



Delft University of Technology

Multi-mode standardisation

A critical review and a research agenda

Wiegmann, Paul Moritz; de Vries, Henk J.; Blind, Knut

DOI

[10.1016/j.respol.2017.06.002](https://doi.org/10.1016/j.respol.2017.06.002)

Publication date

2017

Document Version

Final published version

Published in

Research Policy

Citation (APA)

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

Important note

To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy

Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.



Multi-mode standardisation: A critical review and a research agenda

Paul Moritz Wiegmann^{a,*}, Henk J. de Vries^{a,b}, Knut Blind^{c,d}

^a Rotterdam School of Management, Erasmus University, Chair of Standardisation, Burgemeester Oudlaan 50, 3062 PA Rotterdam, The Netherlands

^b Delft University of Technology, Faculty of Technology, Policy and Management, Section Economics of Technology and Innovation, Jaffalaan 5, 2628 BX Delft, The Netherlands

^c Technische Universität Berlin, Chair of Innovation Economics, MAR 2-5, Marchstraße 23, 10587 Berlin, Germany

^d Fraunhofer Institute for Open Communication Systems, Kaiserin-Augusta-Allee 31, 10589 Berlin, Germany

ARTICLE INFO

Keywords:

Standardization
Committee-based standardization
Standard battles
Regulation
Government-based standardization
Multi-mode standardization

ABSTRACT

Standardisation is key to shaping new technologies and supporting major ongoing trends, such as the increased importance of platforms, developing ‘smart’ technologies and innovating large-scale complex systems. Standardisation plays a key role in shaping the rules that govern these developments and their effects on society. Due to the large variety of actors involved in these trends, the associated standardisation processes are likely to involve all three modes of standardisation identified in the literature: committee-based, market-based and government-based. This multi-mode standardisation challenges the theoretical views on standardisation which predominantly focus on one of the modes. In this paper, we review the existing literatures on individual modes and on multi-mode standardisation. By recombining existing evidence, we generate new insights into multi-mode standardisation processes. These first insights relate to the contributions that each mode can make to such processes’ outcomes and suggest that their impact depends on factors, such as their initiation’s timing and the institutional context in which the standardisation process occurs. Moreover, we consider the conditions under which actors can launch each mode. Based on our observations, we formulate an agenda for future research to obtain a better understanding of multi-mode standardisation. We offer recommendations for industry actors, NGOs, researchers and policy makers involved in shaping technological and societal change.

1. Introduction

Standardisation can be critical in determining a technology’s success and often plays a vital role in supporting major technological and societal trends. Many important ongoing developments, such as the transformation towards a platform economy, making things ‘smart’ and innovating large, complex systems rely on standardisation (e.g. Featherston et al., 2016; Geels, 2004; Ho and O’Sullivan, 2017). Standardisation’s key aim is limiting the number of solutions when using many different options simultaneously is ineffective and inefficient. One would expect the standardisation world to adopt this approach to its own processes and ensure that standardisation itself is ‘standard’. However, closer inspection reveals that this is not the case.

Current literature is organised around three modes of standardisation: committee-based standardisation, sometimes referred to as de-jure standardisation (e.g. Jain, 2012; Narayanan and Chen, 2012); market-based standardisation, sometimes referred to as de-facto standardisation (e.g. Schilling, 2002; Suarez, 2004); and government-based standardisation (e.g. Büthe and Mattli, 2010). Extant literature describes cases where these modes jointly contributed to the final outcome (e.g.

Gao, 2014; Garud et al., 2002; von Burg, 2001), and shows that many impactful standards (such as the ISO shipping container, GSM or Ethernet) emerged in multi-mode standardisation processes, but provides limited theoretical insights into these processes. As we argue in Section 2.1, multi-mode standardisation is likely to become increasingly important in the future. Most (if not all) major ongoing trends, which shape technology and society, bring together previously unrelated stakeholders from different backgrounds (e.g. in terms of industry sector and geography) (e.g. Kenney and Zysman, 2016; Porter and Heppelmann, 2014). As they use standardisation to facilitate and coordinate these developments, they are likely to bring different standardisation ‘cultures’ and strategies to the table and employ the modes of standardisation that they are familiar with, resulting in a large number of multi-mode processes.

Despite this increasing importance of multi-mode standardisation, it has received surprisingly little attention in research. The predominant view in the literature (e.g. Leiponen, 2008; Schilling, 2002) assumes that every standardisation process relies on only one of these three modes. Although many historical cases (e.g. the market battle between VHS and Betamax or ISO 9001’s committee-based development) are in

* Corresponding author.

E-mail address: wiegmann@rsm.nl (P.M. Wiegmann).

<http://dx.doi.org/10.1016/j.respol.2017.06.002>

Received 15 April 2015; Received in revised form 3 June 2017; Accepted 3 June 2017

0048-7333/ © 2017 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

line with this view, it leaves an increasing share of cases unexplained (Section 2). In this review paper, we make four contributions towards generating a better understanding of these trends and the associated standardisation processes. First, we review existing literature and derive the three ideal-typical modes of standardisation that drive the emergence of standards (Section 3). Second, we summarise available theory on multi-mode standardisation and identify its gaps (also Section 3). Third, we recombine evidence from existing literature to make some first steps in formulating additional theory on multi-mode standardisation (Section 4). Fourth, we propose an agenda for research which can add to a more complete understanding of the phenomenon (Section 5.1). Based on these findings, we also offer recommendations, based on the currently available evidence, for industry actors, NGOs, researchers and policymakers in standard developing organisations (SDOs), industry associations and communities of practice involved in shaping major technological trends (Section 5.2).

2. Trends in standardisation

Standardisation aims to resolve situations where involved actors prefer a common solution to a problem, but have not yet agreed which option to choose. For example, this can often be observed during the development of technical specifications for new technologies with network effects. Such network effects mean that the technology's benefits for an individual actor increase along with the number of others using the same technology. The conflicts arising between actors supporting different solutions have been modelled game-theoretically as 'battle-of-the sexes' games (see e.g. Belleflamme, 2002; Besen and Farrell, 1994; Farrell and Saloner, 1988; Mattli and Büthe, 2003). These battles can result in wars of attrition where actors block agreements in the hope that the other side concedes (Farrell and Saloner, 1988; Farrell and Simcoe, 2012). To establish a common solution, standardisation pursues coordination between actors by developing solutions which are then implemented by all of them (Farrell and Saloner, 1988; Farrell and Simcoe, 2012). We group the literature on processes for establishing common solutions around three modes of standardisation in which such coordination occurs: (1) committee-based, (2) market-based and (3) government-based (see Section 3 for a detailed discussion).

2.1. Complexity in standardisation

We observe several empirical cases of widely used and impactful standards emerging from complex processes, where actors use diverse strategies to influence the outcomes, involving multiple modes of standardisation (see Table 1). Moreover, we expect the role of multi-mode standardisation to increase in the future in line with several major trends which underlie the increasing digitalisation of society: large scale innovation of complex systems, the development of smart technologies, the increasing importance of platforms, growing demands for sustainability and responsibility in global supply chains, and globalisation in general. All of these developments bring together a large variety of previously unrelated actors, and rely on coordination between these actors to be able to function. Pursuing these changes is beyond the capabilities of individual firms and even industries, requiring actors to interact and/or cooperate across sectors, and exposing them to new sets of stakeholders (Porter and Heppelmann, 2014). Kenney and Zysman (2016) argue that these trends can even affect actors from all parts of society and require them to find common solutions, not only to technical questions, but also to non-technical issues. Standardisation can be important in establishing these solutions and getting them accepted (e.g. Featherston et al., 2016; Geels, 2004; Ho and O'Sullivan, 2017; Schmidt and Werle, 1998). This implies that standardisation is not only relevant to industry, but also to many other stakeholders. For example, NGOs play an increasingly important role in standardisation (Boström and Tamm Hallström, 2010). The EU's Horizon 2020 programme for funding research projects specifically

considers participation in standardisation as a research output (European Commission, 2011a, 2011b; European Parliament and Council of the European Union, 2013). Germany's government also operates a funding programme for scientists who work on incorporating their research findings into standards (BMW, 2016).

As the involved actors develop standards to support these trends or cope with them, they are likely to base their approaches on standardisation 'cultures' that they are familiar with. These differ greatly. For example, the ICT sector has a standardisation 'culture' where consortia and markets play a big role, whereas other sectors rely to a larger degree on committee-based standardisation (e.g. Blind and Gauch, 2008). The degree to which actors in standardisation rely on collaboration or competition also varies widely across countries (Büthe and Mattli, 2011; Tate, 2001). The role of government in standardisation differs as well. The government plays a defining role in Chinese standardisation (e.g. Chuang, 2016; Gao et al., 2014; Gao, 2014), whereas the "New Approach" in Europe aims to limit the influence of government on technical details and depends on private stakeholders contributing their expertise to standardisation (Borrás, 2007). This implies that standardisation processes, which bring together the diverse actors who are involved in shaping these trends, will rely on multiple modes. Standardisation of the Internet of Things and smart manufacturing is an example of an area driven jointly by players from the ICT field and traditional manufacturing industries and involves elements of all three standardisation modes (see Ho and O'Sullivan, 2017; Lu et al., 2016). Also, national standardisation strategies outline the relationship between government and the other modes of standardisation, for example in China (CNIS, 2016), the Republic of Korea (Choi, 2016), the USA (United States Standards Strategy Committee, 2015), the UK (CBI et al., n.d.), Germany (Deutsche Bundesregierung, 2009); France (Evrard, 2014), Austria (Österreichische Bundesregierung, 2016), and Russia (RF Ministry of Industry Energy, 2008).

Given the increasing complexity in standardisation and the importance of multi-mode standardisation for ongoing technical and societal developments, it is a phenomenon that warrants further investigation.

2.2. The predominant view on standardisation

Much of the existing literature assumes that standards are developed and diffused strictly within the boundaries of one mode (e.g. Belleflamme, 2002; Blind et al., 2017; Chiao et al., 2007; Farrell and Simcoe, 2012; Greenstein, 1992; Leiponen, 2008; Rosen et al., 1988; Schilling, 2002; Timmermans and Epstein, 2010), and thus treats the modes of standardisation as mutually exclusive. Typologies of standardisation are built on this premise and classify cases into the different modes without considering the possibility that some standardisation processes may involve elements of several modes (e.g. Botzem and Dobusch, 2012; Büthe and Mattli, 2011; p. 19; Büthe and Mattli, 2010; David and Greenstein, 1990). Following from this, the literature on success factors in standardisation is divided into different streams of research. The first stream identifies ways to influence processes within standard developing organisations (SDOs) (e.g. Jain, 2012; Leiponen, 2008; Mattli and Büthe, 2003). Another stream focuses on success factors for winning market battles (e.g. den Uijl, 2015; Schilling, 2002; Suarez, 2004; van de Kaa et al., 2011; van den Ende et al., 2012). Work on how actors can successfully influence government-based standardisation is scarcer, although cases have been described (Gilmore et al., 2006) and success factors for lobbying in general (e.g. Bouwen, 2002; Klüver, 2011; Mahoney, 2007) are likely to apply.

This theoretical assumption of standardisation processes taking place within one mode's boundaries is supported by many empirical cases. For example, ISO 9001 originated in the committee-based mode (Tamm Hallström, 2004). Examples of the market-based mode include the battle between AC and DC electricity in the 19th century (David, 1992; David and Bunn, 1988) and VHS vs. Betamax (Cusumano et al.,

Table 1
Overview of cases involving more than one mode of standardisation.

Combination of Modes	Example Cases
Markets and Committees	<ul style="list-style-type: none"> • Ethernet vs. other LAN technologies (von Burg, 2001) • Office document formats (Blind, 2011; Egyedi and Koppenhol, 2010) • Web-browsers (de Vries et al., 2008) • DVD (Vercoulen and van Wegberg, 1998) • Competition between internet telephony technologies (Vercoulen and van Wegberg, 1998) • Competition between 2G mobile telecommunications technologies in the USA (Funk and Methe, 2001; Gandal et al., 2003; Pelkmans, 2001) • USB vs. FireWire (van den Ende et al., 2012) • Wi-Fi vs. HomeRF (van den Ende et al., 2012) • Blu-Ray vs. HD-DVD (den Uijl and de Vries, 2013) • Competition between different standards for Unix operating systems (Axelrod et al., 1995) • Standardisation of LED-lighting technology (LED Inside, 2010)
Governments and Committees	<ul style="list-style-type: none"> • GSM (Bekkers, 2001; Pelkmans, 2001) • TD-SCDMA in China (Gao et al., 2014; Gao, 2014) • TCP/IP (Townes, 2012) • ISO Shipping Container (Egyedi, 2000; Egyedi and Spirco, 2011) • European container sizes for intermodal transport (Meyer, 2012) • Standards for digital and high-definition television (Meyer, 2012) • Requirements for medical devices in the EU (Frank, 2001) • Energy performance requirements for buildings in the Netherlands (de Vries and Verhagen, 2016) • European “New Approach” (Borraz, 2007)
Governments and Markets	<ul style="list-style-type: none"> • Competition between railway track gauges (Puffert, 2002, 2000) • Global market battle between 2G mobile telecommunications technologies (Funk and Methe, 2001) • ADA programming language vs. alternatives (Rosen et al., 1988)
Markets, Committees and Governments	<ul style="list-style-type: none"> • Competition between international accounting standards (Büthe and Mattli, 2011; Hail et al., 2010; Tamm Hallström, 2004)^a • Internet protocols (Abbate, 2001) • CSR and environmental management systems (Delmas and Montiel, 2008; Moratis and Tatang Widjaja, 2014; Wätzold et al., 2001)^b • Standards for Internet of Things and smart manufacturing (Lu et al., 2016) • Plugs for charging electric vehicles in Europe (Bakker et al., 2015) • Food quality and safety standards (Trienekens and Zuurbier, 2008) • Antifouling paint for ships (Thompson Clarke Shipping Pty, 2017; Thompson Clarke Shipping Pty. Ltd. et al., n.d.) • Competition between units of measurement – SI and Imperial Measurement systems (Glazebrook, 1931; National Industry Conference Board, 1921)

^a Büthe and Mattli (2011) and Tamm Hallström (2004) ignore the role of markets in this case. Hail et al.’s (2010) case description focuses on the influence of governments and markets while neglecting committees.

