Power Shifts in International Standardization: Explaining a Leading Standard Setter in Telecommunication

Ph.D. Thesis

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Abstract

Technical Standards have become a new arena of competition in the race for technological leadership since securing their control and ownership provides considerable economic and political advantages. Particularly telecommunication standards, which underpin global networks, can produce substantial economic and strategic benefits for the country and industry that largely shape their process and outcome. In light of these implications, new aspiring standard setters, such as China and South Korea, have actively increased their participation in international standards settings, challenging the predominant position of traditional standard setters such as the United States and European countries. The rise of new aspiring standard setters has provoked shifts in the power structures of international standardization regimes that had mostly reflected the preferences of traditional standard setters in the last decade, implying a redistribution of gains and costs among countries and industries. Despite this, only a few studies have focused on explaining power shifts in international standardization, drawing on IR/IPE theories. In addition, studies have only partially inquired about the political and economic of conditions that might explain such shifts. Against this background, this study aims to contribute to the literature focusing on power shifts in standardization by assessing under what conditions countries turn into leading standard setters. This is evaluated empirically by analyzing the capacity of six technological powers in shaping the three latest generations of telecommunication standards, namely 3G, 4G, and 5G. It deploys a multimethod approach to perform the analysis, combining a Qualitative Comparative Analysis (QCA) with a process tracing (PT) analysis. The study found that the combination of conditions composed of a great innovator, a large economic power, and a highly complementary domestic system resulted in the most consistent sufficiency path, suggesting that when countries hold roughly the same technological and economic capabilities, a complementary system conducive to a strong government-industry partnership proves crucial to shaping standardization. This interpretation calls for further research on the role and influence of governments in securing technological leadership by providing competitive advantages to industries contributing to global standards.

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1. Introduction

The global power structures have been in flux (Kreienkamp & Pegram, 2019). Many studies have provided evidence of changing power structures in various fields of international relations between advanced countries and emerging powers, as well as between state and non-state actors (Drezner, 2019; Gu, 2022). A field that has attracted new attention is the setting of international technical standards, whose complex process occurs at different levels of governance, involving various public and private stakeholders.

Technical standards are essential for the global economic system as they represent "the formal and informal bundles of rules, roles, and relationships that define and regulate the social practices of state and non-state actors in international affairs" (Abbott & Snidal, 2001). In particular, internationally recognized standards that underpin global networks can exercise great structural and network power, providing substantial political and economic benefits to the country and industry that control or own those standards (Bishop, 2015; Strange, 1994).

These standards have become a major source of power mainly because of three changes in their nature and application. First, the increasing harmonization of new disruptive technologies, such as 5G, has enabled large networks that generate greater structural forces for those holding the corresponding standards. Second, the number of patented technologies within standards, which take the name of standard essential patents (SEPs), has increased significantly over the last years, becoming a great source of economic revenue for industries (Pohlmann, 2019). The rise in SEPs implies that more nations and industries are required to pay patent holders for licensing fees. Third, the more prominent inclusion of voluntary standards into internationally binding agreements, such as the Technical Barrier to Trade Agreement in 1995 , has also significantly increased the structural forces of standards (Wei, 2021).

In light of this, countries and industries have increasingly competed over shaping and leading international technical standards over the last decade. In particular, new aspiring standard setters—China, South Korea, Taiwan—have increasingly challenged traditional standard setters —the United States, Japan, and European countries— by altering the "global power structure in [international] standardization" (Blind&VonLaer,2021:20). This competition has been extremely fierce in the setting of telecommunication standards, more precisely in generational standards, such as 5G, since they can create a path dependency resulting in long-lasting economic and strategic benefits (Voo, 2022). As Tanaka similarly notes, whoever holds the largest amount of standard essential patents (SEPs), which are the proprietary patented technologies incorporated into the final standard, "will likely win the race to cultivate a new generation of advanced industries" (2019).

Following this increasing competition, standardization has been defined as one of the main arenas of competition between countries in the race to technological supremacy (Kim et al., 2018; Levis, 2018; Fägersten&Rühlig, 2019). Despite this, there are so far very few studies that explain power structures and shifts in international standardization at the country level across time (Blind&Von Laer, 2021; Mattli&Büthe, 2003). While this level of analysis omits the role of single companies, it might be important in providing a general picture of countries' capacity to shape standardization, which in turn determines their respective positions as standard takers or setters in global power structures in standardization. To do so, this study considers the agency of private actors and domestic agencies as an extension of countries' capacity to shape standardization, assuming that they incorporate and reflect the political and economic preferences of their country of origin (Malkin, 2022).

Various factors plausibly shape power structures in standardization at the country level. Based on research in international relations (IR) and international political economy (IPE) on standardization, four broad categories of factors can be identified: technical, material, institutional, and ideational (Mattli&Büthe, 2003; Rühlig, 2022). While this literature provides great insights into the set of factors that affect power structures in standardization, it does not fully explore these factors in combination in terms of necessity and sufficiency.

