (1998). Planning for Product Platforms. *Sloan Management Review*, 39(4).

Rochet, J. C., & Tirole, J. (2003). Platform competition in two-sided markets. *Competition Policy International*, 10(2), 180–218.

Rodhouse, T. S. G. H., Pesch, U., Cuppen, E. H. W. J., & Correljé, A. F. (2021). Public agency and responsibility in energy governance: A Q study on diverse imagined publics in the Dutch heat transition. *Energy Research & Social Science*, *77*(August 2020), 102046. https://doi.org/10.1016/j.erss.2021.102046

Rodríguez-Pose, A. (2018). The revenge of the places that don't matter (and what to do about it). *Cambridge Journal of Regions, Economy and Society*, *11*(1), 189–209. https://doi.org/10.1093/cjres/rsx024

Rogers, E. M. (1962). Diffusion of Innovations. In *Diffusion of Innovations*. Simon and Schuster.

Rohlfs, J. (1974). A Theory of Interdependent Demand for a Communications Service. *The Bell Journal of Economics and Management Science*, 5(1), 16–37.

Rohlfs, J. (2003). *Bandwagon effects in high-technology industries*. MIT Press.

Rojszczak, M. (2021). Compliance of Automatic Tax Fraud Detection Systems with the Right to Privacy Standards Based on the Polish Experience of the STIR System. *Intertax*, *49*(Issue 1), 39–52. https://doi.org/10.54648/TAXI2021005

Romme, A. G. L. (2003). Making a Difference: Organization as Design. *Organization Science*, *14*(5), 558–573. https://doi.org/10.1287/orsc.14.5.558.16769

Ronnen, U. (1991). Minimum Quality Standards, Fixed Costs, and Competition. *The RAND Journal of Economics*, *22*(4), 490–504.

Rosa, T. (2022). Cooperation and Competition : The Case of Innovation in the Telecommunications Sector. Unpublished Working Paper.

Rossi, J. (2021). What rules the Internet? A study of the troubled relation between Web standards and legal instruments in the field of privacy. *Telecommunications Policy*, *45*(6), 102143. https://doi.org/10.1016/j.telpol.2021.102143

Rouhani, O. M., Niemeier, D., Gao, H. O., & Bel, G. (2016). Cost-benefit analysis of various California renewable portfolio standard targets: Is a 33% RPS optimal? *Renewable and Sustainable Energy Reviews*, *62*, 1122–1132. https://doi.org/10.1016/j.rser.2016.05.049

Rowley, T. J. (1997). Moving beyond Dyadic Ties : A Network Theory of Stakeholder Influences. *The Academy of Management Review*, 22(4), 887–910. http://www.jstor.org/stable/259248

Russell, A. L., Pelkey, J. L., & Robbins, L. (2022). The business of internetworking: Standards, start-ups, and network effects. *Business History Review*, *96*(1), 109–144. https://doi.org/10.1017/S000768052100074X

Rysman, M., & Simcoe, T. (2008). Patents and the performance of voluntary standard-setting organizations. *Management Science*, *54*(11), 1920–1934. https://doi.org/10.1287/mnsc.1080.0919

Saaty, T. L. (1986). Axiomatic Foundation of the Analytic Hierarchy Process. *Management Science*, 32(7), 841–855.

Sandholtz, K. W. (2012). Making Standards Stick: A Theory of Coupled vs. Decoupled Compliance. *Organization Studies*, *33*(5–6), 655–679. https://doi.org/10.1177/0170840612443623

Sanjuán, M. A., & Argiz, C. (2012). The new european standard on common cements specifications EN 197-1:2011. *Materiales de Construccion*, *62*(307), 425–430. https://doi.org/10.3989/mc.2012.07711

Schelly, C. (2014). Implementing renewable energy portfolio standards: The good, the bad, and the ugly in a two state comparison. *Energy Policy*, *67*, 543–551. https://doi.org/10.1016/j.enpol.2013.11.075

Schilling, M. (2002). Technology success and failure in winner-take-all markets: the impact of learning orientation, timing, and network externalities. *Academy of Management Journal*, 45(2).

Schilling, M. A. (2009). *To protect or to diffuse? Appropriability, network externalities, and architectural control. In Platforms, Markets and Innovation* (Issue January, pp. 192–218). Edward Elgar Publishing. https://doi.org/10.4337/9781849803311.00015

Schilling, M. A., & Phelps, C. C. (2007). Interfirm collaboration networks: The impact of large-scale network structure on firm innovation. *Management Science*, *53*(7), 1113–1126. https://doi.org/10.1287/mnsc.1060.0624

Schleich, J., Durand, A., & Brugger, H. (2021). How effective are EU minimum energy performance standards and energy labels for cold appliances? *Energy Policy*, *149*, 112069. https://doi.org/10.1016/j.enpol.2020.112069

Schmidt, J., & Foss, N. J. (2025). Modularity, Adaptation Problems, and the Governance and Problem-Solving Capabilities of Core Firms in Ecosystems. Journal of Management, 51(4), 1484–1513. https://doi.org/10.1177/01492063231215023

Schott, L., & Schaefer, K. J. (2023). Acceptance of Chinese latecomers' technological contributions in international ICT standardization — The role of origin, experience and collaboration. *Research Policy*, *52*(1), 104656. https://doi.org/10.1016/j.respol.2022.104656

Schouten, G., & Bitzer, V. (2015). The emergence of Southern standards in agricultural value chains: A new trend in sustainability governance? *Ecological Economics*, *120*, 175–184. https://doi.org/10.1016/j.ecolecon.2015.10.017

Schweber, L. (2013). The effect of BREEAM on clients and construction professionals. *Building Research and Information*, *41*(2), 129–145. https://doi.org/10.1080/09613218.2013.768495

Sciancalepore, S., Piro, G., Vogli, E., Boggia, G., Grieco, L. A., & Cavone, G. (2016). LICITUS: A lightweight and standard compatible framework for securing layer-2 communications in the IoT. *Computer Networks*, *108*, 66–77. https://doi.org/10.1016/j.comnet.2016.08.003

Scott, J. (1991*). Social Network Analysis*. SAGE Publishing.