^b Although these papers do not explicitly discuss committee-based standardisation, the presence of an ISO standard (ISO 26000) implies that committees played a role in this case.

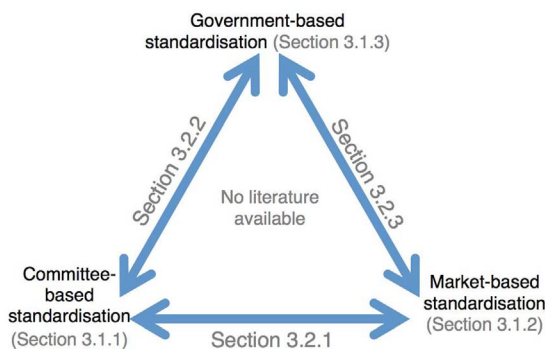


Fig. 1. Literature on standardisation.

1992; Rosenbloom and Cusumano, 1987). Examples of purely government-based standardisation can be found in Latin American milk safety standards (Farina et al., 2005) and the French government’s definition of standard measurements in the 18th century (Rosen et al., 1988). In addition, the standardisation systems of the former Soviet Union (USSR State Standards, 1976) and China before the mid-1980s (Chuang, 2016) were built entirely on government-based standardisation.

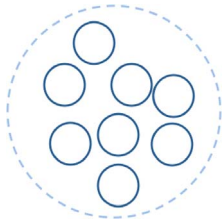
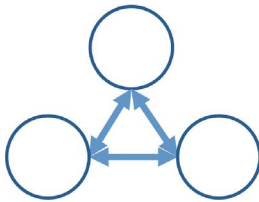
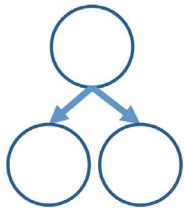
Although there are thus cases supporting the focus on single modes, relying on this view when analysing multi-mode standardisation cases, such as the ones presented in Table 1, means treating elements of additional modes as external influences. For example, Tamm Hallström

(2004) and Büthe and Mattli (2011) view government activities in accounting standards as external to the standardisation process taking place in committees. This approach may constrain a full understanding of such cases, because multi-mode standardisation is characterised by dynamic interactions between modes. In the remainder of this paper, we review the available literature that can help us understand these dynamics and recombine it to generate new insights. We also identify the limitations of existing evidence, and outline an agenda for research to obtain a more complete understanding of multi-mode standardisation processes.

3. Modes of standardisation

We now take a closer look at the three modes of standardisation which represent ideal-typical models of standardisation processes. In Section 3.1, we briefly review the literature on these ideal-typical modes to highlight their defining features and provide the conceptual background for the rest of the paper. In Section 3.2, we review extant research on the interactions between these modes, and deviations from these ideal-types. As indicated in Fig. 1, this body of work focuses on specific pairs of modes. Because standardisation processes are heterogeneous, we also discuss the extent to which the modes of standardisation are likely to form the basis for standardisation processes across this diverse domain (Section 3.3).

Table 2
Ideal-typical modes of standardisation – characteristics (source: authors' own summary of literature).

	Committee-Based Standardisation	Market-Based Standardisation	Government-Based Standardisation
Relationships between actors			
Coordination mechanism	Coordination through <i>cooperation</i> between stakeholders. Standards are developed in committees and only diffused if members agree on a common solution.	Solutions intended as a standard can be developed by anyone. Coordination through <i>competition</i> between solutions in the market, leading often (but not always) to one de-facto standard.	Solutions intended as a standard can come from various sources. Coordination through governments using their <i>hierarchical position</i> to impose these standards' use on others.
Timing of coordination	Coordination takes place during standard <i>development</i> – only one solution is chosen to enter the market.	Coordination takes place during <i>diffusion</i> – different standards are developed and compete with each other.	Governments can intervene in development or mandate using an already developed standard.
Main actors driving the standardisation process	Predominantly private	Predominantly private	Predominantly public
Avenues of influence	Stakeholders cooperating in committees; SDOs providing a platform for standard development.	Individual market actors influencing the outcome of the market competition with their actions.	Governmental bodies developing standards and/or enforcing their use.
Inclusiveness in standard development	High, any interested party can join a committee.	Varies, some standard development venues are open; access to others is restricted.	Medium, lobbying may require high effort.
Examples of empirical research	Leiponen (2008), Mattli and Büthe (2003), Tamm Hallström and Boström (2010), Tate (2001)	den Uijl (2015), Schilling (2002)	Farina et al. (2005), Schmidt and Werle (1998)

3.1. Setting the background of ideal-typical modes of standardisation

Based on literature, we identify three ideal-typical modes of standardisation: committee-based, market-based and government-based. These modes have three defining characteristics: (1) the mechanisms which result in the coordination that standardisation aims for and describe the fundamental relationships between actors in the process (cooperation, competition, hierarchy); (2) the main actors involved (private or public); and (3) the timing in the process (development or diffusion – see below) when actors intervene and coordination occurs. These three defining characteristics lead to two additional distinguishing features of the ideal-typical modes: (1) individual actors' avenues of influence on the process's results and (2) the degree to which standard development is inclusive or exclusive (see Botzem and Dobusch, 2012). We summarise these features in Table 2 and explain them in more detail in Sections 3.1.1–3.1.3.

Timing refers to the clearly discernible phases of standardisation processes (e.g. de Vries, 2010; Lyytinen and King, 2006; Suarez, 2004). We classify these phases in two overarching categories (in line with Botzem and Dobusch, 2012; Weitzel et al., 2006). (1) standard development when solutions that are intended as a standard are created, and (2) standard diffusion which includes spreading information about a new standard, encouraging its application in use, and its actual acceptance and implementation (see Rogers, 2003). Depending on the mode of standardisation, coordination can occur in either of these phases (see Table 2).

3.1.1. Characteristics of committee-based standardisation

Standardisation through *cooperation* usually takes place in committees of SDOs (e.g. the International Organization for Standardization (ISO) or ASTM International), consortia (e.g. the Blu-Ray Disc

Association), professional associations (e.g. IEEE), trade associations (e.g. IATA), or open source initiatives.¹ There, stakeholders collaborate to define standards which propose one solution in the form of an approved document (Blind, 2006, 2002; Büthe and Mattli, 2010; Gallagher, 2007; Hanseth and Monteiro, 1997; Narayanan and Chen, 2012; Rosen et al., 1988; Schmidt and Werle, 1998; Timmermans and Epstein, 2010) – although the exact process varies among standardisation organisations (e.g. Tate, 2001). Actors belonging to the private sphere dominate committees (Büthe and Mattli, 2011, 2010) and any interested stakeholder can join these committees in their ideal-typical form, making the process 'inclusive' (Botzem and Dobusch, 2012).

In terms of timing, coordination in the committee-based mode takes place during standard development. If different options are proposed, they are evaluated before a standard is approved and diffused (Jain, 2012). SDOs aim to define only one solution for each problem – a goal they reach often but not always (Blind, 2011; Egyedi and Koppenhol, 2010). Using standards that were developed in committees is voluntary (e.g. de Vries, 1999; Mattli and Büthe, 2003). Economic benefits, such as reduced transaction costs (e.g. Blind, 2004, 2002; Swann, 2010), and various market demands (Brunsson et al., 2012) are important reasons for their implementation. Other reasons for their implementation lie in

¹ Characterisations of open source communities in the literature (e.g. de Vries et al., 2008; West, 2007; West and O'Mahony, 2008) suggest that they exhibit all defining features of venues for committee-based standardisation (see Table 2 and this section), even though they may not describe their work as 'standardisation activities' (see e.g. Open Source Initiative, 2007). In addition, they also have some characteristics which set them apart from more 'traditional' SDOs, e.g. in terms of intellectual property rules which often allow actors to 'fork' code to create new open source initiatives, or in terms of the length of development cycles. These differences mean that standards, which emerge from open source initiatives, are often more 'fluid' than those that are developed in traditional SDOs.

the path taken in standard development (Botzem and Dobusch, 2012; Markus et al., 2006; Tamm Hallström, 2004) – e.g. the cooperative, inclusive development process can give standards legitimacy which supports their implementation (Botzem and Dobusch, 2012; Tamm Hallström and Boström, 2010). However, implementation of standards is not self-evident and may be hindered by several barriers (de Vries et al., 2009).

Despite this, studies that investigate committee-based standards' diffusion are scarce compared to research on their development. Since coordination takes place before a standard enters the market in committee-based standardisation, literature focuses on standard development in these organisations (see e.g. Belleflamme, 2002; Goluchowicz and Blind, 2011; Mattli and Büthe, 2003) and often sees a standard's release as the end-point of the process.

3.1.2. Characteristics of market-based standardisation

Literature on market-based standardisation describes how battles between different technologies result in de-facto standards.² These technologies and their proponents compete in the market until an equilibrium is reached (Gallagher, 2007; Narayanan and Chen, 2012; Rosen et al., 1988; Schilling, 2002; Schmidt and Werle, 1998; Shapiro and Varian, 1999; Suarez, 2004; Tasey, 2000; Timmermans and Epstein, 2010; van de Kaa et al., 2011). Such battles usually result in one solution emerging as de-facto standard (Cusumano et al., 1992; de Vries, 2006; de Vries and Hendrikse, 2001; Schilling, 2002) due to a bandwagon effect (Belleflamme, 2002; Delcamp and Leiponen, 2014; Farrell and Simcoe, 2012; Geroski, 2000). However, there are also cases where several standards continue existing in parallel and where no coordination is reached (de Vries et al., 2011; Techatassanasoontorn and Suo, 2011).

Competition during the diffusion phase, i.e. after several solutions intended as a standard have been developed, is thus the driving force for coordination between actors in market-based standardisation.³ This competition is predominantly driven by actors from the private sphere (Büthe and Mattli, 2011, pp. 25–29; Büthe and Mattli, 2010). Because standards can be developed by anyone and are often proprietary, inclusiveness in standard development is generally regarded as low in market-based standardisation (Botzem and Dobusch, 2012; Egyedi, 2003).

3.1.3. Characteristics of government-based standardisation

Governments can use their *hierarchical position* to intervene in standardisation, and regulation is an important way of developing and diffusing standards (Khemani and Shapiro, 1993).⁴ Governments can impose mandatory use of standards that were developed elsewhere (Rosen et al., 1988), or can also develop standards themselves and make their use mandatory (Blind et al., 2017; Büthe and Mattli, 2011; pp. 20–23; Büthe and Mattli, 2010; Farina et al., 2005; Narayanan and Chen, 2012; Schmidt and Werle, 1998; Timmermans and Epstein, 2010). Coordination in government-based standardisation can thus occur in either of the phases, i.e. standard development or standard diffusion. Contrary to committee- and market-based standardisation, government-based standardisation is dominated by public actors who

have the authority to impose a standard's use (Büthe and Mattli, 2011; pp. 20–23; Büthe and Mattli, 2010). Private actors can therefore not influence coordination directly but only through lobbying⁵ which may require high effort and may be ineffective. We therefore classify government-based standardisation's inclusiveness (see Botzem and Dobusch, 2012) as medium compared to the other two modes.

Whether governments should play such a role at all in standardisation is a controversial question. Blind et al. (2017) find that such an intervention's effects on innovation depends on the degree of technological uncertainty in the market. In general, some researchers justify government-intervention because of the benefits of compatibility compared to an alternative situation where there is no common standard (e.g. Bekkers, 2001; Funk and Methe, 2001; Pelkmans, 2001). Others argue that avoiding competition between solutions removes the incentive for innovation that would otherwise be needed to ensure a solution's competitive edge and that governments should therefore carefully weigh the benefits and costs of intervening on a case-by-case basis (e.g. Cabral and Kretschmer, 2007; Cabral and Salant, 2014; Gandal et al., 2003). It has therefore been proposed that some of the ways in which government can intervene in standardisation that are described in Section 3.2 are preferable to the ideal-typical government-based standardisation through hierarchical means. This debate mainly focuses on compatibility standardisation, but de Vries and Verhagen (2016) show that government-based standardisation for energy efficiency can also simultaneously stimulate innovation and address societal issues. In other areas (e.g. safety or consumer information standards), government intervention may also be justified in cases of market failure when private actors would settle on solutions which carry negative externalities.

3.2. Existing literature on multi-mode standardisation

The modes of standardisation presented in Section 3.1 present ideal-types of standardisation processes. However, as we argued in Section 2, there are an increasing number of standardisation cases which are not covered by these ideal-types. Despite this, few sources provide detailed case descriptions which clearly show the dynamics in such cases and an even smaller number offers theory that integrates the different modes. Where there is theory on multi-mode standardisation, this combines elements of pairs of modes but we are not aware of theory that integrates all three modes. We provide an overview of the literature with detailed case descriptions and/or theoretical contributions about multi-mode standardisation processes in Tables 3A, 3B and 3C and summarise these theoretical contributions in Sections 3.2.1–3.2.3.

3.2.1. Combinations of market-based and committee-based standardisation

When market-based and committee-based standardisation jointly drive standardisation, elements of cooperation and competition as well as the other characteristics of these modes (see Table 2) are combined. Work that considers these combinations theoretically is either based on (1) the assumption that elements of committee- and market-based standardisation occur sequentially or (2) a dynamic interaction between elements of these modes.

The first type is considered by Axelrod et al. (1995), Markus et al. (2006) and van den Ende et al. (2012). Axelrod et al. (1995) observe that solutions which compete against each other in market battles are often developed in cooperation between actors in different consortia.⁶ In such standardisation processes, the number of potential solutions is therefore first reduced through cooperation in different consortia before

² Market mechanisms also drive the emergence of dominant designs and platforms. Many authors see these and de-facto standards as different concepts (den Uijl, 2015; Gallagher, 2007) although, according to den Uijl (2015), the processes in which they emerge are similar.