In light of these gaps, this study aims to contribute to the literature on power structures and shifts in international standardization by identifying the conditions under which countries become leading standard setters. These conditions are evaluated by adopting a set-theoretic multi-method approach (STMM) that combines a fuzzy set Qualitative Comparative Analysis (QCA) with a process tracing (PT) method.

More precisely, the outcome of interest (explanandum) assesses the membership of a leading standard setter. A leading standard setter is a country (or a set of countries)[1] with a great capacity to shape standardization. Given the public-private nature of standardization, this capacity is measured by considering the nationality of the private and public stakeholders that directly or indirectly shape standardization[2]. Private stakeholders refer to telecommunication companies (vendors and operators) that possess the technical expertise to shape standardization. While public stakeholders refer to the governmental bodies, such as national and regional standard entities, that shape standardization through their regulatory power. Thus, the units of analysis of this research are set at a country level, which is the level at which conclusions are pitched. Whereas the units of observation are at a stakeholder level, which is the level at which data are collected.

[1] The EU countries are considered as a unitary actor given the primacy of European standards
[2] More precisely, the nationality of stakeholders is taken as a time-varying proxy for technological powers' capacity to shape standardization

Four theoretically grounded factors (explanans) might explain a leading standard setter. These factors, which are referred to as conditions, are labeled as (1) a *great innovator*, (2) a *large (digital) economic power*, (3) a *highly complementary domestic institutional framework*, and (4) *a standard-focused policymaker*. Each condition is divided into subdimensions that can vary across cases and time.

The empirical yardstick, against which these conditions and outcomes are evaluated, comprises 18 cases. These cases represent six technological powers across the setting of the three latest generations of mobile network standards (3G, 4G, and 5G)[3], which have been developed by a public-private partnership between two standard development organizations (SDOs), namely the International Telecommunication Union (ITU) and the Third General Project Partnership (3GPP).

These six technological powers include five countries –China, the United States, South Korea, Japan, and Taiwan– and one set of European countries[4] that are considered as a single unitary actor, given the preeminence of European standards over national ones. Hence, six technological powers in three specific time frames, which correspond respectively to a single mobile network generation, establish 18 cases. These cases are selected based on their importance and contribution to the setting of international telecommunication standards. In addition, they can be distinguished into two main categories: traditional standard setters and new aspiring standard setters or 'latecomers' (Kwak et al., 2011).

Based on these considerations, this research addresses the following block of questions:

(i) Under what combinations of conditions do technological powers, through the mediated capacity of their industrial and governmental stakeholders, turn into leading standard setters in telecommunication standards?

[3] These will be also refered as telecommunication standards or more simply generational standards
[4] Namely all those European stakeholders that take part in standardization

(ii) How do these combinations of conditions vary across technological powers (cases) and standard generations (time)?

(iii) To what extent do the theoretical expectations meet the empirical results given by the QCA?

(iv) What is the most suitable pair of cases that explain the process by which the sets of combinations identified explain the outcome of interest? And what are the (casual) mechanisms triggered by the most consistent sufficiency paths?

The first two questions are addressed by a fuzzy set QCA that is divided into three parts: the pre-analytical part, the analytical part, and the post-analytical part (Oana et al., 2021). Following the post analytical part, the last two questions are addressed by a case-oriented PT method, focusing on most typical and deviant coverage cases.

The thesis is divided into five main chapters that are themselves divided into subsections: the first chapter (2) addresses the research puzzle and significance, by identifying gaps and aims of the study. The second chapter (3) provides a conceptual framework, some theoretical elements to guide the research, and a conclusive section on methods and methodology. The third chapter (4) carries out the calibration process, the analyses of necessity and sufficiency, and illustrates the analytical results showing the most consistent sufficiency paths (4). The fourth chapter (5) traces the (causal) mechanisms of the most consistent sufficiency path within the most suitable case studies, evaluating the extent to which the theoretical expectations meet the analytical results. The last chapter draws conclusions, by interpreting results, discussing limitations, and speculating about new research.

2. Research Topic, Research Puzzle, and Significance

Throughout history, powerful nations have competed for technological leadership in order to gain significant influence and advantages in the global system. Disruptive technologies have the potential to shift the balance of power in favor of the leading technological nations. An example of this can be seen with the creation of the steam engine in England during the 19th century, which revolutionized British industry and made it the world leader in terms of production and exports (Hills, 1993). The same trend is likely to happen with a new set of emerging technologies, such as Artificial Intelligence (AI), Big Data, and 5G. Countries that invest in these technologies according to their interests will reap significant political and economic rewards.