Scott, S. V., Van Reenen, J., & Zachariadis, M. (2017). The long-term effect of digital innovation on bank performance: An empirical study of SWIFT adoption in financial services. *Research Policy*, 46(5), 984–1004. https://doi.org/10.1016/j.respol.2017.03.010

Sen, B., Noori, M., & Tatari, O. (2017). Will Corporate Average Fuel Economy (CAFE) Standard help? Modeling CAFE's impact on market share of electric vehicles. *Energy Policy*, *109*(June), 279–287. https://doi.org/10.1016/j.enpol.2017.07.008

Shabila, N. P., Al-Tawil, N. G., Al-Hadithi, T. S., & Sondorp, E. (2014). Using Q-methodology to explore people's health seeking behavior and perception of the quality of primary care services. *BMC Public Health*, *14*(1), 1–9. https://doi.org/10.1186/1471-2458-14-2

Shafi, M., Molisch, A. F., Smith, P. J., Haustein, T., Zhu, P., De Silva, P., Tufvesson, F., Benjebbour, A., & Wunder, G. (2017). 5G: A tutorial overview of standards, trials, challenges, deployment, and practice. *IEEE Journal on Selected Areas in Communications*, *35*(6), 1201–1221. https://doi.org/10.1109/JSAC.2017.2692307

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L. A., Altman, D. G., Booth, A., Chan, A. W., Chang, S., Clifford, T., Dickersin, K., Egger, M., Gøtzsche, P. C., Grimshaw, J. M., Groves, T., Helfand, M., … Whitlock, E. (2015). Preferred reporting items for systematic review and meta-analysis protocols (prisma-p) 2015: Elaboration and explanation. *BMJ (Online)*, *349*(January), 1–25. https://doi.org/10.1136/bmj.g7647

Shankar, V., & Bayus, B. L. (2003). Network effects and competition: An empirical analysis of the home video game industry. *Strategic Management Journal*, 24(4), 375–384. https://doi.org/10.1002/smj.296

Shapiro, C., & Varian, H. R. (1999). *Information Rules* (Vol. 148). Harvard Business School Press.

Shapiro, C., & Varian, H. R. (1999). The art of standards wars. *California Management Review*, *41*(2), 8–32. https://doi.org/10.2307/41165984

Sharma, D., Kanaujia, B. K., & Kumar, S. (2021). Compact multi-standard planar MIMO antenna for IoT/WLAN/Sub-6 GHz/X-band applications. *Wireless Networks*, *27*(4), 2671–2689. https://doi.org/10.1007/s11276-021-02612-3

Sheng, Z., Yang, S., Yu, Y., Vasilakos, A., McCann, J., & Leung, K. (2013). A survey on the ietf protocol suite for the internet of things: Standards, challenges, and opportunities. *IEEE Wireless Communications*, *20*(6), 91–98. https://doi.org/10.1109/MWC.2013.6704479

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

Shin, I. (2006). Adoption of enterprise application software and firm performance. In *Small Business Economics* (Vol. 26, Issue 3, pp. 241–256). https://doi.org/10.1007/s11187-005-0215-9

Shipilov, A., & Gawer, A. (2020). Integrating Research on Interorganizational Networks and Ecosystems. *Academy of Management Annals*, *14*(1), 92–121. https://doi.org/10.5465/annals.2018.0121

Silvestre, B. S., Viana, F. L. E., & Sousa Monteiro, M. de. (2020). Supply chain corruption practices circumventing sustainability standards: wolves in sheep's clothing. *International Journal of Operations & Production Management*, *40*(12), 1873–1907. https://doi.org/10.1108/IJOPM-06-2019-0454

Simcoe, T. (2012). Standard Setting Committees : Consensus Governance for Shared Technology Platforms. *The American Economic Review*, *102*(1), 305–336. http://www.jstor.org/stable/41408776

Simon, H. A. (1969). *The Sciences of the Artificial*. The MIT Press.

Sinclair, R., & Bolt, R. (2013). Third Sector Accounting Standard Setting: Do Third Sector Stakeholders Have Voice? *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations*, *24*(3), 760–784. https://doi.org/10.1007/s11266-013-9356-7

Skilton, P. F., & Bernardes, E. (2015). Competition network structure and product market entry. *Strategic Management Journal*, 36(11), 1688–1696. https://doi.org/10.1002/smj.2318

Slager, R., Gond, J. P., & Moon, J. (2012). Standardization as Institutional Work: The Regulatory Power of a Responsible Investment Standard. *Organization Studies*, *33*(5–6), 763–790. https://doi.org/10.1177/0170840612443628

Soh, P.-H. (2009). Network patterns and competitive advantage before the emergence of a dominant design. *Strategic Management Journal*, *461*(October), 1–43. https://doi.org/10.1002/smj

Soler Garrido, J., Fano Yela, D., Panigutti, C., Junklewitz, H., Hamon, R., Evas, T., André, A.-A., & Scalzo, S. (2023). *Analysis of the preliminary AI standardisation work plan in support of the AI Act*. https://doi.org/10.2760/5847

Soublière, J.-F., Lo, J. Y., & Rhee, E. Y. (2024). Coherence within and across Categories: The Dynamic Viability of Product Categories on Kickstarter. *Academy of Management Journal*, 67(1), 61–91. https://doi.org/10.5465/amj.2022.0105

Srinivas, J., Das, A. K., & Kumar, N. (2019). Government regulations in cyber security: Framework, standards and recommendations. *Future Generation Computer Systems*, *92*, 178–188. https://doi.org/10.1016/j.future.2018.09.063

Srinivasan, A., & Venkatraman, V. N. (2020). Architectural Convergence and Platform Evolution: Empirical Test of Complementor Moves in Videogames. *IEEE Transactions on Engineering Management*, 67(2), 266–282. https://doi.org/10.1109/TEM.2018.2881560

Stango, V. (2004). The Economics of Standards Wars. *Review of Network Economics*, *3*(1). https://doi.org/10.1086/200393

Stedman, R. C. (2002). Toward a Social Psychology of Place: Predicting Behavior From Place-Based Cognitions, Attitude, and Identity. *Environment and Behavior*, *34*(5), 561–581. https://doi.org/10.1177/0013916502034005001

Stephan, A., Schmidt, T. S., Bening, C. R., & Hoffmann, V. H. (2017). The sectoral configuration of technological innovation systems: Patterns of knowledge development and diffusion in the lithium-ion battery technology in Japan. *Research Policy*, *46*(4), 709–723. https://doi.org/10.1016/j.respol.2017.01.009

Stephenson, W. (1935). Technique of Factor Analysis. *Nature*, *136*.