³ Where literature discusses standard development for the market-based mode, it usually refers to processes in consortia, indicating some degree of overlap with the committee-based mode – see Section 3.2.1.

⁴ According to Lessig, 2000; Lessig, 1999 idea that 'code is law', private actors who define architectures for software and the internet may occupy similar hierarchical positions as governments. This is because the architectures that they develop can restrict or encourage certain behaviour in similar ways to rules imposed by governments. Much of what we write in this paper about government-based standardisation might therefore also apply to these actors. However, exploring this is beyond the scope of our paper.

⁵ Lobbying has been investigated in depth from a political science perspective (e.g. Bouwen, 2002; Klüver, 2011; Mahoney, 2007), and from the economic regulatory capture (e.g. Dal Bó, 2006; Laffont and Tirole, 1991) and regulatory relief (e.g. Schmidt, 2002; Wätzold et al., 2001) perspectives.

⁶ Following our definition of the committee-based mode, consortia can be seen as a form of committee because they also develop standards in cooperation.

Table 3A
Literature on the interaction between markets and committees.

Combination of Modes	Paper	Brief Summary	Empirical Grounding	Theory about Multiple Modes	Geographical Context	Industry Context
Market/Committee	von Burg (2001)	Ethernet case	Individual case	No	Mainly USA	IT
	Garud et al. (2002)	Java case	Individual case	No	Global	IT
	Blind (2011), Egyedi and Koppenhol (2010)	Office documents case	Individual case	No	Global	IT
	van den Ende et al. (2012)	USB vs. Firewire, Wi-Fi vs. HomeRF cases	Individual cases	Yes	Global	IT
	Vercoulen and van Wegberg (1998)	DVD & internet telephony cases	Individual cases	Yes	Global	IT, consumer electronics, telecom
	Farrell and Saloner (1988)	Game-theoretic model of strategies in markets and committees	n/a	Yes	n/a	n/a
	van Wegberg (2004)	Economic model of interaction between market and committees	3 case-examples to illustrate model	Yes	Global	IT, consumer electronics, telecom
	Axelrod et al. (1995)	Theory of actors' choice between competing committees	Individual case	Yes	Global	IT
	Markus et al. (2006)	VIS standardisation in US residential mortgage industry	Individual case	Yes	USA	IT

Table 3B
Literature on the interaction between governments and committees.

Combination of Modes	Paper	Brief Summary	Empirical Grounding	Theory about Multiple Modes	Geographical Context	Industry Context
Government/Committee	Bekkers (2001)	GSM case	Individual case	No	Europe	Telecom
	Pelkmans (2001)	GSM case	Individual case	No	Europe	Telecom
	Gao (2014)	TD-SCDMA case	Individual case	No	China	Telecom
	Townes (2012)	TCP/IP case	Individual case	No	Mainly USA	IT
	Egyedi and Spirco (2011), Egyedi (2000)	ISO shipping container case	Individual case	No	Global	Transportation
	Büthe and Mattli (2011)	International accounting standards case	Individual case	No	Global	Financial services
	Tamm Hallström (2004)	International accounting standards case	Individual case	No	Global	Financial services
	NIST (2010)	Results from survey among practitioners	Survey among experts, non-academic	(Yes)	USA	none
	Gao et al. (2014)	TD-SCDMA case	Individual case	Yes	China	Telecom
	Meyer (2012)	Study of government intervention in standardisation	Individual case	Yes	Europe	Transportation, telecom, IT
	Borraz (2007)	New Approach	Individual case	Yes	Europe, France	None
	Blind and Mangelsdorf (2016)	Study of reasons for participating in SDOs	Survey among companies	Yes	Germany	Manufacturing

a market-battle leads to the emergence of a commonly accepted standard. In these cases, Axelrod et al. (1995) expect actors to join consortia which are large but where only few competitors are present in order to maximise the chances of the consortium's solution becoming the standard while enabling actors to reap the benefits of that solution. Furthermore, events in a consortium's cooperative coordination process also affect the chances of the resulting solution being selected in the market (Markus et al., 2006; van den Ende et al., 2012).

Other work questions the sequential occurrence of both modes, and considers a more dynamic interaction. Farrell and Saloner (1988) develop a game-theoretic model to investigate the interplay between markets and committees. In this model, actors decide whether to adopt a solution in the market or negotiate in a committee in each round, and, if they negotiate, whether to insist on their preferred solution or accept the proposed alternative. When comparing this combined model to models of pure market- or committee-based standardisation, Farrell and Saloner (1988) find that its payoffs for participants outperform those that can be achieved in either alternative. van Wegberg (2004) finds this only to be true when switching costs are relatively low. High switching costs are likely to lead to purely market- or committee-based standardisation (van Wegberg, 2004). In addition, standardisation is more likely to include both market- and committee-based elements in industries that are both complex and dynamic (Vercoulen and van

Wegberg, 1998). In these cases, the process can either start in the market and involve committees in later stages or vice versa (Vercoulen and van Wegberg, 1998).

3.2.2. Combinations of government-based and committee-based standardisation

Cases involving elements of government-based and committee-based standardisation combine elements of cooperation and hierarchy as well as other characteristics of these modes (see Table 2). Literature shows very diverse examples of cases where governments intervened in committee-based standardisation (see Tables 1 and 3B). Such interventions deviate from what would be expected under the ideal-types of committee-based and government-based standardisation presented in Section 3.1 and take two basic forms. (1) Government can use hierarchical means to shape the outcome of committee-based standardisation (referred to as a 'hard-law approach' by Meyer (2012)) and (2) government can employ non-hierarchical means to intervene in committees (referred to as an 'entrepreneurial approach' by Meyer (2012)), introducing a powerful actor into the committee-based mode. Such a powerful actor does not exist in the ideal-typical form of committee-based standardisation and violates the expectation that governments rely on hierarchy in standardisation.

Governments in Europe, the USA and China have all been shown to

Table 3C
Literature on the interaction between governments and markets.

Combination of Modes	Paper	Brief Summary	Empirical Grounding	Theory about Multiple Modes	Geographical Context	Industry Context
Government/Market	Puffert (2002, 2000)	Railway track gauges case	Individual case	No	Mainly USA	Transportation
	Rosen et al. (1988)	ADA programming language case	Individual case	No	USA	IT
	Delmas and Montiel (2008)	EMAS case	Individual case	No	Europe	Environmental management
	W & tzold et al. (2001)	EMAS case	Individual case	No	Europe	Environmental management
	Hail et al. (2010)	International accounting standards case	Individual case	No	Global with focus on USA	Financial services
	Funk and Methe (2001)	Global mobile telecom standard battle	Individual case	Yes	Global	Telecom
	Cabral and Kretschmer (2007)	Economic model of government intervention in markets	5 case-examples to illustrate model	Yes	Mainly USA	Telecom, aerospace, nuclear power, IT, pest control
	Cabral and Salant (2014)	Economic model comparing competing standards	n/a	Yes	n/a	n/a
		vs. one standard				
	Gandal et al. (2003)	Comparing economic results of competing standards vs. one standard	Individual cases	Yes	Europe, USA	Telecom

intervene in committee-based standardisation through hierarchical means (Bekkers, 2001; Borraz, 2007; Gao et al., 2014; Meyer, 2012; Pelkmans, 2001). When doing so, governments may support a favoured solution (e.g. in the Chinese TD-SCDMA case (Gao et al., 2014; Gao, 2014)). Such support may even go as far as denying visas to ISO-committee delegates (Kennedy, 2006). Governments see such interventions in standardisation as a means to promote national industries (Gao et al., 2014; Gao, 2014). Alternatively, governments can set broad aims and objectives where they lack the means (e.g. expertise) to reach their goals and leave the technical details to experts in committees. An example of this type of intervention is the European “New Approach” where European SDOs develop standards on request of the European Commission (Borraz, 2007). Meeting these standards gives actors a presumption of conforming to the legislation (Borraz, 2007). Blind and Mangelsdorf (2016) identify this type of labour division as a strong incentive for industry actors to participate in SDOs, because it allows them to influence the implementation of the regulation that they need to adhere to. Meyer (2012) found such ‘hard-law’ interventions with more or less prominent hierarchical elements to have severe drawbacks. In the cases that he studied, the prospect of a committee-based standard being enforced as a mandatory solution mobilised actors who would otherwise not have participated in standard development. This made it more difficult or even impossible to find a commonly acceptable solution in these committees (Meyer, 2012).

Instead of this ‘hard-law’ approach, Meyer (2012) advocates ‘entrepreneurial’ government interventions in committee-based standardisation. In this second type of intervention, governmental actors can play various roles that facilitate the cooperative coordination process. These activities can aim to actively promote one solution in committees and control their work to some extent (Gao et al., 2014), but may also be of a more advisory or observing nature (NIST, 2010). Specifically, they include placing standardisation issues on SDOs’ agendas (Gao et al., 2014; Meyer, 2012); mediating between actors in the process (Bekkers, 2001; Gao et al., 2014; Meyer, 2012; NIST, 2010; Pelkmans, 2001); facilitating the standardisation process, e.g. by providing financial support (Gao et al., 2014; NIST, 2010); or protecting the results of the process from contestation (Bekkers, 2001; Meyer, 2012; Pelkmans, 2001). Furthermore, governments can also influence the context in which standardisation takes place (sometimes unintentionally), thereby creating conditions that favour certain solutions (see Egyedi, 2000; Townes, 2012 for examples).

The literature comes to different conclusions regarding the extent to which such interventions facilitate the standardisation process. For example, Pelkmans’s (2001) analysis of GSM’s development places a large emphasis on the European Commission’s role in making the case successful whereas Bekkers (2001) sees other factors as more important. Meyer (2012) finds that all ways of ‘entrepreneurial’ government intervention in SDOs contribute to successful standardisation whereas American standardisation professionals are critical about agenda-setting by government, and prefer the topics of SDOs’ work agendas to be determined by private actors (NIST, 2010). However, Meyer (2012) also found that such ‘entrepreneurial’ government interventions in standardisation committees can only be successful if they happen early enough in the process, implying that governments need standardisation foresight (see Goluchowicz and Blind, 2011) if they aim to use these means of intervention.

3.2.3. Combinations of government-based and market-based standardisation

Where the government-based and market-based modes jointly occur, elements of hierarchy and competition and their associated characteristics (see Table 2) drive the standardisation process. Similar to the interventions in the committee-based mode, the literature documents government intervention in market-based standardisation using hierarchical and non-hierarchical means. By using their hierarchical position to mandate a specific solution’s use, governments can

cut market battles short or prevent them from occurring altogether (Cabral and Kretschmer, 2007; Cabral and Salant, 2014; den Uijl, 2015; Gandal et al., 2003; van de Kaa et al., 2011 – also see Tables 1 and 3C for examples). Whether governments should intervene in this manner is a topic of contention in the literature. Some authors highlight the benefits related to compatibility, innovation and social welfare whereas others claim that government intervention impacts negatively on innovation (see Section 3.1.3).

Hierarchical interventions can only be used to end a market battle at the national (or – in the case of Europe – regional) level. At the global level, there usually is no government with a hierarchical position to make binding decisions for others. In global standard battles, governments using their hierarchical positions to mandate solutions for big national markets nevertheless send an important signal to other actors that this solution will have a substantial installed base, thus giving it an edge in the battle (Funk and Methe, 2001). Additionally, governments can also intervene in national-level market battles using non-hierarchical means. One way of doing so is developing voluntary standards which then compete against others, such as the EMAS environmental management standard (Delmas and Montiel, 2008; Wätzold et al., 2001). This may be accompanied by granting relief from certain regulatory requirements to parties that implement the standard to encourage its use (Wätzold et al., 2001). Another way of intervening in market battles with non-hierarchical means is using public procurement to build a solution's installed base (Edler and Georgiou, 2007; Rosen et al., 1988). This is likely to be particularly effective in areas such as defence or medical care, where governments purchase goods and services in large quantities, and relies on elements of the market-based mode, giving the government no additional influence beyond that of an important player in the market.

3.3. Heterogeneity of standards and multi-mode standardisation

The examples and literature cited so far show that there are many potential relationships, interactions and interdependences in standardisation processes. Furthermore, standards themselves are also very diverse: They can apply to either the company, local, national or transnational levels. In addition, they differ in many other aspects, such as (1) the industry sector(s) for which they are relevant; (2) their economic functions (e.g. compatibility or safety, see Blind, 2004); (3) whether they address products, services or processes (see Tassey, 2000); (4) whether their scopes cover small technical details or architectures for entire systems; and (5) the uncertainty and complexity of the technology that they relate to (see Blind et al., 2017; de Vries, 1999). Standards are therefore extremely heterogeneous. The stakes involved in their development and the characteristics of the involved actors are likely to depend on the standard's attributes. This implies a vast variety in standardisation processes with very case-specific dynamics and interactions. How exactly these dynamics play out in a process depends on the participating stakeholders, their interests and their strategies to attain these interests.

Nevertheless, the modes of standardisation introduced above form the foundation of these processes. Standardisation processes in all areas have in common that actors would benefit from a common solution but have different preferences. We are not aware of literature that proposes other mechanisms to achieve the required coordination than cooperation, competition and hierarchy. This means that, regardless of a standardisation process's specifics, it will be based on one or multiple modes. Since the trends identified in Section 2.1, which lead to increasing complexity in standardisation, affect many different settings, we expect multi-mode standardisation to become increasingly common across the heterogeneous domain of standardisation.

Tables 3A, 3B and 3C show that there is a lack of work that studies the combination of all three standardisation modes⁷ and a relative scarcity of work providing theoretical insights about multi-mode standardisation (15 out of 33 studies). These tables also show two strong biases in this literature towards the IT and telecommunications sectors on the one hand and Europe and the US on the other hand. Literature on multi-mode standardisation therefore still has substantial gaps, because it only covers a small range of standardisation 'cultures'. These two biases deserve closer attention.