Many countries have vied for technological leadership in many areas, from procuring precious materials to acquiring technologies and developing infrastructures. Among these, setting technical standards is primary in providing technological leadership. The outcome of these standards can greatly impact technological competition. The country, whose technology is recognized as the international technical standards, stands to gain the most and is in the best position to maintain technological leadership. Despite this, international relations (IR) and international political economy (IPE) studies have generally overlooked the competition over technical standards.

Research on interstate competition over technical standards have only become more prominent in the field of IR/IPE over the past two two decade[5] (Mattli, 2001a; Mattli 2001b). Before this time, studies on standards were mostly done by economists and lawyers, who

[5] Even though there had been important power-based studies in the early 90s as well. For example, the studies of Cowhey (199) and Krasner (1991)

typically ignored the political and economic dimensions and implications of technical standards (Mattli, 2001a; Peña, 2015).

This chapter is divided into three sections and respective subsections. The first section explains why technical standards have been politically neglected, what kind of power they can exercise, and their political and economic implications. The second section instead delves into the research puzzle that seeks to set out the rationales behind studying changing power structures in mobile network standards. The remainder of this chapter shows the importance of being a leading standards setter, particularly in telecommunication, which has been at the center of great power competition in the past as much as in the present.

2.1 Shedding (Political) Light on Technical Standards

The lack of political attention to technical standards in the past "is not surprising because the political relevance of standardization is not self-explanatory" (Rühlig, 2022:2). In particular, three aspects make the political nature of standards not self-explanatory: the voluntary-based nature of standards, its consensus-driven process, and its cooperative framework (Table 1).

Standards are generally voluntary based, meaning that countries and their industries are not legally bound to adopt them. In other words, actors are commonly free to choose which standard to adopt based on their interests and needs. This is somehow different from standards that are internationally recognized. International standards are also voluntary in nature; however, by having a global outreach, they define de facto the perimeter of the global economy within which numerous actors with different interests operate (Blancato, 2019). Actors not complying with international standards would be automatically cut off from international markets and relations. Therefore, even if standards are voluntary, those with a global outreach have the capacity to directly or indirectly constrain the behavior of countries and their industries in the global economy.

Standards are also the result of a consensus-based process which implies that no single stakeholder formally opposes the standard. In standardization, "consensus" is generally defined as a "general agreement, characterized by the absence of a sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments" (ISO/IEC directives, 2004: 26). The consensus-based process by which standards are developed is however seldom impartial, also involving power dynamics and conflicts (Hass, 2019). Stakeholders tend to reach a consensus on the best technical specifications that define the standard; yet, given the vested interests embedded in these specifications, decisions over standards are also dictated by the power structure of standardization, namely the distribution of power of countries and their industries within the process. Based on this view, standards are not only conceived as "a non-political enabler of connectivity but [also] as a matter of distribution of power" (Hyun 2022: 52).

Furthermore, standards are generally seen as a cooperative process between stakeholders (Baron & Pohlmann, 2013; Leiponen, 2008; Bar & Leiponen, 2014). Cooperation is indeed a precondition for standardization. Stakeholders come together to agree on several rules, proceedings, and decisions. However, arguing that standardization is a purely cooperative matter might be too simplistic. Standardization is also described as a war of attrition between competing stakeholders in which "proponents argue for their preferred solution, or simply hold out, until one side concedes" (Farrell&Simcoe, 2009: 1). The cooperative and competitive aspects in standardization are particularly discernable in technology standards, where stakeholders cooperate and compete against each other over compatible (but rival) technologies (Shapiro and Varian, 1999).

If closely analyzed, technical standards are politically meaningful. They are voluntary yet highly constraining if they underpin great networks; they are consensus-based, yet the most influential stakeholders drive and build such consensus; they are cooperative-driven, yet their outcome is the result of competing (industrial) coalitions.

Table 1

Implications behind Technical Standards

Standard features	**Implications**
Standards are voluntary-based	(International) Standards impose economic and political constraints on stakeholders operating at the international level
Standards are the result of a consensus-based process	Consensus is never (fully) impartial and skewed in favor of most influential stakeholders
Standardization is driven by cooperation	Within standardization cooperative framework stakeholders compete with each other over promoting their patents into the standard

2.1.2 What Power do Standards Exercise?

Technical standards can be embedded with political and economic implications that turn standards into a "source of power" (Gratz, 2019; Krasner, 1991; Rühlig, 2020). The literature distinguishes three forms of power exerted by standards: network power, structural power, and, more recently, dispositional power. These three types of power share some similarities.

Standards that underpin global networks hold network power, by establishing the coordination by which global networks function (Grewal, 2008). In light of this, countries or industries that control such standards can potentially establish the coordination of global networks in line with their interests (Hyun, 2022). The greater the network underpinned by the standard, the greater the network power conferred to the country or industry that set that standard (Katz & Shapiro,1985). So, standards "can be both beneficial and thwarting as they can facilitate interaction among people while foreclosing other possibilities" (Hyun, 2022: 53).