Stepman, H. C. M., Tiikkainen, U., Stöckl, D., Vesper, H. W., Edwards, S. H., Laitinen, H., Pelanti, J., & Thienpont, L. M. (2014). Measurements for 8 Common Analytes in Native Sera Identify Inadequate Standardization among 6 Routine Laboratory Assays. *Clinical Chemistry*, *60*(6), 855–863. https://doi.org/10.1373/clinchem.2013.220376

Stevenson, W. B., & Greenberg, D. (2000). Agency and Social Networks: Strategies of Action in a Social Structure of Position, Opposition, and Opportunity. *Administrative Science Quarterly*, *45*(4), 651–678. https://doi.org/10.2307/2667015

Strauss, A. (1978). *Negotiations: Varieties, Contexts, Processes, and Social Order*. Jossey-Bass Inc. Pub.

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

Suarez, F. F., Grodal, S., & Gotsopoulos, A. (2015). Perfect timing? Dominant category, dominant design, and the window of opportunity for firm entry. *Strategic Management Journal*, *36*(3), 437–448. https://doi.org/10.1002/smj.2225

Subramanian, H., Mitra, S., & Ransbotham, S. (2021). Capturing value in platform business models that rely on user-generated content. *Organization Science*, 32(3), 804–823. https://doi.org/10.1287/orsc.2020.1408

Sun, P., & Nie, P. yan. (2015). A comparative study of feed-in tariff and renewable portfolio standard policy in renewable energy industry. *Renewable Energy*, *74*, 255–262. https://doi.org/10.1016/j.renene.2014.08.027

Susanto, A. . (1988). *Methodik zur Entwicklung von Normen. DIN-Normungskunde Band 23*. DIN & Beuth.

Swann, G. M. P. (2002). The functional form of network effects. *Information Economics and Policy*, 14(3), 417–429. https://doi.org/10.1016/S0167-6245(02)00051-3

Swann, G. M. P. (2010). The economics of standardization: An update. *Report for the UK Department of Business, Innovation and Skills (BIS)*, 1–78.

Swanson, D. G., & Baumol, W. J. (2005). Reasonable and nondiscriminatory (RAND) royalties, standards selection, and control of market power. *Antitrust Law Journal*, *73*(1), 1–58.

Swanson, D., Barg, S., Tyler, S., Venema, H., Tomar, S., Bhadwal, S., Nair, S., Roy, D., & Drexhage, J. (2010). Seven tools for creating adaptive policies. *Technological Forecasting and Social Change*, *77*(6), 924–939. https://doi.org/10.1016/j.techfore.2010.04.005

Sydow, J., Windeler, A., Schubert, C., & Möllering, G. (2012). Organizing R&D Consortia for Path Creation and Extension: The Case of Semiconductor Manufacturing Technologies. *Organization Studies*, *33*(7), 907–936. https://doi.org/10.1177/0170840612448029

Syverson, C. (2011). What Determines Productivity? *Journal of Economic Literature*, *49*(2), 326–365. https://doi.org/10.1257/jel.49.2.326

Taeuscher, K., & Rothe, H. (2021). Optimal distinctiveness in platform markets: Leveraging complementors as legitimacy buffers. *Strategic Management Journal*, 42(2), 435–461. https://doi.org/10.1002/smj.3229

Taeuscher, K., Bouncken, R., & Pesch, R. (2021). Gaining legitimacy by being different: Optimal distinctiveness in crowdfunding platforms. *Academy of Management Journal*, 64(1), 149–179. https://doi.org/10.5465/AMJ.2018.0620

Tamm Hallström, K., & Boström, M. (2010). *Transnational multi-stakeholder standardization : organizing fragile non-state authority*. Edward Elgar Publishing, Cheltenham, UK, 2010.

Tan, Q., Ding, Y., Zheng, J., Dai, M., & Zhang, Y. (2021). The effects of carbon emissions trading and renewable portfolio standards on the integrated wind–photovoltaic–thermal power-dispatching system: Real case studies in China. *Energy*, *222*, 119927. https://doi.org/10.1016/j.energy.2021.119927

Tanaka, M., & Chen, Y. (2013). Market power in renewable portfolio standards. *Energy Economics*, *39*, 187–196. https://doi.org/10.1016/j.eneco.2013.05.004

Tassey, G. (2000). Standardization in technology-based markets. *Research Policy*, *29*(4–5), 587–602. https://doi.org/10.1016/S0048-7333(99)00091-8

Tate, J. (2001). National Varieties of Standardization. In *Varieties of Capitalism* (pp. 442–473). Oxford University Press. https://doi.org/10.1093/0199247757.003.0014

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, *15*, 285–305.

Teece, D. J. (2018). Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world. *Research Policy*, *47*(8), 1367–1387. https://doi.org/10.1016/j.respol.2017.01.015

Tennent, R., & Lockie, S. (2012). Production Relations under GLOBALG.A.P: The Relative Influence of Standards and Retail Market Structure. *Sociologia Ruralis*, *52*(1), 31–47. https://doi.org/10.1111/j.1467-9523.2011.00555.x

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

The CMS Collaboration. (2015). Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the standard model predictions using proton collisions at 7 and 8 TeV. *European Physical Journal C*. https://doi.org/10.1140/epjc/s10052-015-3351-7.c

The State Council of the People's Republic of China. (2021). *National Standardization Development Outline*. https://www.gov.cn/zhengce/2021-10/10/content_5641727.htm

The White House. (2023). *United States Government National Standards Strategy for Critical and Emerging Technology* (Issue May). https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/04/fact-sheet-biden-harris-administration-announces-national-standards-strategy-for-critical-and-emerging-technology/

Thévenot, L. (2009). Governing life by standards: A view from engagements. *Social Studies of Science*, *39*(5), 793–813. https://doi.org/10.1177/0306312709338767

Thompson, J. D., Zald, M. N., & Scott, W. R. (1967). *Organizations in Action*. Routledge. https://doi.org/10.4324/9781315125930

Timmermans, S. (2015). Trust in standards: Transitioning clinical exome sequencing from bench to bedside. *Social Studies of Science*, *45*(1), 77–99. https://doi.org/10.1177/0306312714559323

Timmermans, S., & Almeling, R. (2009). Objectification, standardization, and commodification in health care: A conceptual readjustment. *Social Science and Medicine*, *69*(1), 21–27. https://doi.org/10.1016/j.socscimed.2009.04.020

Timmermans, S., & Epstein, S. (2010). A world of standards but not a standard world: Toward a sociology of standards and standardization. *Annual Review of Sociology*, *36*, 69–89. https://doi.org/10.1146/annurev.soc.012809.102629

Tinarelli, S., Ribani, A., Utzeri, V. J., Taurisano, V., Bovo, C., Dall'Olio, S., Nen, F., Bovo, S., Schiavo, G., Gallo, M., & Fontanesi, L. (2021). Redefinition of the Mora Romagnola Pig Breed Herd Book Standard Based on DNA Markers Useful to Authenticate Its "Mono-Breed" Products: An Example of Sustainable Conservation of a Livestock Genetic Resource. *Animals*, *11*(2), 526. https://doi.org/10.3390/ani11020526