Blind et al. (2017) find technological uncertainty to be a key element in determining the effectiveness of committee- and government-based standardisation. While this finding applies to single-mode standardisation, it highlights the technological context's importance for standardisation in general. A generalisable theory about multi-mode standardisation therefore requires considering different technological contexts and sectors. The predominance of IT and telecommunications in the literature raises the question whether multi-mode standardisation occurs in other sectors and technological contexts to the same degree. Markets play an important role in IT-related fields (see Section 2), but this does not explain why these fields also dominate the literature on the combination between governments and committees. We observe that the cases of government-committee interaction documented in the literature occurred in key national industries that are heavily regulated⁸ or have a history of state ownership (e.g. the telecommunications sector – see Schmidt and Werle, 1998). Even if government intervention in standardisation were to only occur in such sectors, this leaves a gap in terms of sectors covered. We would then expect multi-mode standardisation with government involvement to also occur, e.g., in the healthcare, food and financial services sectors. This expectation is in line with existing evidence. NIST (2010) mentions examples of government intervention in healthcare and nuclear standardisation. In the European Union, government involvement in standardisation exists in all major areas as documented by the "New Approach" standardisation requests in CEN/CENELEC's 2017 work programme (CEN/CENELEC, 2017).

Given the importance of the institutional context in government activities but also in shaping markets and committees (Tate, 2001), we also see that the literature is biased in its geographic coverage. Our discussion in Section 2.1 shows that multi-mode standardisation exists in various political settings, such as in Europe, the USA and more recently China, but also that substantial differences appear to exist in how such multi-mode standardisation manifests itself in these contexts. Similar differences can be expected in other countries, e.g. Japan, the Republic of Korea or various developing countries.

We expect that the underlying characteristics of multi-mode standardisation apply regardless of the exact type of standard. Nevertheless, how they translate into the specific dynamics of a standardisation process is likely to depend on many factors. The biases in the literature on which we base our insights therefore present a limitation of our further discussion in that regard and present an important opportunity for future research.

4. Achieving coordination in multi-mode standardisation

As outlined in the Section 2, achieving coordination between actors who would benefit from using a common solution to a problem, but may have different preferences for this solution, is a key aim of standardisation. While the literature is very clear about how this goal can be reached in single-mode standardisation, our discussion in Section 3.3 shows that substantial gaps still exist which limit our understanding of

⁷ This is despite our observation in Table 1 that influential standards in various areas emerged from such processes.

⁸ Although IT is not heavily regulated in general, all IT-related cases with government involvement in our literature overview have a link to the defence sector.

Table 4
Activating modes of standardisation.

	Committee-Based Standardisation	Market-Based Standardisation	Government-Based Standardisation
Activator	Any actor who initiates a standardisation committee.	Any actor who releases a solution intended as standard into the market.	Only governmental actors can activate elements of government-based mode. Private actors can lobby them.
Motivations for activation	Increasing the activator's influence on the standardisation process.		Following a policy-related rationale for intervening.
Conditions for successful activation and contribution to process	Willingness to cooperate and sufficient expertise to contribute in committees. Convincing others to also participate.	<i>Producers</i> need sufficient resources to release solutions into the market. <i>Standard users</i> must be willing to adopt solutions given risk of incurring switching costs.	Governments can become active out of their own volition or if convinced by private actors. Several factors help private actors to convince governments: <ul style="list-style-type: none"> • Ability to provide relevant information • Membership of larger groups • Salience of cause to government • Signalling credible threats • Having ties to government

coordination in multi-mode standardisation. Filling these gaps requires further research (see Section 5.1), but we can gain initial insights by recombining existing findings and theorising based on cases that so far have only been considered individually. We do so by relying on an inductive logic and base our insights on the evidence that has already been published, without a pre-conceived theoretical lens.

In Section 4.1, we consider how standardisation ‘cultures’ emerge and are maintained. Section 4.2 examines how individual actors can activate specific new modes of standardisation, given this background. Section 4.3 focuses on timing in multi-mode standardisation, and Section 4.4 looks at the interactions between modes that drive the outcomes of a standardisation process. Combined, these observations imply that multi-mode standardisation is an ongoing process without a clear end point – an idea that we explore in Section 4.5.

4.1. Emergence and maintenance of standardisation ‘Cultures’

As outlined earlier, approaches towards standardisation differ considerably between industry sectors and also between countries (Blind and Gauch, 2008; Büthe and Mattli, 2011; Hawkins, 1999; Tate, 2001). This means that in each sector and country common understandings about the ‘rules of setting the rules’, i.e. about how standards usually emerge and what is seen as a legitimate standard (see Botzem and Dobusch, 2012; Tamm Hallström and Boström, 2010), are likely to exist. An important element of such implicit rules is the roles that co-operation, competition and hierarchy usually play during a standardisation process.

How such implicit rules emerge may be explained by Fligstein and McAdam’s (2012) strategic action field theory. According to this theory, actors establishing new fields attempt to shape the field according to their preferences in dynamic processes. These processes result in a settlement which includes the field’s rules of operation. We expect such a process to also take place when standardisation activities first emerge in a country or in an industry sector, i.e. when a new standardisation field emerges.

As Fligstein and McAdam (2012) note, such processes are also influenced by the new field’s environment. In the standardisation context, at least three factors are likely to be particularly important: (1) At the national level, standardisation often relates to the ‘variety of capitalism’ in a particular country (Tate, 2001). Depending on how business is usually conducted in countries, actors also make different uses of standardisation as a tool (Tate, 2001) and require different types of legitimacy to see a standard as an acceptable solution (see Botzem and Dobusch, 2012; Tamm Hallström and Boström, 2010). This is likely to influence their activities in setting up new standardisation fields. (2) Related to this point, the legal framework and other existing rules (e.g. industry codes of practice) also shape the way in which the modes of standardisation are typically used. For example, the European Union’s ‘New Approach’ (see Borraz, 2007) sets a clear framework for the

relationship between committee- and government-based standardisation in certain areas. New standardisation efforts in areas covered by such legal frameworks are therefore likely to reflect the provisions therein. (3) Following Blind et al.’s (2017) findings about the influence of technological uncertainty on whether government- or committee-based standardisation deliver better results, this is also likely to affect the emergence of a standardisation ‘culture’. They argue that high technological uncertainty is also linked to market uncertainty, implying that the market-based mode may gain a more prominent role in standardising technologically uncertain fields. On the other hand, low technological and market uncertainty may facilitate standardisation in committees and the government-based mode.

Once established, these rules are likely to be enforced by powerful actors in the field and/or governments (see Fligstein and McAdam, 2012) but also to some extent by path-dependence – i.e. actors might stick to approaches to standardisation that have worked in the past, even though better alternatives may be available. Deviating from these rules by activating modes of standardisation that are not yet involved in a field is hence relatively difficult. Nevertheless, doing so can be a good strategic move, as it can offer actors additional avenues to influence standardisation. Furthermore, external shocks, such as technological change and resulting mergers of fields (e.g. because of ICT being integrated into many areas), may put a field in crisis (see Fligstein and McAdam, 2012). Under such circumstances, a new settlement about these ‘rules of setting the rules’ may be required. This leads to a dynamic process, similar to the one that occurs when the field is initially established, to determine new commonly accepted standardisation practices.

4.2. Activating modes of standardisation

We examine how (easily) modes that are normally not involved in a field can be activated. Doing so may provide actors with new strategic options but is subject to certain constraints. Below, we discuss the activation of elements of committee-, market-based (Section 4.2.1), and government-based standardisation (Section 4.2.2). We summarise the key elements of this discussion in Table 4.

4.2.1. Activating market-based and committee-based standardisation

Market-based and committee-based standardisation are predominantly driven and activated by private actors (see Table 2). Farrell and Saloner (1988) assume that each private actor has a choice of joining committees or adopting a solution in the market to signal their commitment. This implies that elements of market-based or committee-based standardisation are activated by the first actor who makes a unilateral decision to seek competition and/or cooperation with others. Indeed, some of the cases cited earlier support this expectation. In the US 2G mobile communication case, Qualcomm initiated a market battle by introducing its solution in the market to compete with the result of

committee-based standardisation (Funk and Methe, 2001; Pelkmans, 2001). In the LAN case, several parties engaged in market-based standardisation before any result had been obtained in committees (von Burg, 2001). In the Java case, Sun activated the committee-based mode by proposing Java as a solution in ISO standardisation (Garud et al., 2002).

These observations make it seem relatively easy for any private actor to invoke elements of market- and/or committee-based standardisation. However, this might be more difficult in reality. When actors try to activate elements of a mode that are usually not involved in standardisation in their institutional context, they might encounter strong resistance. For example, when they involve committees in settings where standards are usually determined in markets, they need to mobilise other actors to cooperate. Activating competition in a standardisation process where standards are usually set through cooperation may undermine the (input) legitimacy which Botzem and Dobusch (2012) and Tamm Hallström and Boström (2010) see as important for standardisation to successfully reach coordination.

Such invocations of a new mode are akin to ‘innovative action’ in Fligstein and McAdam’s (2012) strategic action field theory which may cause an ‘episode of contention’ in a settled field. Whether such action achieves its desired outcome depends on many factors, such as its supporters’ strength and positions in the field or the opponents’ responses (Fligstein and McAdam, 2012). In these contexts, individual actors can only shape the rules if they are sufficiently strong and navigate the field well (Fligstein and McAdam, 2012). Applying Fligstein and McAdam’s (2012) theory to standardisation therefore suggests that actors can only successfully introduce elements of market-based and/or committee-based standardisation if they are in a strong enough position to do so. Unfortunately, extant literature that we are aware of does not provide sufficient evidence about the exact circumstances when this is likely to be successful. Consequently, this is a topic for future research.

4.2.2. Activating government-based standardisation

Contrary to committee- and market-based standardisation, government-based standardisation is driven by public actors (see Table 2). Only governmental actors can thus invoke elements of government-based standardisation themselves. Private actors who want elements of the government-based mode to be involved must therefore first convince the government to intervene. Regardless of whether governments become active out of their own volition or because private actors convince them, the cases documented in literature (see Tables 3B and 3C) suggest that governments will only do so if they see wider policy implications beyond the standard itself. Examples of such policy goals in past cases include building the European Single market (Bekkers, 2001; Borraz, 2007; Pelkmans, 2001), supporting defence activities (Rosen et al., 1988), ensuring financial markets’ stability (Büthe and Mattli, 2011; Hail et al., 2010; Tamm Hallström, 2004), promoting energy efficiency (de Vries and Verhagen, 2016), and promoting national industries (Gao et al., 2014; Gao, 2014).

This implies that private actors must provide a clear policy-related rationale to persuade governments to intervene. Both cases of successful and failed attempts to involve government have been documented, for example by David (1992), David and Bunn (1988), Gao et al. (2014), and Gao (2014). Standardisation literature offers no insights into the reasons for these successes or failures, but the findings in other streams of literature may apply in this context. Literature on lobbying and regulatory capture argues that private actors who successfully convince governments of a point of view are those who (1) can provide information that is needed by governmental actors (Bouwen, 2002; Dal Bó, 2006); (2) belong to larger groups arguing for the same cause (Klüver, 2011; Mahoney, 2007); and/or (3) have a cause which is salient to the government (Klüver, 2011). In addition, also those who signal credible threats, e.g. about legal action against government decisions, may successfully convince governments to act in line with their preferences (Dal Bó, 2006; Schmidt, 2002). Strategic action field theory

offers an alternative explanation. It argues that important players who dominate a field (referred to as ‘incumbents’) often have close ties to the government and are able to enlist its support if their dominance is threatened (Fligstein and McAdam, 2012). A recent example of this is the European Commission’s response to car makers’ pressure to weaken emission standards following the Volkswagen Diesel scandal (Neslen, 2015). This would also explain how governments choose which specific solutions to support when they intervene out of their own volition. For example, in the GSM case, national governments supported specific solutions that were designed by incumbents in their national telecommunications industries (Bekkers, 2001; Pelkmans, 2001). Another example is the competition between accounting standards where support for US GAAP from important American actors influenced the US government’s decision not to endorse IFRS standards (Hail et al., 2010). Of course, the difficulty of invoking government into a standardisation process is also likely to vary based on national standardisation ‘cultures’ which determine what role governments typically play and how legitimate their activities are perceived.

4.3. Timing in multi-mode standardisation

In addition to the combination of standardisation modes that constitute a standardisation process, the timing in which they occur is another key feature. While government-based standardisation can occur at any time, successful committee- and market-based standardisation are linked to distinct phases in the standardisation process (see Table 2). This suggests that elements of these modes can only be used at certain times and that there is a clear sequence to be followed. Such a clear sequence can be observed in some multi-mode cases (e.g. Wi-Fi vs. Home RF – see van den Ende et al., 2012), but this is not always the case.

Botzem and Dobusch (2012) see standardisation as a recursive process where each cycle of development and diffusion is followed by another, and events in the previous cycle influence what happens in the next cycle. This idea is supported by the Java standardisation case where a de-facto standard first emerged in the market before committees were involved (Garud et al., 2002). In addition, elements of the modes may also occur in parallel. The dynamic interactions between elements of these modes discussed in Section 3.2.1 (see Farrell and Saloner, 1988; van Wegberg, 2004; Vercoelen and van Wegberg, 1998) rely on the assumption that elements of market-based and committee-based standardisation can occur simultaneously, which has been documented in the Blu-Ray vs. HD-DVD case (see den Uijl and de Vries, 2013). The intensity with which the different modes influence the process may vary at different stages. For example, in the development of international accounting standards, the government-based mode’s impact was very pronounced at several key points when governments passed new rules which impacted on standard development in committees (see Büthe and Mattli, 2011). During other stages in the process, government’s role was less pronounced (Büthe and Mattli, 2011).

This implies that there is a large variety in timing of multi-mode standardisation processes and that elements of the different modes can impact a process in many different sequences. Although varying this sequence from the usual one in a specific institutional setting is likely to lead to similar resistance as introducing entirely new modes (see Section 4.2), this further expands the number of strategic options for actors in the process. We discuss the consequences of varying the sequence of a standardisation process below.