Similar to the concept of network power, Jung argues that standards underpinning global networks also confer structural power to standard setters. This power is exerted by establishing the structure within which actors interact and operate. Strange defines structural power as "the power to shape and determine the structures of the global political economy within which other states, their political institutions, their economic enterprise, and their scientists and other professional people have to operate" (1988: 24). As explained before, this structure is not binding given the voluntary nature of standards; yet, actors feel constrained by adopting the standard that is set to underpin the global system, since any defections from it would result in being cut off from that system and their gains.

Thus, standards have a powerful influence on the choices made by actors, directing them towards a particular standard without exerting direct pressure (Strange 1988). While actors have the freedom to choose the most convenient standard for their products and services, adhering to internationally accepted standards is crucial for the success of their business activities. Failure to do so would render their products and services incompatible with the global market (de La Bruyère & Picarsic, 2020).

In the context of structural power, Gu also argues that standards exercise dispositional powers, by which countries or industries "take advantage of structures shaped by their own standards more than others that do not contribute to standardization even though they may be much stronger in manufacturing or designing" (Gu, 2022: 107). This implies that the underlying structure of standards shapes the behavior and actions of all the actors operating in that structure regardless of their resources and capabilities.

Against this background, standards represent the foundations of global economic governance, defining how various state and non-state actors compete and cooperate (Blancato, 2019; Ding, 2020). Standards that underpin great networks and systems provide harmonization to multiple competing technologies; however, by doing so, they also exercise constraining effects on stakeholders operating under such standards.

There are two examples in the literature that illustrate the power of international standards networks and structures/dispositions: Japan's PC standard and China's national 3G standard. In the case of Japan's PC standard in the early 1990s, the Japanese government decided to promote its own domestic standard in response to the US and European standards, which were at the time the dominant ones in the global market (Huyn, 2022). By underestimating the global reach and the structural effects of such standards, Japan’s decision to bet on its domestic standard resulted in a terrible economic policy that delayed the entry of Japanese industry into the global market and, in some cases, even excluded the Japanese industry from it (Kim, 2012). Something similar happened ten years later in China. In early 2000, China sought to reduce its dependency on foreign technologies by establishing its domestically developed 3G standard as mandatory for its national industry. This domestic standard struggled to gain international recognition; therefore, the Chinese telecommunication industry with international aspirations found themselves de facto excluded from a global market based on US and European standards. This exclusion eventually led the Chinese government to give up the idea of imposing a domestic standard and rethink its standard strategy (Kwak et al., 2014). These two cases illustrate why countries are interested in standards and want their industries to succeed in securing the globally dominant standard. Setting a global standard coordinating large networks provides considerable economic benefits and political leverage in shaping the governance structure in which different actors operate internationally.

2.1.3 Standard Power across Four Dimensions

The network and structural power of standards can be traced across four main dimensions: technological, commercial, normative, and political (Rühlig, 2022). Each dimension shows why standards matter and how they implicitly confer network and structural power to standard setters (Table 3). Starting from the technological dimension, standards guarantee technical harmonization between various technologies. In particular, standards ensure that new technologies entering the market during commercialization satisfy specific technical requirements that ensure quality, security, compatibility, and interoperability. As Cihon argues, standards are important governance tools to harmonize competing technologies in the international market and guarantee that technologies conform with international norms (Cihon, 2019). For telecommunication standards, these technical requirements guarantee that countries, firms, and individuals can efficiently communicate with each other and safely exchange information and data across the world.

Before reaching a significant level of harmonization, telecommunication standards were highly fragmented. As history shows, the first telecommunication systems were based on different national standards. People in the United States could hardly communicate with those in the EU unless they switched to the required standard. The growing international interdependence eventually led countries and their industries to invest in international standards that could guarantee compatibility and interoperability across different economic sectors.

Greater standard harmonization has consequently translated into larger telecommunication networks over the last decades across various sectors. Telecommunication is a general purpose technology (GPT), which is a technology with the capacity to "affect the production process of a large number of sectors" simultaneously (Baron&Schmitd, 2019).

Previous examples of GPTs are the steam engine system, the railroad system, and the electricity system. The great size of telecommunication networks and their wide-ranging effects explains why countries have been so eager to secure the dominant standards in telecommunication.

In addition to technological harmonization, standards are commercially essential in expanding markets. Indeed, the development of a set of technologies under a common standard puts economic actors in the condition to create larger markets. In particular, a high level of compatibility guarantees that various technologies can be commercialized across different countries without encountering technical issues that could damage both the seller and the user relying on that technology. In addition, given the network effect of standards, the value of technologies rises with increased participation (Banton 2022).