Toh, P. K., & Miller, C. D. (2017). Pawn to Save a Chariot, or Drawbridge Into the Fort? Firms' Disclosure During Standard Setting and Complementary Technologies Within Ecosystems. *Strategic Management Journal*, *2236*(October), 1–43. https://doi.org/10.1002/smj

Toh, P. K., & Pyun, E. (2024). Risky business: How standardization as coordination tool in ecosystems impacts firm-level uncertainty. *Strategic Management Journal*, *45*(4), 649–679. https://doi.org/10.1002/smj.3562

Trappey, A. J. C., Trappey, C. V., Govindarajan, U. H., Chuang, A. C., & Sun, J. J. (2017). A review of essential standards and patent landscapes for the Internet of Things: A key enabler for Industry 4.0. *Advanced Engineering Informatics*, *33*, 208–229. https://doi.org/10.1016/j.aei.2016.11.007

Trappey, A. J. C., Trappey, C. V., Govindarajan, U. H., Sun, J. J., & Chuang, A. C. (2016). A Review of Technology Standards and Patent Portfolios for Enabling Cyber-Physical Systems in Advanced Manufacturing. *IEEE Access*, *4*, 7356–7382. https://doi.org/10.1109/ACCESS.2016.2619360

U.S. Department of Justice, & Federal Trade Commission. (2010). Horizontal Mergers Guidelines. https://www.justice.gov/atr/horizontal-merger-guidelines-08192010

U.S. Department of Labor. (2019). Opinion letter FLSA2019-6, addressing whether a service provider for a virtual marketplace company is an employee of the company or an independent contractor under the FLSA.

UNECE. (2018). Standards for the Sustainable Development Goals. United Nations.

United Nations. (2024). UN General Assembly High-level plenary meeting on Addressing the existential threats posed by sea-level rise (Issue September).

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, *28*, 817–830. https://doi.org/10.1016/S0301-4215(01)00098-2

Updegrove, A. (2006). Value Propositions, Roles and Strategies: Participating in a SSO. In *The Essential Guide to Standards*. https://www.consortiuminfo.org/guide/participating-in-a-sso/value-propositions-roles-and-strategies/

Utterback, J. M., & Abernathy, W. J. (1975). A dynamic model of process and product innovation. *Omega*, *3*(6), 639–656. https://doi.org/10.1016/0305-0483(75)90068-7

Uzunca, B., Rigtering, J. P. C., & Ozcan, P. (2018). Sharing and Shaping: A Cross-Country Comparison of How Sharing Economy Firms Shape Their Institutional Environment to Gain Legitimacy. *Academy of Management Discoveries*, *4*(3), 248–272. https://doi.org/10.5465/amd.2016.0153

Uzunca, B., Sharapov, D., & Tee, R. (2022). Governance rigidity, industry evolution, and value capture in platform ecosystems. *Research Policy*, 51(7), 104560. https://doi.org/10.1016/j.respol.2022.104560

Vakili, K. (2016). Collaborative promotion of technology standards and the impact on innovation, industry structure, and organizational capabilities: evidence from modern patent pools. *Organization Science*, *27*(6), 1504–1524. https://doi.org/10.1287/orsc.201...Users

Valero-Gil, J., Surroca, J. A., Tribo, J. A., Gutierrez, L., & Montiel, I. (2023). Innovation vs. standardization: The conjoint effects of eco-innovation and environmental management systems on environmental performance. *Research Policy*, *52*(4). https://doi.org/10.1016/j.respol.2023.104737

van de Kaa, G. (2018). Who's pulling the strings? The influence of network structure on standard dominance. *R and D Management*, *48*(4), 438–446. https://doi.org/10.1111/radm.12295

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., & 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., 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., Kamp, L., & Rezaei, J. (2017). Selection of biomass thermochemical conversion technology in the Netherlands: A best worst method approach. *Journal of Cleaner Production*, *166*, 32–39. https://doi.org/10.1016/j.jclepro.2017.07.052

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 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 van Den Hurk, M., & Verhoest, K. (2016). The challenge of using standard contracts in public–private partnerships. *Public Management Review*, *18*(2), 278–299. https://doi.org/10.1080/14719037.2014.984623

van der Loos, H. Z. A., Negro, S. O., & Hekkert, M. P. (2020). Low-carbon lock-in? Exploring transformative innovation policy and offshore wind energy pathways in the Netherlands. *Energy Research & Social Science*, *69*, 101640. https://doi.org/10.1016/j.erss.2020.101640

van Dyck, M., Lüttgens, D., Diener, K., Piller, F., & Pollok, P. (2024). From product to platform: How incumbents' assumptions and choices shape their platform strategy. *Research Policy*, 53(1), 104904. https://doi.org/10.1016/j.respol.2023.104904

van Oorschot, J. A. W. H., Hofman, E., & Halman, J. I. M. (2018). A bibliometric review of the innovation adoption literature. *Technological Forecasting and Social Change*, 134(April), 1–21. https://doi.org/10.1016/j.techfore.2018.04.032

van Roozendaal, G. (2015). The Diffusion of Labour Standards: The Case of the US and Guatemala. *Politics and Governance*, *3*(2), 18–33. https://doi.org/10.17645/pag.v3i2.182

van Tulder, R., & van Mil, E. (2023). *Principles of Sustainable Business Frameworks for Corporate Action on the SDGs*. Routledge.

van Wegberg, M. (2004). Standardization process of systems technologies: Creating a balance between competition and cooperation. *Technology Analysis and Strategic Management*, *16*(4), 457–478. https://doi.org/10.1080/0953732042000295784

Vanhaverbeke, W., & Noorderhaven, N. G. (2001). Competition between alliance blocks: The case of the RISC microprocessor technology. *Organization Studies*, 22(1), 1–30. https://doi.org/10.1177/0170840601022001001

Verbrugge, L. M. (1979). Multiplexity in Adult Friendships. *Social Forces*, 57(4), 1286–1309. https://doi.org/10.1093/sf/57.4.1286

Verman, L. C. \. (1973). *Standardization - A new discipline*. Archon Books, TheShoe String Press Inc.

Vir Singh, P., Tan, Y., & Mookerjee, V. (2011). Network Effects: The Influence of Structural Capital on Open Source Project Success. *MIS Quarterly*, 35(4).