4.4. Interactions between modes in multi-mode standardisation processes

As we already found in existing literature, the modes of standardisation interact with each other dynamically. Within these interactions, they can fulfil different functions, such as creating different types of legitimacy (see Botzem and Dobusch, 2012; Tamm Hallström and Boström, 2010), facilitating agreement among actors with different

Table 5
Interactions between modes.

	Impact on	In early stages of process	In late stages of process
Committee-Based Standardisation	Market-Based Standardisation	<ul style="list-style-type: none"> ● Providing guidance to standard users before large-scale implementation ● Facilitating agreement between producers, thus avoiding market-battles ● Providing the basis for government procurement 	
	Government-Based Standardisation		<ul style="list-style-type: none"> ● Providing post-hoc input legitimacy for standards chosen in market ● Building support for challenging established standards ● Keeping standard specifications up-to-date and providing platform for standard maintenance
Market-Based Standardisation	Committee-Based Standardisation	<ul style="list-style-type: none"> ● Signalling commitment to committees 	
	Government-Based Standardisation	<ul style="list-style-type: none"> ● Building installed bases for solutions ● Signalling commitment to governments 	<ul style="list-style-type: none"> ● Challenging standards chosen in committees
Government-Based Standardisation	Committee-Based Standardisation	In national standardisation: <ul style="list-style-type: none"> ● Resolving wars of attrition ● Creating conditions in favour of proposed solutions ● Raising actors' stakes in committees if committee-based standard could become mandatory In international standardisation	
	Market-Based Standardisation	Jointly developing international governmental standards In national standardisation: <ul style="list-style-type: none"> ● Resolving wars of attrition ● Creating conditions in favour of proposed solutions In international standardisation: <ul style="list-style-type: none"> ● Building installed bases in national markets 	

interests, building an installed base for a solution, or providing a process for ensuring regular updates of the standard.

In this section, we recombine observations from the literature to generate tentative new insights into these interactions that go beyond what has been theorised so far. To do so, we consider ways in which elements of each mode can impact parallel and/or subsequent developments in other modes. We first consider the interactions between the committee- and market-based modes (Section 4.4.1). Section 4.4.2 discusses the potential impact of the government-based mode in multi-mode standardisation. Section 4.4.3 examines three-way interactions that are likely to occur in cases involving all three modes. Table 5 summarises the key points of this section.

4.4.1. Interactions between committees and markets

When there is no government involvement, standards emerge in one or both of the other modes. We focus on situations involving both committees and markets. In such cases, committees and markets are strongly mutually dependent.

Actors in markets may look for guidance from committees regarding the eventual solution to be chosen as a standard. Although standards developed in committees are voluntary (e.g. de Vries, 1999; Mattli and Büthe, 2003), markets often follow committees' choices of standards because these decisions signal support by many important players, resulting in a bandwagon effect (e.g. Delcamp and Leiponen, 2014) and legitimising solutions (Botzem and Dobusch, 2012; Garud et al., 2002; Tamm Hallström and Boström, 2010). Absence of such clear signals from committees can lead to very fragmented markets as Meyer (2012,

pp. 134–165) observed in the case of container sizes for European intermodal transportation. Failure to reach a decision on a standard in committees may therefore also contribute to several solutions continuing to exist in parallel in the market. This is a factor contributing to no de-facto standard emerging, adding to the ones identified by Techatassanasoontorn and Suo (2011) and de Vries et al. (2011).

The voluntary nature of committee-based standards also means that markets can be used to challenge a standard chosen in a committee if an actor is dissatisfied with it. Once a committee has agreed on a standard, its actual use and implementation is up to the choices of actors in the market. Because coordination is only reached if actors use a common solution, the diffusion in the market confirms or overrules the decision made in a committee. The cases of USB vs. FireWire (van den Ende et al., 2012) and 2G mobile telecommunications (Funk and Methe, 2001; Gandal et al., 2003; Pelkmans, 2001) show that standards developed by SDOs can still become one solution competing with others in a market battle. Support from an SDO may then be a key factor in such a market battle but is neither necessary nor sufficient for emerging as the common solution.

Since acceptance in the market is eventually decisive for a standard to reach its goal of coordination, actors in committees can be heavily influenced by parallel or earlier developments in the market. A solution's installed base sends strong signals of commitment (Blind, 2011; Egyedi and Koppenhol, 2010; Farrell and Saloner, 1988; Garud et al., 2002). Committees may also be involved *after* a de-facto standard has been chosen in the market to make it acceptable to users who require high degrees of input legitimacy (e.g. Microsoft in the office document

format case (Blind, 2011; Egyedi and Koppenhol, 2010) and Sun in the Java case (Garud et al., 2002)). Furthermore, it is also conceivable that an actor uses the committee-based mode to build broad support for a new solution that challenges one which previously emerged as the de facto standard.

4.4.2. Interactions involving governments

Governments' hierarchical position enables them to decide standardisation processes and resolve wars of attrition if they have legislative power over the entire geographic area for which the standard is developed. This means that governments choosing and enforcing a solution is decisive, even if this choice is not aligned with other actors' preferences. This solution will then remain in place unless the government reverses its decision (possibly due to lobbying).

Not only do governments impact on developments in markets or committees, the reverse direction of influence has also been observed. In several cases, such as GSM (Bekkers, 2001; Pelkmans, 2001), TD-SCDMA (Gao et al., 2014; Gao, 2014), and the competition between accounting standards (Hail et al., 2010), specific government interventions were reactions to events in the committee- and/or market-based modes. In addition to such ad-hoc influences, the literature also documents two institutionalised ways in which committees' decisions have implications for the outcomes of governments' involvement: (1) the European "New Approach" (Borraz, 2007) and (2) governments' preference to refer to committee-based standards in their procurement (Edler and Georghiou, 2007; Rosen et al., 1988). Such fixed avenues of influencing government policy through committee-based standardisation suggest that multi-mode standardisation opens up avenues for regulatory capture (see e.g. Dal Bó, 2006; Laffont and Tirole, 1991). This is because participating in committees gives more direct influence on the outcome of a standardisation process than lobbying governments, especially in more mature markets (Blind et al., 2017). Blind et al. (2017) find that committee-based standardisation is more prone to providing a basis for regulatory capture when technological uncertainty is low. This suggests that this effect also relates to timing. Standardisation processes often coincide with a technology's development and thus also with decreasing technological uncertainty. Using committee-based standardisation as a tool to influence government policy may therefore be most effective in a standardisation process's later stages.

The observations made so far in this section apply to the national level of standardisation. At the transnational level, actors with hierarchical positions similar to those of governments rarely exist (the European Commission being a notable exception). In cases where governments want to contribute to transnational standardisation, they can make use of the cooperative or competitive coordination mechanisms. Governments can jointly develop standards in international organisations, such as the FAO (Food and Agriculture Organization of the United Nations, which develops the Codex Alimentarius food safety standards), and may then commit themselves to using their hierarchical position to enforce the resulting standard at the national level (Büthe and Mattli, 2011, 2010). Alternatively, their interventions in national markets (through hierarchy or purchasing power – see Edler and Georghiou, 2007; Funk and Methe, 2001; Rosen et al., 1988) either directly build a solution's installed base, or signal that a large installed base of a solution can be expected to develop in a country. Funk and Methe (2001) find that this may significantly impact transnational standardisation because other governments or actors in committees or in other countries' markets may choose a solution which has such an (expected) installed base.

4.4.3. Interactions between all three modes of standardisation

In addition to these direct interactions between pairs of standardisation modes, activities within one mode of standardisation may also

have a 'moderating' effect on the dynamics between the other two modes. For example, actions by the government can have a direct effect on committee- and/or market-based standardisation but may also change the interactions between these two modes. This would further add to the potential dynamics that occur in multi-mode standardisation. Extant literature provides two examples of such 'moderating effects'. (1) Meyer (2012) argues that the European Commission's early intervention into the 2G and 3G mobile telecommunication standardisation prevented interactions between committee- and market-based standardisation that were observed in the parallel US standardisation process. However, other types of government intervention can also raise actors' stakes in standardisation and make standardisation processes more contested (Meyer, 2012). This could potentially lead actors to engage in committees and markets simultaneously to improve the chances of their solution emerging as the standard. (2) Governments often rely on standards which emerge from committees in their procurement (e.g. Edler and Georghiou, 2007; Rosen et al., 1988). In cases where governments intervene in market battles through procurement, doing so means that the results of committee-based standardisation also influence the interactions between markets and governments.

In addition to a mode influencing the relationship between the remaining two modes, the dynamics of this relationship may also impact what happens within that mode (i.e. the causality may exist in both directions). Like the interactions between pairs of modes, these relationships are likely to be reciprocal and potentially highly dynamic. For example, actors who anticipate that governments will intervene in market battles may engage in relevant committees to ensure that the resulting standards reflect their preferences (see Blind and Mangelsdorf, 2016). Another example would be government intervening in a standardisation process in response to interactions between the committee- and market-based modes which lead to an unsatisfactory result of the standardisation process, as observed in the case of e-mobility charging plugs in Europe (see Bakker et al., 2015).

Although these examples on their own cannot be generalised, they point towards an additional potentially important feature of multi-mode standardisation that has so far not been documented in the literature. It is likely that the dynamics in multi-mode standardisation also include indirect effects, where the activities in one mode affect the dynamics that unfold between the other two modes and vice versa.

4.5. Multi-mode standardisation as an ongoing process

The ways in which the modes can impact on each other discussed so far provide actors with a large number of strategic options. Which options they apply and what impact they have on a standardisation process depends on their individual strategies. This raises the question, how to reach a balance among these interactions and which elements will eventually be decisive for the results.

We can already identify two factors that influence the relative importance of the modes in a process: (1) The standardisation 'culture' in a country and/or sector is likely to impact on each mode's importance (see Section 4.1). (2) Actors' available resources and knowledge. Effectively participating in market-based standardisation as a producer requires substantial investments, e.g. in production capacities or marketing (e.g. den Uijl, 2015; van de Kaa et al., 2011; see also von Burg, 2001, pp. 78–99). It also requires standard implementers and users who are willing to invest in building up installed bases and to bear the switching costs in case they made the 'wrong bet' (e.g. Belleflamme, 2002). Participating in committee-based standardisation also requires investments, e.g. costs for experts who can represent an actor, but they are usually much lower compared to those needed for participating in market-based standardisation. The resources and knowledge needed for effectively influencing the government-based mode are likely to lie in between the other two.

Lobbying government does not require large investments in production facilities but the logic of influence on the result is less straightforward than in committees and the outcomes are more uncertain. Government- and especially market-based standardisation are therefore likely to become relatively more important in a multi-mode standardisation process if actors are willing and able to spend the necessary resources and use them effectively.

Neither of these two factors is likely to be static. In the medium- to long-term, the standardisation ‘culture’ in a field can change if it is challenged by sufficiently strong actors, or if it needs to adapt to outside shocks. In the short-term, available resources and knowledge can also fluctuate, e.g. because actors acquire them or because actors join or leave the standardisation process. This suggests that the relative weights of the modes can change throughout the process, as was observed in the development of international accounting standards (see Bütthe and Mattli, 2011).

Such changes and the options to challenge coordination outcomes identified above also imply that multi-mode standardisation is potentially indefinitely ongoing, rather than a definite process as assumed in the ideal-typical views. Where extant literature already considers standardisation as an ongoing process, it mainly focuses on efforts in committees to extend or maintain standards (Botzem and Dobusch, 2012; Egyedi and Blind, 2008; Jain, 2012) or on work in committees to replace existing standards when technological change makes them obsolete (Egyedi and Blind, 2008).

Instead of being the end point to a process, an established standard is a situation with a short-term equilibrium between the involved actors, i.e. where, for the time being, no actor attempts to challenge the status quo. An established standard therefore resembles a settled strategic action field (see Fligstein and McAdam, 2012). Such a settlement can be challenged at any time. The interactions between standardisation modes discussed above and the potentially shifting weights of the modes in a standardisation process mean that actors can launch new activities in one or multiple modes that then may affect on other modes and the overall standardisation process.

To sum up, standardisation is therefore not only an ongoing process because standards need to be updated regularly, as already acknowledged in extant literature, but also because actors may disagree with an established standard and challenge it. The objective of coordination is thus only reached if no actor challenges the standard successfully. The success of such activities is likely to depend on a range of factors, such as the standardisation ‘culture’ in the field, the environment in which the standardisation process takes place, the challenging actor’s resources and knowledge, and other actors’ willingness to defend the standard.

5. Conclusions and agenda for further research

Standardisation is vital for driving forward the major current trends related to smart systems and platforms. Due to these systems’ complexity and variety of involved stakeholders, we expect multi-mode standardisation to become increasingly prevalent. This means that a better understanding of the phenomenon is needed. Although such multi-mode standardisation processes can be expected to have case-specific dynamics, these dynamics are likely to result from combinations of certain underlying features related to the ideal-typical modes of standardisation. Our work provides the basis for further research into these features by adding three major contributions to the literature. (1) We crystallise the three modes underlying standardisation processes and their defining characteristics (coordination mechanisms, timing of coordination, main actors driving the process, avenues of influence, inclusiveness in standard development). (2) We provide an overview of the available literature on the interactions between these modes and identify its gaps. (3) We recombine the evidence from this literature to generate tentative insights, beyond what has been documented in literature so far, into the interactions and dynamics that are likely to occur in multi-mode standardisation.

These interactions and dynamics are summarised in Fig. 2.⁹ In addition to the direct interactions between modes that are already evident from existing literature, we also expect developments in each mode to have a reciprocal impact on the dynamics between the other two modes. Because each mode of standardisation offers an ‘avenue’ for actors to contribute to a standardisation process, these actors’ actions drive the dynamics in multi-mode standardisation. Actors can activate new modes at various points in the process (although this is subject to limitations related to the field’s standardisation ‘culture’ and relies on their ability to wield sufficient influence over the field). Once a mode has been activated, every actor can decide whether to engage in this mode and how to use the opportunities for manoeuvring that it offers. These complex dynamics occur against the backdrop of the field’s standardisation ‘culture’ and institutional context. This backdrop has an important impact on the degree to which actors can rely on certain modes of standardisation, whether their activities within the modes are perceived as legitimate and how the developments within the modes affect each other. A further element of this backdrop is the technological context (which relates both to the technology’s complexity and the degree of uncertainty of its development) in which the standard is developed. Compared to the standardisation ‘culture’ and the institutional context, extant literature offers a weaker base for theorising about the technological context’s impact on multi-mode standardisation processes, making this a first area for further research.