More importantly, standards are fundamental in establishing the evolutionary trajectories of markets by locking industries into specific technical solutions over long periods (Smith et al. 1998). Leading patent holders (standard-setters) set these trajectories, promoting the technical specifications that favor their commercial interests into standards. Standards, indeed, not only bring numerous alternative technologies under a common umbrella, but they also establish which complex technological system gets widely adopted in the market (Lerner&Tirole, 2015, Baron&Spulber 2018).

For example, the second mobile network generation standards (2G) were fully used worldwide for over 15 years. The US and European industries, which included most of their patented technologies into these standards, were entirely responsible for setting the market trajectories of telecommunication, by which they benefitted immensely from royalty payments and no switching costs (Leiponen, 2008). Through such benefits[6], the US and EU industries

[6] The is a strong correlation between SEPs and market revenue (Baron, 2020; Pohlmann, 2016)

also gained a competitive advantage in developing the following standards. This example shows how standard setters (countries) expand and project markets according to their commercial interests through the structural power of standards.

Standards are also crucial for being normative benchmarks carrying specific sets of values. As previously mentioned, standards are commonly voluntary and non-binding; however, they can be incorporated into international law as benchmarks. In the past, some countries resorted to national standards as non-tariff barriers to protect their domestic markets and infantry industries from international competition. This practice was widespread throughout the 1980s when some countries, above all China and Japan, arbitrarily applied national standards to disadvantage foreign companies in their respective domestic markets. Confronted by these trade issues, countries eventually agreed on a set of international treaties under the World Trade Organization (WTO) framework, establishing “international standards as crucial benchmarks” in binding regulations (Rühlig, 2022:9). All these treaties, such as the Technical Barriers to Trade (TBT) agreement, established standards as crucial benchmarks to facilitate international trade and economic integration.

The incorporation of international standards as normative benchmarks in regulations has become customary across many sectors, such as telecommunication. National standards generally refer to and comply with international standards. The opposite would imply sanctions or exclusions from the global economy (Cihon, 2019). For this reason, countries and industries operating globally often comply with the strictest international standards and, above all, attempt to set international standards in line with their interests and norms (Fägersten&Rühlig, 2019). Indeed, the countries and industries that set the international standard can effectively determine the norms used for developing and providing goods and services. Rühlig argues that standards “formulate a basic recipe setting the rules by which different manufacturers develop specific products. As such, they shape the physical world around all of us and contribute to the constitution of our social lives" (Rühlig, 2022:10).

Based on similar considerations, some scholars have defined standards as social institutions (Krislov, 1997). Standards, indeed, embody different sets of norms, including various ideas and values. As Olson argues (2020:1), international technical standards are "also imbued with broader societal and philosophical overtones".

The sets of norms that prevail at the international level depend "on the extent one country can secure international acceptance for its standards (Olson, 2020: 1). For example, Wi-Fi prevailed over the WAPI as the dominant WLAN standard because international standard development organizations (SDOs) prioritized data security over technological performance[7] (Lee & Oh, 2006; Rühlig, 2022; Suttmeier et al., 2009). Wi-Fi as the dominant standard reflected the norms prioritized by the power structures of the standards development organization (SDO), primarily concentrated in the hands of the US industry.

Internet governance is another clear illustration of how standards are influenced by the values of those who create them. The stakeholder framework and free speech philosophy of Internet governance are primarily based on a set of Western norms that the US and European countries promote. This perspective has been recently challenged by a new aspiring standard setter, China, which seeks to establish a more centralized system that would give national governments greater control and surveillance power (Olson, 2020). In the next decade, these two contrasting perspectives on Internet governance will continue to clash and be determined by globally recognized standards.

The same will occur with other emerging technologies, such as facial recognition and surveillance systems. These technologies have also been at the center of countries' normative

[7] WAPI promised greater performance but fewer data security compared to WIFI

disputes. For instance, Chinese surveillance technologies, which some countries around the world have already adopted, have been criticized for allegedly violating human rights because of their degree of intrusion and profiling[8] (Olson, 2020; Wang 2021). According to Wang (2021:1), such technologies could project at the international level "a set of values [authoritarianism and control] that undergirds the Chinese state." Therefore, decisions about which technology becomes the dominant standard also have normative implications, considering that some countries share diverging sets of norms ranging from human rights to the environment.

Standards are also "a strategic vehicle for setting a new geopolitical order in the world" (Lee 2021:44). They do so by determining an "invisible" yet constraining "matrix" of rules at the international level (Pop et al. 2021). The structural constraints of such a matrix also have profound geopolitical implications. Standard setters not only have the power to enhance their economic competitiveness and promote their values but also (potentially) establish technological spheres of influence by supplying technologies that enable key strategic infrastructures such as telecommunication.