Von Geibler, J. (2013). Market-based governance for sustainability in value chains: Conditions for successful standard setting in the palm oil sector. *Journal of Cleaner Production*, *56*, 39–53. https://doi.org/10.1016/j.jclepro.2012.08.027

Waguespack, D. M., & Fleming, L. (2009). Scanning the commons? evidence on the benefits to startups participating in open standards development. *Management Science*, *55*(2), 210–223. https://doi.org/10.1287/mnsc.1080.0944

Wakke, P., Blind, K., & De Vries, H. J. (2015). Driving factors for service providers to participate in standardization: Insights from the Netherlands. *Industry and Innovation*, *22*(4), 299–320. https://doi.org/10.1080/13662716.2015.1049865

Wakke, P., Blind, K., & Ramel, F. (2016). The impact of participation within formal standardization on firm performance. *Journal of Productivity Analysis*, *45*(3), 317–330. https://doi.org/10.1007/s11123-016-0465-3

Wamsler, C., Luederitz, C., & Brink, E. (2014). Local levers for change: Mainstreaming ecosystem-based adaptation into municipal planning to foster sustainability transitions. *Global Environmental Change*, *29*, 189–201. https://doi.org/10.1016/j.gloenvcha.2014.09.008

Wang, X., Mao, S., & Gong, M. X. (2017). An Overview of 3GPP Cellular Vehicle-to-Everything Standards. *GetMobile: Mobile Computing and Communications*, *21*(3), 19–25. https://doi.org/10.1145/3161587.3161593

Wang, X., Yan, R., Zhao, Y., Cheng, S., Han, Y., Yang, S., Cai, D., Mang, H.-P., & Li, Z. (2020). Biogas standard system in China. *Renewable Energy*, *157*, 1265–1273. https://doi.org/10.1016/j.renene.2020.05.064

Wang, Z., & Wei, W. (2021). Regional economic resilience in China: measurement and determinants. *Regional Studies*, *55*(7), 1228–1239. https://doi.org/10.1080/00343404.2021.1872779

Wang, Z., Yang, L., & Hahn, J. (2023). Winner Takes All? The Blockbuster Effect on Crowdfunding Platforms. *Information Systems Research*, 34(3), 935–960. https://doi.org/10.1287/ISRE.2022.1154

Wasserman, S., & Faust, K. (1994). *Social Network Analysis: Methods and Applications*. Cambridge University Press: New York.

Watts, D. J. (1999). Networks, Dynamics, and the Small-World Phenomenon. *American Journal of Sociology*, *105*(2), 493–527.

Watts, S., & Stenner, P. (2005). Doing Q methodology: theory, method and interpretation. *Qualitative Research in Psychology*, *2*(1), 67–91. https://doi.org/10.1191/1478088705qp022oa

Weber, M. (1964). *The Theory Of Social And Economic Organization*. Oxford/New York: Oxford University Press.

Weitzel, T., Beimborn, D., & König, W. (2006). A unified economic model of standard diffusion: The impact of standardization cost, network effects, and network topology. *MIS Quarterly: Management Information Systems*, *30*(SPEC. ISS.), 489–514. https://doi.org/10.2307/25148770

Wen, W., Forman, C., & Jarvenpaa, S. L. (2022). The effects of technology standards on complementor innovations: Evidence from the IETF. *Research Policy*, *51*(6). https://doi.org/10.1016/j.respol.2022.104518

Wiarda, M., van de Kaa, G., Doorn, N., & Yaghmaei, E. (2022). Responsible innovation and de jure standardisation: An in-depth exploration of moral motives, barriers, and facilitators. *Science and Engineering Ethics*.

Wiegmann, P. M. (2019). *Managing Innovation and Standards*. Springer International Publishing. https://doi.org/10.1007/978-3-030-01532-9

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., de Vries, H. J., & Eom, D. (2023). *Measuring Societal Impact of Standards*. Technische Universiteit Eindhoven. https://research.tue.nl/en/publications/measuring-societal-impact-of-standards-2

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

Wiig, A., & Silver, J. (2019). Turbulent presents, precarious futures: urbanization and the deployment of global infrastructure. *Regional Studies*, *53*(6), 912–923. https://doi.org/10.1080/00343404.2019.1566703

Wijen, F. (2014). Means versus ends in opaque institutional fields: Trading off compliance and achievement in sustainability standard adoption. *Academy of Management Review*, *39*(3), 302–323. https://doi.org/10.5465/amr.2012.0218

Wijen, F., & Chiroleu-Assouline, M. (2019). Controversy Over Voluntary Environmental Standards: A Socioeconomic Analysis of the Marine Stewardship Council. *Organization & Environment*, *32*(2), 98–124. https://doi.org/10.1177/1086026619831449

Wilhelm, H., Bullinger, B., & Chromik, J. (2020). White Coats at the Coalface: The Standardizing Work of Professionals at the Frontline. *Organization Studies*, *41*(8), 1169–1200. https://doi.org/10.1177/0170840619862833

Williams, R. (1985). *Keywords: A Vocabulary of Culture and Society*. Oxford University Press.

Wingard, C., Bosman, J., & Amisi, B. (2016). The legitimacy of IFRS. *Meditari Accountancy Research*, *24*(1), 134–156. https://doi.org/10.1108/MEDAR-02-2014-0032

Wiser, R., Mai, T., Millstein, D., Barbose, G., Bird, L., Heeter, J., Keyser, D., Krishnan, V., & Macknick, J. (2017). Assessing the costs and benefits of US renewable portfolio standards. *Environmental Research Letters*, *12*(9), 094023. https://doi.org/10.1088/1748-9326/aa87bd

Word Economic Forum. (2024). *Global Risk Report 2024*.

World Trade Organization. (2021). *The WTO Agreements Series: Technical Barriers to Trade*. https://www.wto.org/english/res_e/publications_e/tbt3rd_e.htm

WTO. (2023). *World Trade Report 2023: Re-globalization for a secure, inclusive and sustainable future*. https://www.wto.org/english/res_e/publications_e/wtr23_e.htm

Wu, Y., & de Vries, H. J. (2022). Effects of participation in standardization on firm performance from a network perspective : Evidence from China.