These findings establish the elements that are likely to be key for multi-mode standardisation processes, and provide a good basis for further research into this important phenomenon. All the elements included in Fig. 2 require further enquiry, as outlined in the agenda for research in Section 5.1. Furthermore, our findings already lead to some recommendations for practitioners, see Section 5.2.

5.1. Implications for theory and agenda for further research

Multi-mode standardisation is likely to shape the dynamics of standardisation and major technological and social developments in the future. Theory about standardisation needs to reflect this better. We propose that additional research should approach multi-mode standardisation from three perspectives: (1) dynamics of multi-mode standardisation processes and how they contribute to coordination; (2) strategies for individual actors; and (3) the role of governments and other facilitating actors like SDOs. Generating an understanding based on these three perspectives will also provide a foundation for evaluating the impact of multi-mode standardisation on business and society, which represents a fourth area of research.

The first suggested area for research could look in more detail into the processes leading to the emergence of new standards. As outlined in Section 4.3, multi-mode standardisation processes are highly dynamic but current literature does not provide sufficient evidence about the interactions in these processes. Using a theoretical angle from sociology, such as Fligstein and McAdam’s (2012) strategic action fields, may help to get a better grasp of these processes. Topics that need to be considered in this context include the specific roles that actors can play (e.g. in terms of designing and selecting solutions), the exact mechanisms behind the interactions between modes of standardisation, and the conditions under which multi-mode standardisation leads to one or multiple competing standards.

The second area for research could investigate how multi-mode standardisation affects individual actors and their strategies and how they drive collective action. This research should aim to understand how individual actors navigate around these processes to reach their goals. Engaging in multiple modes gives actors a large number of potential ways to influence the standardisation outcome but may also involve

⁹ Blue lines signify elements that have already been acknowledged in previous literature. Orange lines represent new elements that arise from our discussion.

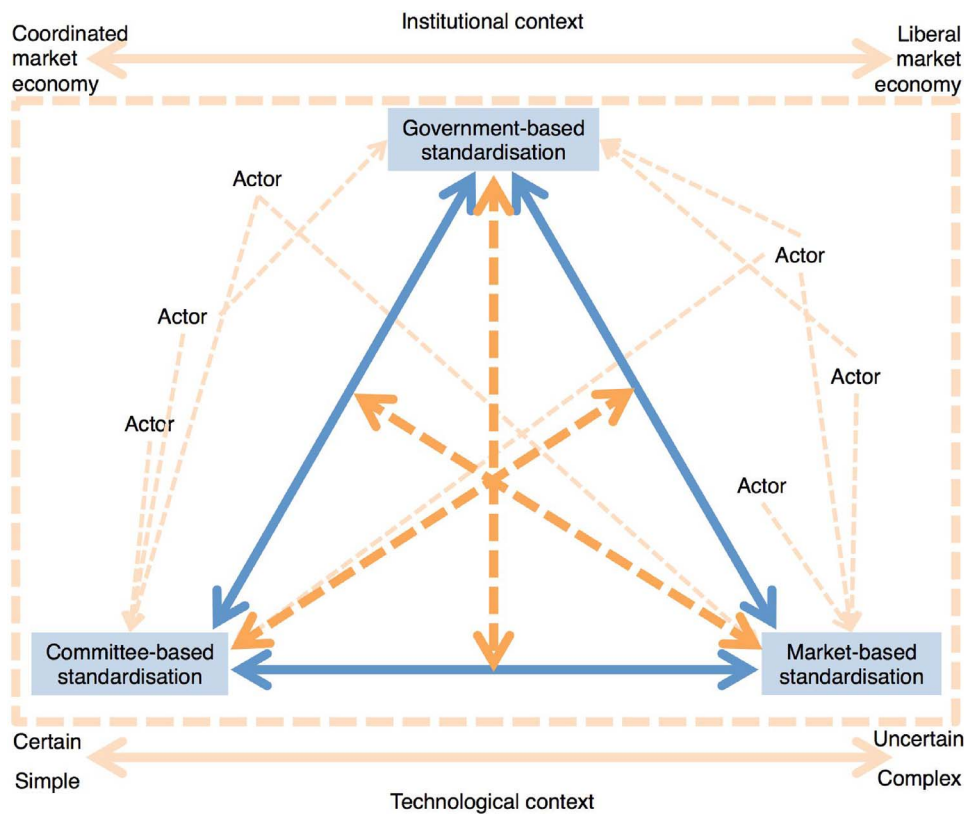


Fig. 2. Interactions in multi-mode standardisation.

substantial costs and hurdles. Nevertheless, it remains unclear under which conditions the benefits of using these possibilities outweigh the costs. Such research could focus on success factors in multi-mode standardisation (building on the literature that investigates them in a single-mode context). Other potentially useful theoretical angles for this topic include again strategic action fields (see [Fligstein and McAdam, 2012](#)), focusing on the activities of individual actors within a field instead of the entire field's development; or the resource-based, knowledge-based and relational views ([Dyer and Singh, 1998](#); [Grant, 1996](#); [Lavie, 2006](#); [Wernerfelt, 1984](#)). It would be particularly interesting to explore which resources, knowledge, and relationships organisations require to participate successfully in multi-mode standardisation.

A third promising avenue of research could focus on the role of governments and other facilitating actors. As [Ho and O'Sullivan \(2017\)](#) note, the increasing complexity in standardisation requires actors who can support standardisation processes. Diverse roles of governments have been documented (see Sections 3.2 and 4) but a systematic overview is lacking. As a first step, a more complete review of national strategies towards standardisation is needed. Such research could build on [Tate's \(2001\)](#) work. The resulting typology could serve as input for investigations into the effects of government intervention in multi-mode standardisation. Topics could include what government activities best support standardisation processes, whether the outcomes contribute to promoting national industries, and whether government involvement in multi-mode standardisation can promote a country's position in international competition. Such research could also consider non-economic effects, such as how interventions impact large societal and technological innovations. In addition to looking at the roles of government in this process, this research could also take into account other actors, such as SDOs, industry associations or powerful individual actors (in line with [Lessig, 2000](#); [Lessig, 1999](#) idea that 'code is law'), and their contributions to managing and steering multi-mode standardisation processes.

Another relevant area of study is the role of different modes of standardisation in regulatory relief. Existing literature identifies

standardisation as a way for business to reduce the burden of regulation (e.g. [Schmidt, 2002](#); [Wätzold et al., 2001](#)) but does not consider the option of multi-mode standardisation in this context. It would be interesting to investigate how the three modes influence each other in setting rules that might replace or complement regulation. In such situations, the various interactions between government-based standardisation and the other modes (see Fig. 2) may provide ample opportunities for private actors to increase the chances that government policy reflects their special interests. Theories on regulatory capture (see e.g. [Dal Bó, 2006](#); [Laffont and Tirole, 1991](#)) could therefore provide a particularly relevant theoretical background for studies related to these topics.

As mentioned above, developing theory on multi-mode standardisation in this manner would provide a basis for better understanding the effect of standardisation on large social and technological changes. Although the literature already acknowledges the need for standardisation to make these large scale innovations happen, the findings from the research we outline above might be integrated into theoretical approaches, such as [Geels, 2004](#); [Geels, 2002](#) socio-technical transitions. This could help to find out how different configurations of standardisation processes (e.g. in terms of the involved modes, the sequence in which they get involved, or their contributions' relative importance for the process) can support or hinder major change, e.g. by affecting legitimacy, speed or technological development. In line with [Blind et al.'s \(2017\)](#) finding that the effectiveness of individual modes depends on the technological context, such research needs to study multi-mode standardisation in various technological and institutional settings. The effectiveness with which specific configurations of modes can support or hinder such change is very likely to depend on the context in which a standardisation process takes place. An analysis of the welfare implications is also needed. While many academic and non-academic studies (e.g. [Blind, 2004](#); [Blind and Jungmittag, 2008](#); [Swann, 2010](#)) have already assessed this for single mode standardisation, it remains unknown whether the developments discussed in this paper make a difference in this regard.

5.2. Implications for practice

In addition to the implications for theory building, our results are also relevant for practice. Anyone who has a stake in the ongoing large social and technological changes is likely to be affected by the outcome of standardisation processes which we expect to be or become multi-modal in many cases. Industrial actors, trade associations, NGOs and research organisations should therefore all be aware of how standards emerge.¹⁰ If they decide to participate in the process, they should consider the large variety of options that multi-mode standardisation offers for their strategies. Activating more than one standardisation mode (e.g. by lobbying governments to intervene) requires sufficient knowledge and resources. On the other hand, the discussion in Section 4 shows that actors who do so gain a large variety of options to influence standardisation, some of which only arise at certain stages of the process. To apply these options as part of a coherent strategy, actors should be aware of the dynamics that are likely to result from this. Even if stakeholders decide against activating certain modes, they need to be prepared for their competitors' actions. They should consider carefully whether to follow into new modes, and avoid being blindsided by influences resulting from modes in which they are not active.

SDOs need to shape their procedures in such a way that they are responsive to influences from other modes and attractive for stakeholders who have the choice between engaging in committee-based standardisation and other modes. They also need to be prepared for intensified competition within the committee-based mode, e.g. because SDOs from other fields (e.g. ICT) are becoming potentially suitable forums for standard development, or because of the emergence of new actors like open-source communities. Strategies to remain relevant in this context could include managing standardisation projects in such a way that standards are not only developed and approved but their implementation is stimulated and supported as well. Moreover, SDOs could emphasise their strengths, such as being able to facilitate cooperation and agreement among diverse groups of stakeholders, and could focus their contributions where these strengths are most important. For example, SDOs could promote committee work to define overarching frameworks and architectures for new large systems which support activities in the market to establish standards for the individual elements within them. Where solutions that meet SDOs' requirements for a standard have already emerged in the market, it may be sensible to absorb them into a formal standard to avoid duplicating efforts, as observed in Section 4. Similar implications are likely to apply to other organisations which pursue committee-based standardisation activities, such as communities of practice or open source communities, and which also need to attract contributors and ensure that their solutions are widely implemented.

Governmental policymakers can use our findings in using standardisation to support policy and/or when they consider intervening in standardisation, especially where there are strong opposed interests and considerable societal implications. Standards that are used to support policy (e.g. under the "New Approach") mostly come from formal SDOs in the committee-based mode. The importance of market-based standardisation in some areas suggests that governments may also benefit from incorporating them into their policy, instead of fostering the development of new committee-based standards in addition to pre-existing de-facto standards. Especially in contexts of complex systems, where standards do not stand alone but need to be aligned, this may prevent fragmentation. When governments intervene in ongoing standardisation projects, non-hierarchical intervention is preferable (see Meyer, 2012), but this requires timely identification of the problem. Hierarchical intervention may therefore be needed as a last resort when markets and committees are likely to lead to unsatisfactory results.

¹⁰ For researchers, having knowledge of standardisation processes may also be beneficial when applying for funding in programmes that support standardisation as a means of disseminating research results.

Acknowledgements

We would like to thank the editor, Martin Kenney, and four anonymous reviewers for their insightful comments and their patience throughout the revision process. In our opinion, we were able to improve the paper substantially, thanks to their ideas. We also thank Ursula Lohr-Wiegmann for her support and our colleagues at the Department of Technology and Operations Management at Rotterdam School of Management, Erasmus University for their advice on how to take this paper through the review process. Errors and omissions remain the responsibility of the authors. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