As Rühlig argues, standards can "impinge on what is often regarded as the crown jewel of state power: security"(2021:6). Developers are assumed to have a greater understanding of how technologies work and where they could present some vulnerabilities. For instance, vulnerabilities could be a "backdoor", by which developers could get access to private information or hack the security systems of third parties. Therefore, when a technology becomes an international standard or part of it, the developer of that technology, which turns

[8] Some countries such as Ecuador and Kyrgystan have already applied Chinese technologies exposing their citizens to Chinese surveillance systems

into the standard setter, could potentially use such "prime knowledge" to undermine the security framework of a country (Rühlig, 2022).

Some observers rebut the idea that technical standards that are recognized internationally could hide vulnerabilities of which the leading developer is only aware. They argue that standardization is based on a process driven by consensus and contribution, guaranteeing the highest level of transparency. Therefore, it is highly unlikely that international standards present hidden vulnerabilities that countries could use at the expense of others (Rühlig, 2022). Furthermore, SDOs commonly operate according to the highest principles of fairness and transparency, especially when stakeholders disclose their SEPs. However, the same degree of fairness and transparency might not be met at the bilateral level when the selection of standards results from cooperation frameworks in which countries mutually recognize their standards. Sometimes these standards do not conform to international ones.

Through technical standards, countries can also create technological spheres of influence. Countries could use this technological influence to ask for economic and political concessions or directly undermine the strategic infrastructures of third countries. China has allegedly tried to do so through the Belt and Road Initiative (BRI), in which standards play a fundamental role in projecting China's influence along the routes of the BRI.

For instance, China has provided significant financial and technical help for strategic infrastructures to third countries, such as Laos and Djibouti, under the condition that Chinese technologies would underpin the construction and maintenance of such infrastructures. Some of these countries have become technologically dependent on China, by adopting Chinese technologies as standards. When such standards do not conform to international ones, the maintenance of their infrastructures depends on technologies that can be only provided by Chinese suppliers, de facto cutting out US or European suppliers.

In addition to technological dependency, standards also have reputational implications. Countries whose technologies are recognized as international standards gain significantly in international reputation. Setting international standards is a sign of “technological supremacy and societal progress”, which affects countries' perceptions at the international level (Rühlig, 2022).

Given some of the (geo)political implications of the standards mentioned above, competition over standards has been newly conceptualized as one of the major technological battlegrounds between countries (Lewis, 2018; Kim et al., 2020). Some scholars have even defined such competition as a “Standards World War” since competition over standards has been occurring globally, potentially affecting all countries regardless of their involvement (Lee, 2021).

The last standard strategies set out by China, the United States, and the European Union confirm the increasing geopolitical importance attributed to standards and the importance of being a leading standard setter (Table 2). China has been one of the first players to set a standard strategy for new emerging technologies. China officially launched its ‘China Standards 2035’ strategy in 2018. The overarching goal of this strategy is to turn China’s industry into a leading standard setter in emerging technologies such as 5G, the Internet of Things (IoT), and Artificial Intelligence (AI). To this end, China has planned a series of actions to elevate China’s industrial presence in international standard settings through economic and political support and to establish bilateral cooperation on standards through the Belt and Road Initiative (BRI) (Sheehan et al., 2021).

Table 2

(Geopolitical) Standard Strategies

Country	**Strategy**	**Main Goals**
China	China Strategy 2035 (2018)	Elevate Chinese industrial base as global standard setter and promote their standards through the BRI
US	Executive Order on America's Supply Chain (2020)	Preserve US dominant position as global standard setter and build partnerships with like-minded countries
EU	EU Strategy on Standardization - Setting global standards in support of a resilient, green and digital EU single market (2022)	Promote EU economic competitiveness, technological innovations, and democratic values

The US reacted slowly to China's standards strategy. Only in 2020, the Trump administration published a document called 'United States Strategic Approach to the People's Republic of China' in which great attention to technology standards was paid[9] (Lee, 2021). The document argues that China's standardization strategy is "designed to reshape international norms, standards, and networks to advance Beijing's global interests and vision, while also serving China's domestic economic requirements" (The White House, 2020: 3). To respond to such challenges, the document further argues that the US should preserve its leading position

[9] The word standards as technical specifications appear ten times in the text (Lee, 2021)

in standard settings and “work with allies and partners to ensure that discriminatory industrial standards do not become global standards” (The White House, 2020: 8).

The Biden administration has taken a similar stance. The US President himself wrote, "the United States is leading change in innovation. There is no reason [the US] should be falling behind China or anyone else when it comes to clean energy, quantum computing, artificial intelligence, 5G, high-speed rail” (Biden, 2020). Similar to Trump’s administration's strategy against China, Biden also called upon greater cooperation in standards-settings with likeminded partners, arguing that “the most effective way to meet that [chinese] challenge is to build a united front of US allies and partners to confront China’s abusive behaviors” (Biden, 2020).