Technological Forecasting & Social Change, *175*(November 2021), 121376. https://doi.org/10.1016/j.techfore.2021.121376

Xia, J., Wang, J., Hu, H., & Liu, S. (2024). Optimal distinctiveness across different benchmarks: Implications for platform complementors to strategically position new products. *Journal of Business Research*, 183. https://doi.org/10.1016/j.jbusres.2024.114846

Xiong, W., Zhao, S., Liu, Y., Wang, X., & Sun, Y. (2024). Can participating in standards development improve enterprise performance? Evidence from China's high-tech industry. *Journal of Infrastructure, Policy and Development*, *8*(1). https://doi.org/10.24294/jipd.v8i1.3014

Yan, Y., & Guan, J. C. (2018). Social capital, exploitative and exploratory innovations: The mediating roles of ego-network dynamics. *Technological Forecasting and Social Change*, 126(August 2017), 244–258. https://doi.org/10.1016/j.techfore.2017.09.004

Yang, D., Jing, Y., Wang, C., Nie, P., & Sun, P. (2021). Analysis of renewable energy subsidy in China under uncertainty: Feed-in tariff vs. renewable portfolio standard. *Energy Strategy Reviews*, *34*, 100628. https://doi.org/10.1016/j.esr.2021.100628

Yanuardi, Y., Vijge, M. J., & Biermann, F. (2021). Improving governance quality through global standard setting? Experiences from the Extractive Industries Transparency Initiative in Indonesia. *The Extractive Industries and Society*, *8*(3), 100905. https://doi.org/10.1016/j.exis.2021.100905

Yao, L., Li, J., Chen, K., & Yu, R. (2024). Winning the second race of technology standardization: Strategic maneuvers in SEP follow-on innovations. *Research Policy*, *53*(6). https://doi.org/10.1016/j.respol.2024.105023

Young, D., & Bistline, J. (2018). The costs and value of renewable portfolio standards in meeting decarbonization goals. *Energy Economics*, *73*, 337–351. https://doi.org/10.1016/j.eneco.2018.04.017

Zabala, A. (2014). qmethod: A Package to Explore Human Perspectives Using Q Methodology. *The R Journal*, *6*(2), 163. https://doi.org/10.32614/RJ-2014-032

Zhang, X. Z., Liu, J. J., & Xu, Z. W. (2015). Tencent and Facebook Data Validate Metcalfe's Law. *Journal of Computer Science and Technology*, 30(2), 246–251. https://doi.org/10.1007/s11390-015-1518-1

Zhang, Y., Liu, J., & Sheng, S. (2020). Strategic orientations and participation intentions for technical standardisation. *Technology Analysis and Strategic Management*, *32*(8), 881–894. https://doi.org/10.1080/09537325.2020.1719057

Zhu, F., & Iansiti, M. (2019). Why Some Platforms Thrive and Others Don't. *Harvard Business Review.*

Zhu, K., Kraemer, K. L., & Xu, S. (2003). Electronic Business Adoption by European Firms: A Cross-country Assessment of the Facilitators and Inhibitors. *European Journal of Information Systems*, *12*, 251–268. www.crito.uci.edu

Zhu, K., Kraemer, K. L., Gurbaxani, V., & Xu, S. X. (2006). Migration to open-standard interorganizational systems: Network effects, switching costs, and path dependency. *MIS Quarterly: Management Information Systems*, 30(SPEC. ISS.), 515–539. https://doi.org/10.2307/25148771

Zhu, S., Shi, B., Li, Q., & Lau, K. M. (2018). 1.5 μm quantum-dot diode lasers directly grown on CMOS-standard (001) silicon. *Applied Physics Letters*, *113*(22). https://doi.org/10.1063/1.5055803

Zoo, H., de Vries, H. J., & Lee, H. (2017). Interplay of innovation and standardization: Exploring the relevance in developing countries. *Technological Forecasting and Social Change*, *118*, 334–348. https://doi.org/10.1016/j.techfore.2017.02.033

Acknowledgements

There would be no PhD completion without the ability of a PhD candidate to cope with failures. It is thus more important to empathize with one's failures during a PhD trajectory than to celebrate its completion. Throughout the past years, I learned that the people surrounding you deeply affect your resilience to failure. In my case, rather than considering myself a particularly good researcher, I consider myself, for whatever reason, incredibly rich in social capital. And this paved the way for me to somehow complete this journey.

The main social contacts I had for quite a while, after starting amid a global pandemic, were with my three supervisors and promoters, Geerten van de Kaa, Rudi Bekkers, and Henk de Vries. I will never be thankful enough to be backed up by such a competent and well-matched team in terms of knowledge and character.

Geerten, with you, I never felt held back from saying what I thought or pursuing any crazy research idea for fear of a potential mistake. Despite my being your first PhD student as a first and corresponding promotor, you were always open to a brainstorming session or practical advice, preventing me from making dangerous choices. I think (and hope) that as I grew as a scholar under your mentorship, you grew as a mentor thanks to my trajectory. It took me a while to really learn what doing research is about, but as the pandemic restrictions started fading, we built a more personal relationship, you understood my strong and weak points, and I could learn more from you. By selecting me from among many candidates, you placed your trust in me. I will be forever indebted to you for that.

Rudi, in you, I found a reference for what I consider a perfectly well-rounded scholar. When counting conferences, top publications, education awards, policy activities, and PhD supervision, with your spare time as a family man, telecommunication networks geek, globetrotter and marathon runner, I cannot figure out if your days are really made of 24 hours or more. Your energy was motivating to say the least, and I also appreciated your efficient way of giving low-quantity but high-quality feedback. On several occasions, you also took time to sit down with me for entire working days to tinker with data and rewrite bits of papers. Besides your humility, the enthusiasm you had on these occasions when the data finally said something meaningful was contagious. Outside of work, you also promoted several out-of-office activities that now represent very nice memories (those whose remembrance was not altered by some drinking).

Henk, you had the tedious job of adding rigor to the academic freedom that Geerten and Rudi left me. For this reason, without you, the papers in this thesis would be of much less depth and quality. Your "carrot and stick" supervision style really paid off. There were many "stick" moments, but they made me strive for perfection. The "carrot" moments were fewer, but I can most definitely remember all of them. My favorite "carrot" moment was when, after the initial months of reading and conceptual writing, you were impressed by how quickly I could elaborate on my first bunch of data (resulting in Figure 7-2). I also remember some enlightening chats (later turned into Chapter 3) about how all types of standards, in some way, generate network effects. I would come back home happy after those talks, knowing that my weird critical thinking made sense to someone. In sum, all my work has benefited from your immense knowledge of standardization, and I have always admired your dedication to producing good and unbiased research.