- Abbate, J., 2001. Government, business, and the making of the internet. *Bus. Hist. Rev.* 75, 147–176.
- Axelrod, R., Mitchell, W., Thomas, R.E., Bennett, D.S., Bruderer, E., 1995. Coalition formation in standard-setting alliances. *Manage. Sci.* 41, 1493–1508.
- Büthe, T., Mattli, W., 2010. International standards and standard-setting bodies. In: Coen, D., Grant, W., Wilson, G. (Eds.), *The Oxford Handbook of Business and Government*. Oxford University Press, Oxford, pp. 440–471.
- Büthe, T., Mattli, W., 2011. *The New Global Rulers*. Princeton University Press, Princeton, NJ.
- BMW, 2016. WIPANO [WWW Document]. URL <http://www.bmw.de/DE/Themen/Technologie/Rahmenbedingungen/patente,did=774168.html> (Accessed 29 July 2016).
- Bakker, S., Leguijt, P., van Lente, H., 2015. Niche accumulation and standardization—the case of electric vehicle recharging plugs. *J. Clean. Prod.* 94, 155–164. <http://dx.doi.org/10.1016/j.jclepro.2015.01.069>.
- Bekkers, R., 2001. *Mobile Telecommunications Standards: UMTS, GSM, TETRA, and ERMES*. Artech House, Boston, MA.
- Belleflamme, P., 2002. Coordination on formal vs. de facto standards: a dynamic approach. *Eur. J. Polit. Econ.* 18, 153–176. [http://dx.doi.org/10.1016/S0176-2680\(01\)00073-8](http://dx.doi.org/10.1016/S0176-2680(01)00073-8).
- Besen, S.M., Farrell, J., 1994. Choosing how to compete: strategies and tactics in standardization. *J. Econ. Perspect.* 8, 117–131. <http://dx.doi.org/10.1257/jep.8.2.117>.
- Blind, K., Gauch, S., 2008. Trends in ICT standards: the relationship between European standardisation bodies and standards consortia. *Telecomm. Policy* 32, 503–513. <http://dx.doi.org/10.1016/j.telpol.2008.05.004>.
- Blind, K., Jungmittag, A., 2008. The impact of patents and standards on macroeconomic growth: a panel approach covering four countries and 12 sectors. *J. Product. Anal.* 29, 51–60. <http://dx.doi.org/10.1007/s11223-007-0060-8>.
- Blind, K., Mangelsdorf, A., 2016. Motives to standardize: empirical evidence from Germany. *Technovation* 48–49, 13–24. <http://dx.doi.org/10.1016/j.technovation.2016.01.001>.
- Blind, K., Petersen, S.S., Riillo, C.A.F., 2017. The impact of standards and regulation on innovation in uncertain markets. *Res. Policy* 46, 249–264. <http://dx.doi.org/10.1016/j.respol.2016.11.003>.
- Blind, K., 2002. Driving forces for standardization at standardization development organizations. *Appl. Econ.* 34, 1985–1998. <http://dx.doi.org/10.1080/0003684011011115>.
- Blind, K., 2004. *The Economics of Standards – Theory, Evidence, Policy*. Edward Elgar, Cheltenham.
- Blind, K., 2006. Explanatory factors for participation in formal standardisation processes: empirical evidence at firm level. *Econ. Innov. New Technol.* 15, 157–170. <http://dx.doi.org/10.1080/10438590500143970>.
- Blind, K., 2011. An economic analysis of standards competition: the example of the ISO ODF and OOXML standards. *Telecomm. Policy* 35, 373–381. <http://dx.doi.org/10.1016/j.telpol.2011.02.007>.
- Borraz, O., 2007. Governing standards: the rise of standardization processes in France and in the EU. *Governance* 20, 57–84. <http://dx.doi.org/10.1111/j.1468-0491.2007.00344.x>.
- Boström, M., Tamm Hallström, K., 2010. NGO power in global social and environmental standard-setting. *Glob. Environ. Polit.* 10, 36–59. http://dx.doi.org/10.1162/GLEP_a.00030.
- Botzem, S., Dobusch, L., 2012. Standardization cycles: a process perspective on the formation and diffusion of transnational standards. *Organ. Stud.* 33, 737–762. <http://dx.doi.org/10.1177/0170840612443626>.
- Bouwen, P., 2002. Corporate lobbying in the European Union: the logic of access. *J. Eur. Public Policy* 9, 365–390. <http://dx.doi.org/10.1080/13501760210138796>.
- Brunsson, N., Rasche, A., Seidl, D., 2012. The dynamics of standardization: three perspectives on standards in organization studies. *Organ. Stud.* 33, 613–632. <http://dx.doi.org/10.1177/0170840612450120>.
- CBI, DTI, BSI, n.d. National Standardization Strategic Framework [WWW Document]. URL <http://www.strategicstandards.com/files/UK.pdf> (Accessed 28 July 2016).
- CEN/CENELEC, 2017. Work Programme 2017 [WWW Document]. URL http://www.cenelec.eu/News/Publications/Publications/cen-cenelec-wp2017_en.pdf (Accessed 17 January 2017).
- CNIS, 2016. China Releases Five-Year Plan for National Standardization System [WWW

- Document]. URL http://en.cnis.gov.cn/xwtd/bzhdt/201601/t20160127_21286.shtml (Accessed 28 July 2016).
- Cabral, L.M.B., Kretschmer, T., 2007. Standards battles and public policy. In: Greenstein, S., Stango, V. (Eds.), *Standards and Public Policy*. Cambridge University Press, Cambridge, pp. 329–344.
- Cabral, L.M.B., Salant, D., 2014. Evolving technologies and standards regulation. *Int. J. Ind. Organ.* 36, 48–56. <http://dx.doi.org/10.1016/j.ijindorg.2013.07.006>.
- Chiao, P., Lerner, J., Tirole, J., 2007. The rules of standard-setting organizations: an empirical analysis. *RAND J. Econ.* 38, 905–930. <http://dx.doi.org/10.1111/j.0741-6261.2007.00118.x>.
- Choi, D., 2016. The 4th National Standards Plan 2016–2020.
- Chuang, L.H., 2016. Chinese standardization system: past history, current status, future challenges. In: Jakobs, K., Mione, A., Cutting-Decelle, A.-F., Mignon, S. (Eds.), *EURAS Proceedings 2016 – Co-Optation and Open Innovation*. Wissenschaftsverlag Mainz, Aachen, pp. 105–121.
- Cusumano, M.A., Mylonadis, Y., Rosenbloom, R.S., 1992. Strategic maneuvering and mass-market dynamics: the triumph of VHS over beta. *Bus. Hist. Rev.* 66, 51–94.
- Dal Bó, E., 2006. Regulatory capture: a review. *Oxford Rev. Econ. Policy* 22, 203–225. <http://dx.doi.org/10.1093/oxrep/grj013>.
- David, P.A., Bunn, J.A., 1988. The economics of gateway technologies and network evolution: lessons from electricity supply history. *Inf. Econ. Policy* 3, 165–202. [http://dx.doi.org/10.1016/0167-6245\(88\)90024-8](http://dx.doi.org/10.1016/0167-6245(88)90024-8).
- David, P.A., Greenstein, S.M., 1990. The economics of compatibility standards: An introduction to recent research. *Econ. Innov. New Technol.* 1, 3–41.
- David, P.A., 1992. Heroes, herds and hysteresis in technological history: Thomas Edison and the battle of the systems reconsidered. *Ind. Corp. Chang.* 1, 129–180. <http://dx.doi.org/10.1093/icc/1.1.129>.
- Delcamp, H., Leiponen, A.E., 2014. Innovating standards through informal consortia: the case of wireless telecommunications. *Int. J. Ind. Organ.* 36, 36–47. <http://dx.doi.org/10.1016/j.ijindorg.2013.07.004>.
- Delmas, M., Montiel, I., 2008. The diffusion of voluntary international management standards: responsible care, ISO 9000, and ISO 14001 in the chemical industry. *Policy Stud. J.* 36, 65–93. <http://dx.doi.org/10.1111/j.1541-0072.2007.00254.x>.
- Deutsche Bundesregierung, 2009. Normungspolitisches Konzept der Bundesregierung [WWW Document]. URL <https://www.bmwi.de/BMWi/Redaktion/PDF/M-O/normungspolitisches-konzept-der-bundesregierung,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf> (Accessed 28 July 2016).
- de Vries, H.J., Hendrikse, G.W.J., 2001. The dutch banking chipcard game. *Int. Stud. Manag. Organ.* 31, 106–125.
- de Vries, H.J., Verhagen, W.P., 2016. Impact of changes in regulatory performance standards on innovation: a case of energy performance standards for newly-built houses. *Technovation* 48–49, 56–68. <http://dx.doi.org/10.1016/j.technovation.2016.01.008>.
- de Vries, H., de Vries, H.J., Oshri, I., 2008. Standards Battles in Open Source Software – The Case of Firefox. Palgrave Macmillan, Basingstoke.
- 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. CEN/CENELEC, Brussels.
- de Vries, H.J., de Ruijter, J.P.M., Argam, N., 2011. Dominant design or multiple designs: the flash memory card case. *Technol. Anal. Strateg. Manag.* 23, 249–262. <http://dx.doi.org/10.1080/09537325.2011.550393>.
- de Vries, H.J., 1999. *Standardization – A Business Approach to the Role of National Standardization Organizations*. Kluwer Academic Publishers, Boston, Dordrecht, London.
- de Vries, H.J., 2006. Competing e-purse systems: a standards battle. *J. Cases Inf. Technol.* 8, 1–15.
- de Vries, H.J., 2010. Fundamentals of standards and standardization. In: Hesser, W. (Ed.), *Standardisation in Companies and Markets*. Helmut Schmidt University, Hamburg, pp. 1–44.
- den Uijl, S., de Vries, H.J., 2013. Pushing technological progress by strategic manoeuvring: the triumph of Blu-ray over HD-DVD. *Bus. Hist.* 55, 1361–1384. <http://dx.doi.org/10.1080/00076791.2013.771332>.
- den Uijl, S., 2015. The Emergence of De-Facto Standards. Erasmus Research Institute of Management (ERIM), Rotterdam.
- Dyer, J.H., Singh, H., 1998. The relational view: cooperative strategy and sources of interorganizational competitive advantage. *Acad. Manag. Rev.* 23, 660–679. <http://dx.doi.org/10.5465/AMR.1998.1255632>.
- Edler, J., Georgiou, L., 2007. Public procurement and innovation – resurrecting the demand side. *Res. Policy* 36, 949–963. <http://dx.doi.org/10.1016/j.respol.2007.03.003>.
- Egyedi, T.M., Blind, K., 2008. General introduction. In: Egyedi, T.M., Blind, K. (Eds.), *The Dynamics of Standards*. Edward Elgar, Cheltenham, pp. 1–14.
- Egyedi, T.M., Koppenhol, A., 2010. The standards war between ODF and OOXML: does competition between overlapping ISO standards lead to innovation? *Int. J. IT Stand. Stand. Res.* 8, 49–62. <http://dx.doi.org/10.4018/jitsr.2010120704>.
- Egyedi, T.M., Spircio, J., 2011. Standards in transitions: catalyzing infrastructure change. *Futures* 43, 947–960. <http://dx.doi.org/10.1016/j.futures.2011.06.004>.
- Egyedi, T.M., 2000. The standardised container: gateway technologies in cargo transport. In: In: Holler, M.J., Niskanen, E. (Eds.), *EURAS Yearbook of Standardization*, vol. 3. Accedo Verlagsgesellschaft, Munich, pp. 231–262.
- Egyedi, T.M., 2003. Consortium problem redefined: negotiating democracy in the actor network on standardization. *Int. J. IT Stand. Stand. Res.* 1, 22–38.
- European Commission, 2011a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Horizon 2020 – The Framework Programme for Research and Innovation [WWW Document]. URL http://ec.europa.eu/research/horizon2020/pdf/proposals/communication_from_the_commission_-_horizon_2020_-_the_framework_programme_for_research_and_innovation.pdf (Accessed 29 July 2016).
- European Commission, 2011b. Proposal for a Regulation of the European Parliament and of the Council establishing Horizon 2020 – The Framework Programme for Research and Innovation (2014–2020) [WWW Document]. URL [https://ec.europa.eu/research/horizon2020/pdf/proposals/proposal_for_a_regulation_of_the_european_parliament_and_of_the_council_establishing_horizon_2020_-_the_framework_programme_for_research_and_innovation_\(2014-2020\).pdf](https://ec.europa.eu/research/horizon2020/pdf/proposals/proposal_for_a_regulation_of_the_european_parliament_and_of_the_council_establishing_horizon_2020_-_the_framework_programme_for_research_and_innovation_(2014-2020).pdf) (Accessed 29 July 2016).
- European Parliament, Council of the European Union, 2013. Regulation (EU) No 1290/2013 of the European Parliament and of the Council. *Off. J. Eur. Union* L347.
- Evraud, L., 2014. Politique nationale de normalisation et stratégie pour la compétitivité de notre économie [WWW Document]. URL <http://www.ladocumentationfrancaise.fr/var/storage/rapports-publics/154000103.pdf> (Accessed 28 July 2016).
- Farina, E.M.M.Q., Gutman, G.E., Lavarello, P.J., Nunes, R., Reardon, T., 2005. Private and public milk standards in Argentina and Brazil. *Food Policy* 30, 302–315. <http://dx.doi.org/10.1016/j.foodpol.2005.05.008>.
- Farrell, J., Saloner, G., 1988. Coordination through committees and markets. *RAND J. Econ.* 19, 235–252.
- Farrell, J., Simcoe, T., 2012. Choosing the rules for consensus standardization. *RAND J. Econ.* 43, 235–252. <http://dx.doi.org/10.1111/j.1756-2171.2012.00164.x>.
- Featherston, C.R., Ho, J.-Y., Brévignon-Dodin, L., O'Sullivan, E., 2016. Mediating and catalysing innovation: a framework for anticipating the standardisation needs of emerging technologies. *Technovation* 48–49, 25–40. <http://dx.doi.org/10.1016/j.technovation.2015.11.003>.
- Fligstein, N., McAdam, D., 2012. *A Theory of Fields*. Oxford University Press, New York.
- Frank, S., 2001. An assessment of the regulations on medical devices in the european union. *Food Drug Law J.* 56, 99–122.
- 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. *Res. Policy* 30, 589–610. [http://dx.doi.org/10.1016/S0048-7333\(00\)00095-0](http://dx.doi.org/10.1016/S0048-7333(00)00095-0).
- Gallagher, S., 2007. The complementary role of dominant designs and industry standards. *IEEE Trans. Eng. Manag.* 54, 371–379. <http://dx.doi.org/10.1109/TEM.2007.893991>.
- Gandal, N., Salant, D., Waverman, L., 2003. Standards in wireless telephone networks. *Telecomm. Policy* 27, 325–332. [http://dx.doi.org/10.1016/S0308-5961\(03\)00026-0](http://dx.doi.org/10.1016/S0308-5961(03)00026-0).
- Gao, P., Yu, J., Lyytinen, K., 2014. Government in standardization in the catching-up context: case of China's mobile system. *Telecomm. Policy* 38, 200–209. <http://dx.doi.org/10.1016/j.telpol.2013.10.002>.
- Gao, X., 2014. A latecomer's strategy to promote a technology standard: the case of Datang and TD-SCDMA. *Res. Policy* 43, 597–607. <http://dx.doi.org/10.1016/j.respol.2013.09.003>.
- Garud, R., Jain, S., Kumaraswamy, A., 2002. Institutional entrepreneurship in the sponsorship of common technological standards: the case of sun microsystems and java. *Acad. Manag. J.* 45, 196–214. <http://dx.doi.org/10.2307/3069292>.
- Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Res. Policy* 31, 1257–1274. [http://dx.doi.org/10.1016/S0048-7333\(02\)00062-8](http://dx.doi.org/10.1016/S0048-7333(02)00062-8).
- Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems. *Res. Policy* 33, 897–920. <http://dx.doi.org/10.1016/j.respol.2004.01.015>.
- Geroski, P.A., 2000. Models of technology diffusion. *Res. Policy* 29, 603–625. [http://dx.doi.org/10.1016/S0048-7333\(99\)00092-X](http://dx.doi.org/10.1016/S0048-7333(99)00092-X).
- Gilmore, A.B., Collin, J., McKee, M., 2006. British American Tobacco's erosion of health legislation in Uzbekistan. *Br. Med. J.* 332, 355–358.
- Glazebrook, R., 1931. Standards of measurement: their history and development. *Nature* 128.
- Goluchowicz, K., Blind, K., 2011. Identification of future fields of standardisation: an explorative application of the Delphi methodology. *Technol. Forecast. Soc. Change* 78, 1526–1541.
- Grant, R.M., 1996. Toward a knowledge-based theory of the firm. *Strateg. Manag. J.* 17, 109–122. <http://dx.doi.org/10.1002/smj.4250171110>.
- Greenstein, S.M., 1992. Invisible hands and visible advisers: an economic interpretation of standardization. *J. Am. Soc. Inf. Sci.* 43, 538–549.
- Hail, L., Leuz, C., Wysocki, P., 2010. Global accounting convergence and the potential adoption of IFRS by the U.S. (Part II): political factors and future scenarios for U.S. accounting standards. *Account. Horizons* 24, 567–588. <http://dx.doi.org/10.2308/ach.2010.24.4.567>.
- Hanseth, O., Monteiro, E., 1997. Inscribing behaviour in information infrastructure standards. *Account. Manag. Inf. Technol.* 7, 183–211. [http://dx.doi.org/10.1016/S0959-8022\(97\)00008-8](http://dx.doi.org/10.1016/S0959-8022(97)00008-8).
- Hawkins, R., 1999. The rise of consortia in the information and communication technology industries: emerging implications for policy. *Telecomm. Policy* 23, 159–173. [http://dx.doi.org/10.1016/S0308-5961\(98\)00085-8](http://dx.doi.org/10.1016/S0308-5961(98)00085-8).
- Ho, J., O'Sullivan, E., 2017. Strategic standardisation of smart systems: a roadmapping process in support of innovation. *Technol. Forecast. Soc. Change* 115, 301–312. <http://dx.doi.org/10.1016/j.techfore.2016.04.014>.
- Jain, S., 2012. Pragmatic agency in technology standards setting: the case of Ethernet. *Res. Policy* 41, 1643–1654. <http://dx.doi.org/10.1016/j.respol.2012.03.025>.
- Kennedy, S., 2006. The political economy of standards coalitions: explaining China's involvement in high-tech standards wars. *Asia Policy* 2, 41–62. <http://dx.doi.org/10.1353/asp.2006.0021>.
- Kenney, M., Zysman, J., 2016. The rise of the platform economy. *Issues Sci. Technol.* 32.
- Khemani, R.S., Shapiro, D.M., 1993. *Glossary of Industrial Organisation Economics and Competition Law*. OECD Directorate for Financial, Fiscal and Enterprise Affairs, Paris.
- Klüver, H., 2011. The contextual nature of lobbying: explaining lobbying success in the European Union. *Eur. Union Polit.* 12, 483–506. <http://dx.doi.org/10.1177/>