In line with this, the Biden administration took some policy actions in February 2021 with the ‘Executive Order on America’s Supply Chain.’ The executive order requested the Department of Commerce (DOC) and the Department of Homeland Security (DHS) to carry out a report on US ICT supply chains. Among several goals, the report aimed to identify critical areas in which the US government could help establish strong domestic standards and advocate for their global recognition (Lee, 2021; Olson, 2020).

In February 2022, the EU also developed a standardization strategy to preserve and promote its status as a global standard setter. Technical standards have always been vital to the EU’s strategic autonomy and economic competitiveness. As commissioner for the Internal Market, Thierry Breton, said “Europe's technological sovereignty, ability to reduce dependencies and protection of EU values will rely on our ability to be a global standard-setter. With today's Strategy, we are crystal clear on our standardization priorities and create the conditions for European standards to become global benchmarks. We take action to preserve the integrity of the European standardization process, putting European SMEs and the European interest at the center” (EU press release, 2022). This strategy covers five sets of actions, from addressing standardization needs in strategic areas to enhancing European leadership in global standards.

Table 3

Why Do Standard Matter?

Dimensions	**Importance**	**Implications**
Technological	Guarantees quality, compatibility and interoperability	Harmonizing technical specifications to set technological boundaries and directions for new technologies
Commercial	Expands trade and sets market trajectories	Patent royalty payments and switching costs
Normative	Establishes normative benchmarks in national regulations	The imposition of (diverging) norms and values
(Geo)political	Sets the “invisible matrix” of rules at the international level, reflecting power relationships between standard setter and takers	Security vulnerabilities, spheres of technological dependency and international reputation

2.2 From Research Topic to Research Puzzle

The setting of technical standards as a source of power has become a major arena of interstate competition over securing the dominant standard or more precisely leading the standard setting. This competition has mainly increased because of the greater gains obtained from intellectual property rights (IPRs) embedded in standards, the larger access to new global markets guaranteed by standards (Kwak et al, 2011:789), and, more importantly, the voluntary yet influential rulemaking established by standards (La Bruyère 2020, 5).

In particular, the competition has been between standard setters that are concerned with maintaining their influential position and standard takers that aspire to become standard setters themselves. In the second half of the twentieth century, the United States, some European countries, and Japan were the major standard setters, by which they largely defined the global economic structure according to their respective interests and values. In the last two decades, however, their dominance has been challenged by new aspiring standard setters, such as China, South Korea, and Taiwan, whose footprint increased significantly in SDOs, by presumably altering the power structure of international standardization.

Some studies analyze power structures and shifts in standardization, but very few do so at a country level by systematically combining different indicators. Blind and Von Laer measures the influence of countries in two SDOs considering the number of leadership positions held by domestic standard bodies in standard working groups (2021). Leadership positions can be very indicative of countries' influence in SDOs. There are, however, other equally important indicators. The existing literature identifies, along with leadership positions, three other indicators that measure influence in standardization: participation, standard contribution, and standard essential patents (Rühlig, 2022). These indicators, which are primarily complementary, capture a specific element of influence. If combined, they could provide a better understanding of the phenomenon. This research attempts to systematically combine such indicators to measure the capacity of countries to shape standardization by which power structures in standardization can be comprehensively identified.

Power structures in standardization vary according to the capacity of countries and their respective industries to shape standardization. This capacity implies turning patented technologies into standard essential patents (SEPs). Turning patented technologies into SEPs requires significant consensus, which is obtained by creating large (industrial) coalitions that commonly provide such consensus in SDOs. Patented technologies that do not gather significant consensus among competing stakeholders in the process of standardization do not make it into the standard or are not recognized as such at the international level. For example, China's WAPI standard, the rival standard to WIFI, failed to be recognized as an international standard given the little consensus obtained at the international level (Kennedy, 2006). Therefore, having a great capacity to shape standardization implies building a large consensus on SEPs through strong industrial coalitions. Countries with such capacity to shape standardization are generally defined as leading standard setters.

From an IR/IPE perspective, standardization and its power structures that are given by countries' capacity to shape standardization can be affected by four broad categories of factors that entail respectively: technical, material, institutional, and ideational factors. Technical factors can focus on the level of innovation and expertise of countries and their industries in producing new knowledge and technologies (Suarez, 2004; Van de Kaa&Greeven, 2017; Weiss, 1990). Material factors instead examine the market power of countries and their industries relative to the technology that is standardized (Krasner, 1991; Brezner, 2007). Institutional factors explore countries' domestic institutional and regulatory framework upon which public and private stakeholders coordinate with each other to exchange information about standards (Mattli&Büthe, 2003). Finally, ideational factors delve into the policy ideas and national strategies of governments that promote standard leadership.