Working with the three of you and integrating into your three research groups was a very enriching and intellectually stimulating journey. From the *Economics of Innovation and Technology* section at TU Delft, I learned the value of interdisciplinarity, a pivotal concept in my thesis, and the ability to look beyond my own backyard – there is much more to research than standards. The *Technology, Innovation and Society* group at TU Eindhoven taught me that research is not as far from practice as one may think, as clearly exemplified by the "Brainport". Also, I was truly impressed by how genuine and welcoming your work environment is. The *Innovation Management* group at the Rotterdam School of Management helped me stay closer to my roots as an innovation and management scholar. After joining RSM , I learned why its M.Sc. in Innovation Management is considered among the best in the world. I am grateful to all colleagues met through three beautiful groups; you made going to the office a pleasure rather than a duty.

Among these colleagues, some deserve a special mention. My two paranymphs, Flavio and Aleks, were those who could more actively empathize with me about my job and be friends at the same time. Flavio, ever since we met in Sweden some seven years ago, I could already tell we looked at the world through the same lens. Our friendship went from being simple exchange-semester peers to proper friends and now even co-authors. I could write an entire chapter on the precious advice you gave me and the nice experiences we had together over the years. Among these, the trip to South America in 2022 is one of the best recent memories I have. Starting a project together, a few months later, that eventually resulted in one chapter of this thesis, was the real cherry on the cake of our friendship. Aleks, you joined our section at TU Delft when I was facing a difficult moment in my trajectory. Our small talk in the corridor changed into much deeper conversations, most of which felt to me like mentoring sessions. Thanks to your empathy, I now consider you a (not so) older sister, and I hope that in your toughest moments, I have been able to return half of the endorsement and warmth you gave me during these years.

Martijn and Vladimir, sharing most of this trajectory with you has also been a blessing. Having you as office mates would always guarantee some time both for productive chats and relaxation. Martijn, deciding to apply together for the ISO Research Grant after "a couple" of pints says much about our relationship. Winning it and writing two reports and one article with a researcher like you has been an honor. Vladimir, with you, I had my first ever teaching experiences, spent my first conference back in Italy, and had a colleague to discuss and learn more about digital platforms. The three of us are now based in different universities, and, in hindsight, I am sure that our chats and retreats contributed to making the three of us great scholars.

Between 2023 and 2024, I spent some months at the Bordeaux School of Economics to work with Valerio Sterzi. Valerio, you are obviously much more than a professor I visited for a research exchange. Your close friendship with my brother Fabrizio was an opportunity for me to have another older brother since birth, who eventually became a work mentor. You first encouraged me to apply for this PhD position, then you welcomed me to the beautiful Bordeaux, where I could learn almost all I know about statistics and economics and could write Chapter 4 of this thesis. There, I also met amazing colleagues and friends with whom I enjoyed a lighthearted and memorable journey into the French culture, language, and wines.

Besides Flavio, Martijn, Valerio, and my supervisors, this thesis benefited from the co-authorship of four other great scholars. Thank you, Stefano, Neelke, Paul and Amin, for your guidance and contribution to this book. I also collaborated with two important institutions. The Dutch standards body, NEN, in part, funded my PhD grant. Thanks to your research foundation, SOONS, and especially Arnoud Muizer, for the support and the freedom you gave me to conduct this research. I also collaborated with the Research & Innovation team at ISO. I am thankful to have

been awarded your research grant and for having had the chance to work with your supportive, professional, and lively team on the important topic of rising sea levels.

Davide, you were the initiator of my academic journey. You forwarded me the vacancy for this PhD back when we were colleagues in Milan. I was not considering academic positions at the time. I trusted your enthusiasm for academic life and for TU Delft's prestige (which I was completely unaware of) and luckily got in on my first try. I am happy that we bonded even more and could share our feelings as you started your successful PhD in Copenhagen, in parallel to mine.

One of the coolest aspects of doctoral life is engaging with your peers when attending conferences. Reem, Elona, Lennart, Luzie, and Sokol, you and many others made me enthusiastic about going to conferences and made me stay up late and hang out in whatever city around the world, forgetting about early-morning presentations. An additional acknowledgment goes to the EURAS community, which made me understand how valuable it is to be part of a small but strongly tied community. Lastly, a special thanks to Justus, Yanis, and Santiago, who started as simple conference peers but eventually became my new family at BRELA and Northwestern University.

Although there are only academics cited up to this point, having support from friends outside of academia is equally, if not more, important. Your support was unwavering regardless of any work-related achievement. You made me understand the importance of other things outside of the PhD. In some cases, the support came from far away. Sometimes, I would feel guilty about not being there for many of you, because the distance would not allow for it. However, I learned that real friendship goes beyond distance, and this made me write Proposition 5 attached to this thesis.

Through my childhood memories, I can still visualize moments spent with Biagio, Jacopo, Luigi, Filippo and Paolo. I feel gifted to have grown up with you and still have you all in my life. Thanks to my group of friends from my time as a university student in Rome: Ste, Anton, Lucone, Ludo, Giadina, Vero, Conte, Ida, Luca, Simo, Olya, Pandolf, Gloria. We are a truly unique group, and I get happier and prouder as we regularly retreat and have a great time. Thanks to my group of friends from my Swedish experience: Giulia, Lollo, Otta, Chiara, Massi, Fede, Davide, Antonio, Ele, Marta S., Marta P., Luca, Giulio, and Michelino. Quoting my master's thesis' acknowledgments, "you made this an unforgettable journey of friendship", and I will probably never feel the same freedom again.

Building a social life in Rotterdam, during a pandemic, at a very introverted moment in my life, was one of the hardest quests I ever faced. Until I met Alessandro. Ale, you have been the best flatmate I could ever ask for. We centered our co-living around hospitality, good food, and *gezelligheid*. And this made Geertsemastraat a Michelin-starred shelter for Rotterdammers of all kinds. You also introduced me to your social network, thanks to which we built an extraordinary group of friends. Giacomo, Claudia, Marco, Cami, Patte, Nina, Anna, Lara, Paso, Musillo, Fabio, Candida, Domi, Leo, Ciro, Benito, Vittoria, Diletta, Silvia, Nic, Bea, Jan, Josie, and many others. Being expats created a magical bond of shared joys and problems, and I am so grateful we rode this rollercoaster together.

Diego, Sophie, Adela, Eva, Frasco, Raffaele, Alessia, Grant, Nicola, Martina, Maria, Giulia. I met you all on very different occasions, and I have built a friendship with each of you that goes well beyond this thesis. I associate each of you with one or more places around the world where you made me feel at ease. Thank you for being, despite the distance, stimulating, empathetic, and heartwarming friends. Thanks to water polo, to Z&PC Rotterdam, to captain Roy, to Sergio, Emanuele, Max, and all the teammates with whom I shared pool battles. Being part of a sports team after many years was a leap out of my comfort zone, and you made it incredibly smooth and enjoyable.