- 1465116511413163.
- LED Inside, 2010. International Lighting Companies Form a Consortium for Global Standardization of LED Lighting Products [WWW Document]. LED Insid. Website. URL http://www.ledinside.com/node/view/research/2010-4/zhaaga_consortium_20100407 (Accessed 26 May 2017).
- Laffont, J.-J., Tirole, J., 1991. The politics of government decision-making: a theory of regulatory capture. *Q. J. Econ.* 106, 1089–1127. <http://dx.doi.org/10.2307/2937958>.
- Lavie, D., 2006. The competitive advantage of interconnected firms: an extension of the resource-based view. *Acad. Manag. Rev.* 31, 638–658. <http://dx.doi.org/10.5465/AMR.2006.21318922>.
- Leiponen, A.E., 2008. Competing through cooperation: the organization of standard setting in wireless telecommunications. *Manage. Sci.* 54, 1904–1919. <http://dx.doi.org/10.1287/mnsc.1080.0912>.
- Lessig, L., 1999. *Code and Other Laws of Cyberspace*. Basic Books, New York, NY.
- Lessig, L., 2000. *Code is Law: On Liberty in Cyberspace* [WWW Document]. URL <http://harvardmagazine.com/2000/01/code-is-law-html> (Accessed 27 April 2017).
- Lu, Y., Morris, K.C., Frechette, S., 2016. Current Standards Landscape for Smart Manufacturing Systems. National Institute of Standards and Technology, Gaithersburg, MD. <http://dx.doi.org/10.6028/NIST.IR.8107>.
- Lyttinen, K., King, J.L., 2006. Standard making: A critical research frontier for information systems research. *MIS Q.* 30, 405–411.
- Mahoney, C., 2007. Lobbying success in the United States and the European Union. *J. Public Policy* 27, 35–56. <http://dx.doi.org/10.1017/S0143814X07000608>.
- Markus, M.L., Steinfield, C.W., Wigand, R.T., Minton, G., 2006. Industry-wide information systems standardization as collective action: the case of the U.S. Residential Mortgage Industry. *MIS Q.* 30, 439–465.
- Mattli, W., Büthe, T., 2003. Setting international standards: technological rationality or primacy of power? *World Polit.* 56, 1–42. <http://dx.doi.org/10.1353/wp.2004.0006>.
- Meyer, N., 2012. Public Intervention in Private Rule Making: The Role of the European Commission in Industry Standardization. The London School of Economics and Political Science (LSE).
- Moratis, L., Tatang Widjaja, A., 2014. Determinants of CSR standards adoption: exploring the case of ISO 26000 and the CSR performance ladder in The Netherlands. *Soc. Responsib. J.* 10, 516–536. <http://dx.doi.org/10.1108/SRJ-01-2013-0005>.
- NIST, 2010. In: NIST Summary of the Responses to the National Science and Technology Council's Sub-Committee on Standards Request-for-Information. Gaithersburg, MD.
- Narayanan, V.K., Chen, T., 2012. Research on technology standards: accomplishment and challenges. *Res. Policy* 41, 1375–1406. <http://dx.doi.org/10.1016/j.respol.2012.02.006>.
- National Industry Conference Board, 1921. *The Metric Versus the English System of Weights and Measures*. The Century Co., New York, NY.
- Neslen, A., 2015. EU Caves in to Auto Industry Pressure for Weak Emissions Limits [WWW Document]. *Guard.* URL <http://www.theguardian.com/environment/2015/oct/28/eu-emissions-limits-nox-car-manufacturers> (Accessed 31 August 2016).
- Open Source Initiative, 2007. The Open Source Definition [WWW Document]. Open Source Initiat. Website. URL <https://opensource.org/docs/osd> (Accessed 8 May 2017).
- Österreichische Bundesregierung, 2016. Österreichische Normungsstrategie der Bundesregierung 2016 [WWW Document]. URL http://www.bmwf.gv.at/TechnikUndVermessung/Bauprodukte/Documents/_Normungsstrategie2016_Ministerrat15-03-2016.pdf (Accessed 28 July 2016).
- Pelkmans, J., 2001. The GSM standard: explaining a success story. *J. Eur. Public Policy* 8, 432–453. <http://dx.doi.org/10.1080/13501760110056059>.
- Porter, M.E., Heppelmann, J.E., 2014. How smart, connected products are transforming competition. *Harv. Bus. Rev.* 92, 64–88.
- Puffert, D.J., 2000. The Standardization of Track Gauge on North American Railways, 1830–1890. *J. Econ. Hist.* 60, 933–960. <http://dx.doi.org/10.1017/S0022050700026322>.
- Puffert, D.J., 2002. Path dependence in spatial networks: the standardization of railway track gauge. *Explor. Econ. Hist.* 39, 282–314. <http://dx.doi.org/10.1006/exeh.2002.0786>.
- RF Ministry of Industry Energy, 2008. Russia's National Standards Strategy [WWW Document]. URL <http://www.strategicstandards.com/files/Russia.pdf> (Accessed 28 July 2016).
- Rogers, E.M., 2003. *Diffusion of Innovations*, 5th ed. Free Press, New York.
- Rosen, B.N., Schnaars, S.P., Shani, D., 1988. A comparison of approaches for setting standards for technological products. *J. Prod. Innov. Manag.* 5, 129–139. [http://dx.doi.org/10.1016/0737-6782\(88\)90004-5](http://dx.doi.org/10.1016/0737-6782(88)90004-5).
- Rosenbloom, R.S., Cusumano, M.A., 1987. Technological pioneering and competitive advantage: the birth of the VCR industry. *Calif. Manage. Rev.* XXIX, 51–76.
- Schilling, M.A., 2002. Technology success and failure in winner-take-all markets: the impact of learning OrientationTiming, and network externalities. *Acad. Manag. J.* 45, 387–398. <http://dx.doi.org/10.2307/3069353>.
- Schmidt, S.K., Werle, R., 1998. *Coordinating Technology – Studies in the International Standardization of Telecommunications*. The MIT Press, Cambridge, MA.
- Schmidt, P., 2002. Pursuing regulatory relief: strategic participation and litigation in U.S. OSHA rulemaking. *Bus. Polit.* 4, 71–89. <http://dx.doi.org/10.2202/1469-3569.1031>.
- Shapiro, C., Varian, H.R., 1999. The art of standards wars. *Calif. Manage. Rev.* 41, 8–32. <http://dx.doi.org/10.2307/41165984>.
- Simcoe, T., 2012. Standard setting committees: consensus governance for shared technology platforms. *Am. Econ. Rev.* 102, 305–336. <http://dx.doi.org/10.1257/aer.102.1.305>.
- Suarez, F.F., 2004. Battles for technological dominance: an integrative framework. *Res. Policy* 33, 271–286. <http://dx.doi.org/10.1016/j.respol.2003.07.001>.
- Swann, P., 2010. The Economics of Standardization: An Update [WWW Document]. URL <http://www.bis.gov.uk/assets/biscore/innovation/docs/e/10-1135-economics-of-standardization-update.pdf> (Accessed 21 March 2013).
- Tamm Hallström, K., Boström, M., 2010. *Transnational Multi-Stakeholder Standardization: Organizing Fragile Non-State Authority*. Edward Elgar, Cheltenham.
- Tamm Hallström, K., 2004. *Organizing International Standardization – ISO and the IASC in Quest of Authority*. Edward Elgar, Cheltenham.
- Tassey, G., 2000. Standardization in technology-based markets. *Res. Policy* 29, 587–602. [http://dx.doi.org/10.1016/S0048-7333\(99\)00091-8](http://dx.doi.org/10.1016/S0048-7333(99)00091-8).
- Tate, J., 2001. National varieties of standardization. In: Hall, P.A., Soskic, D. (Eds.), *Varieties of Capitalism*. Oxford University Press, Oxford, pp. 442–473. <http://dx.doi.org/10.1093/0199247757.003.0014>.
- Techatassanasontorn, A., Suo, S., 2011. Influences on standards adoption in de facto standardization. *Inf. Technol. Manag.* 12, 357–385. <http://dx.doi.org/10.1007/s10799-011-0089-2>.
- Thompson Clarke Shipping Pty. Ltd., CTI Consultants Pty. Ltd., Lewis, J.A., n.d. Antifouling Performance Standards for the Maritime Industry – Development of a Framework for the Assessment, Approval and Relevance of Effective Products [WWW Document]. Aust. Gov. – Dep. Environ. Energy Website. URL <https://www.environment.gov.au/system/files/resources/00cbf46f-06e7-44c7-8ff5-eb25d4ca3481/files/antifouling-framework.pdf> (Accessed 1 May 2017).
- Timmermans, S., Epstein, S., 2010. A world of standards but not a standard world: toward a sociology of standards and standardization. *Annu. Rev. Sociol.* 36, 69–89. <http://dx.doi.org/10.1146/annurev.soc.012809.102629>.
- Townes, M., 2012. The spread of TCP/IP: how the internet became the internet. *Millenn.—J. Int. Stud.* 41, 43–64. <http://dx.doi.org/10.1177/0305829812449195>.
- Trienekens, J., Zuurbier, P., 2008. Quality and safety standards in the food industry, developments and challenges. *Int. J. Prod. Econ.* 113, 107–122. <http://dx.doi.org/10.1016/j.ijpe.2007.02.050>.
- USSR State Standards, 1976. *State System of Standardization*. State Committee for Standards of the USSR Council of Ministers, Moscow.
- United States Standards Strategy Committee, 2015. *United States Standards Strategy* [WWW Document]. URL https://share.ansi.org/shareddocuments/StandardsActivities/NSSC/USSS.Third.edition/ANSI_USSS.2015.pdf (Accessed 28 July 2016).
- Vercoulen, F., van Wegberg, M., 1998. In: *Standard Selection Modes in Dynamic, Complex Industries: Creating Hybrids between Market Selection and Negotiated Selection of Standards* (No. NIBOR/RM/1998/06). Eindhoven.
- van Wegberg, M., 2004. Standardization process of systems technologies: creating a balance between competition and cooperation. *Technol. Anal. Strateg. Manag.* 16, 457–478. <http://dx.doi.org/10.1080/0953732042000295784>.
- 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. *Technol. Forecast. Soc. Change* 78, 1397–1411. <http://dx.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. *Organ. Stud.* 33, 705–736. <http://dx.doi.org/10.1177/0170840612443625>.
- von Burg, U., 2001. *The Triumph of Ethernet: Technological Communities and the Battle for the LAN Standard*. Stanford University Press, Stanford.
- Wätzold, F., Bültmann, A., Eames, M., Lulofs, K., Schucht, S., 2001. EMAS and regulatory relief in Europe: lessons from national experience. *Eur. Environ.* 11, 37–48. <http://dx.doi.org/10.1002/eet.249>.
- 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 Q.* 30, 489–514.
- Wernerfelt, B., 1984. A resource-based view of the firm. *Strateg. Manag. J.* 5, 171–180.
- West, J., O'Mahony, S., 2008. The role of participation architecture in growing sponsored open source communities. *Ind. Innov.* 15, 145–168. <http://dx.doi.org/10.1080/13662710801970142>.
- West, J., 2007. Seeking open infrastructure: contrasting open standards, open source and open innovation. *First Monday* 12, 1–16. <http://dx.doi.org/10.5210/fm.v12i6.1913>.