Above all friends and colleagues, I owe all of this to my family. Mamma Marina e Papà Mimmo, Fabrizio, Alessandro, Carolina, thanks for being my nest and for always being there, despite my winter migrations. Thanks to Silvia, Francesco, and Claudio for having beautifully enriched my nest. Thanks to my nephew Simone and my soon-to-arrive niece Beatrice for giving me hope for the future.

Lastly, thanks to Robi for being my first supporter ever since we met. Having you by my side will make life after the PhD a happy one.

About the author

Filippo Grillo was born in Rome, Italy, on July 6th, 1995.

He conducted his undergraduate studies in Economics and Management at University of Rome LUISS Guido Carli, during which he developed a passion for technologies and the telecommunications sector. His graduate studies were split between Italy and Sweden, where he earned a double Master of Science degree in Management of Innovation awarded by LUISS Guido Carli (cum laude) and the University of Gothenburg, also obtaining a merit scholarship from the LUISS Alumni Association. In Gothenburg, he wrote his master's thesis on telecommunications for smart factories in collaboration with the Swedish company Ericsson.

After graduation, Filippo spent two years in Milan, Italy, working for Deloitte Digital and British Telecom as a consultant and project assistant for various projects on cost reduction, business process re-engineering, and implementation of technologies, including smart speakers, mobile apps, and telecommunications networks.

He started his PhD trajectory at TU Delft in September 2020. During his PhD, Filippo published his work in the *Academy of Management Annals*, at the time the highest-ranked journal in the field of management and business. He was also awarded the *ISO Research Grant* (2022) for a project on standards for climate adaptation. He was a visiting scholar at TU Eindhoven and the Bordeaux School of Economics. In September 2024, he started a one-year research appointment at the Rotterdam School of Management. He lectured for the bachelor-level course "Strategic Management" and master-level course "Technology Battles" at TU Delft, and held guest lectures at the Rotterdam School of Management and Paris École des Mines. He also supervised several master's thesis students and attended numerous international conferences.

Filippo speaks Italian, English, Spanish and French, and thrives in multicultural environments. He is currently a research affiliate at the Center on Law, Business and Economics at Northwestern University, and a research associate at BRELA Research in Economics and Legal Analytics, where he is continuing his research endeavors on the economics of technology and standardization.

List of publications and conference presentations

Publications

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*, *July*, 788–830. https://doi.org/10.5465/annals.2023.0072

Breeman, M. P., **Grillo, F.,** & van de Kaa, G. (2022). Battles in space: De-facto standardization of Global Navigation Satellite Systems. *Journal of Engineering and Technology Management - JET-M*, *65*. https://doi.org/10.1016/j.jengtecman.2022.101693

Besana, F., **Grillo, F.**, & Wiarda, M. (2024). Standardization for adaptation to sea level rise: Recommendations for policymakers. *Publications of the International Organization for Standardization (ISO)* https://www.iso.org/publication/PUB100489.html

Besana, F., **Grillo, F.**, & Wiarda, M. (2024). Standardization for adaptation to sea level rise: Recommendations for the technical community. *Publications of the International Organization for Standardization (ISO)* https://www.iso.org/publication/PUB100488.html

Grillo, F., & de Vries, H. J. (2023). A Multi-Stakeholder Approach for Digital Platforms: Lessons Learned From the World of Technical Standardization. *Medium.com* - https://medium.com/@reshaping_work/a-multi-stakeholder-approach-for-digital-platforms-lessons-learnedfrom-the-world-of-technical-c24c812cd25f

Manuscripts under review

Grillo, F., de Vries, H.J., van de Kaa, G., & Bekkers, R. – Rethinking network structure for network effects in standards and platforms adoption

Grillo, F., Besana, F., Wiarda, M., de Vries, H. J., Doorn, N., van de Kaa, G. – Flexible standardization for place-based and time-based adaptation: the challenge of Sea-Level Rise

Manuscripts in preparation

Grillo, F., van de Kaa, G., Bekkers, R., de Vries, H. J., Sterzi, V. – Effects of participating in technical standardization on the economic performance of firms

Conference presentations

2021 – European Academy for Standardisation (EURAS)
Presentation title: *Standards and standardization: An interdisciplinary literature review*
Location: Eindhoven University of Technology, Eindhoven (NL)

2022 – European Academy for Standardisation (EURAS)
Presentation title: *The application of network effects to standards and platforms*
Location: Adam Smith Business School – Glasgow (UK)

2022 – R&D Management Conference
Presentation title: *A taxonomy of network effects for standards and platforms*
Location: Università degli Studi di Trento – Trento (IT)

2022 – Erasmus Research Institute of Management Seminars
Presentation title: *A taxonomy of network effects for standards and platforms*
Location: Rotterdam School of Management – Rotterdam (NL)

2023 – ISO Technical Committee 207 Sub-Committee 7 Plenary Meeting
Presentation title: *Standardization for adaptation to rising sea levels*
Location: Association Française de Normalisation (AFNOR) – Paris (FR)

2023 – EuroTech Alliance Summer School
Presentation title: *Coordination through standards and platforms: the mechanisms behind network effects and value*
Location: Danmarks Tekniske Universitet – Copenhagen (DK)

2023 – European Academy for Standardisation (EURAS).
Presentation title: *Coordination through standards and platforms: the mechanisms behind network effects and value*
Location: Rheinisch-Westfälische Technische Hochschule – Aachen (DE)

2024 – Geography of Innovation (GeoINNO) Conference
Presentation title: *Standardization for Sea Level Rise adaptation*
Location: Alliance Manchester Business School – Manchester (UK)

2024 – Economics of Science and Innovation Workshop
Presentation title: *Who leads Standard-Setting Organizations? The influence of network embeddedness on firm performance*
Location: Bordeaux School of Economics – Bordeaux (FR)

2024 – Journal of Economic Geography Paper Development Workshop
Presentation title: *Standardization for Sea Level Rise adaptation*
Location: Utrecht University – Utrecht (NL)

2024 – European Academy for Standardisation (EURAS)
Presentation title: *Who leads Standard-Setting Organizations? The influence of network embeddedness on firm performance*
Location: Delft University of Technology – Delft (NL)

2024 – Fourth Annual Empirical Research Conference on Standardization
Presentation title: *Who leads Standard-Setting Organizations? The influence of network embeddedness on firm performance*
Location: Northwestern University – Chicago (US)

2025 – Fifth Annual Empirical Research Conference on Standardization
Presentation title: *Standardization and the effects on innovation in critical and emerging technologies*
Location: Northwestern University – Chicago (US)