Each of these factors has shown a certain degree of correlation with the capacity of countries to shape standardization; however, their effects are often found subject to the influence of other factors, which contravenes the main assumption of correlation-based approaches. To overcome this, this study adopts a configurational approach (QCA) to examine different combinations of conditions and their degree of necessity and sufficiency. QCA, however, is just a starting point for the analysis since it does not explain whether conditions are causal or scope conditions nor whether they operate simultaneously or form a sequence. QCA is indeed used in an explorative way to identify the set of conditions that possibly trigger the sufficient causal mechanisms that produce the outcome of interest. Following the QCA analysis, this study, therefore, resorts to a process-tracing method to identify the mechanism and test the theoretical claims generated by such combinations of conditions.

Being a leading standard setter might be achieved through various combinations. The existing literature has particularly focused on innovation or the combination of market power and complementary institutions (Krasner, 1982; Mattli&Büthe, 2003). However, there are also instances in which leading standard setters have resulted from domestic and international factors (Kennedy, 2006). For instance, Kwak argues that the outcome of standards is also given by the level of cooperation stakeholders reach between competing coalitions (Kwak et al., 2011). In light of this, this research also aims to understand which sets of mechanisms are more consistent in explaining under which conditions countries become leading standard setters.

Power shifts in standardization are particularly observable in telecommunication standards. In the past, the US and Europe were the dominant SEPs holder, which gave them a leading role in international standardization. However, in the early 2000s, new contenders such as China, South Korea, and Taiwan started to gain control of numerous telecommunication SEPs (Polhman&Blind, 2016). In particular, these players have emerged due to the strategic significance of controlling telecommunication. Indeed, globally established telecommunication standards govern a set of rules that impact nations and industries, regardless of their involvement (Lee, 2021). For this reason, these standards are commonly considered a major source of interstate competition when it comes to securing the dominant standard (Rühlig, 2020; Seaman, 2019; Doshi&McGuiness, 2021). Despite this, little research has been done on power structures over the three latest mobile network standards (3G, 4G, 5G) and how these power structures have shifted over time, given countries' capacity to shape standardization (Table 4).

Table 4

Potential Gaps

Title	**Empirical observations/existing literature**	**Gap identification**	**Attempted (Gap-fill) contribution**
Gap I	Increased interstate competition over technical standards given the rise of new aspiring standards setter in SDOs and emerging technologies such as 5G	Power structures between countries in international standardization are not clearly defined and measured across time and technological powers	Explaining changes in power structures by identifying leading standard setters (countries with a high capacity to shape standardization) based on a set of combined indicators
Gap II	Different factors can shape countries'industrial capacity to shape standardization	Factors are analyzed individually plus their theoretical mechanisms are not traced and tested	Identifying combinations of conditions under which countries become leading standard setters and testing the theoretical mechanisms triggered by such combinations
Gap III	Great power competition over telecommunication (control)	Interstate competition over mobile network standards	Identifying and explaining power shift in mobile network standards (at a country level)

2.3 The Importance of Being a (Leading) Standard Setter in Technology Standards

The power embedded in standards and their various effects across different dimensions show why observing power structures in international standardization is important. Leading standard setters shape standards according to their interests and values, benefiting from them in various ways.

Through technical standards, they can potentially expand markets and determine their direction by locking products and services into their standards. Technological changes often build on existing SEPs that ordinarily last two decades (Telenau, 2021). For example, mobile network standards, such as 5G, draw on SEPs that underpin their previous generations. Standards can thereby produce lock-in effects in favor of leading standard setters holding most of the patents (Ramel et al., 2018).

Through such effects, leading standard setters also benefit from patent royalty payments. Leading standard setters, which hold large portfolios of SEPs, can obtain enormous gains from licensing their patented technologies to third parties. For example, Qualcomm, a very influential US technological company, gained approximately 5.2 billion euros, which equaled more than 20% of its total revenue, from patent licensing in 2018 (Strumpf, 2019). In light of such payments, patenting innovations have increased significantly over the last decade, as have the gains from licensing. According to some statistics, approximately 55% of ICT standards are patented (Rühlig, 2021).

SEPs as a source of revenue have become increasingly important during the current trade war between China and the US. SEPs allow excluded companies to still earn revenues through SEPs licensing. The case of Huawei is very illustrative. Huawei's technologies have been banned in the US market for various political and economic reasons. Despite this, Huawei's considerable portfolio of SEPs in 5G standards has allowed Huawei to earn large revenues from their licensing (Xui, 2019). SEPs' secure revenue source explains why countries and their industries have been increasingly interested in patenting their innovations and promoting them as SEPs.

Furthermore, changes in technical standards imply switching costs, especially if the new standards do not draw on the previous ones, as in the case of G standards. Countries whose industry sets the dominant standard face little if no switching costs compared to countries that might have invested in rival technologies. Countries deviating from the prevailing standard typically incur higher switching costs, being forced to redesign their products and pay licensing fees to access the relevant SEP. High switching costs sometimes have led countries and industries to maintain their national standards, producing standard fragmentations at the international level.

Leading standard setters can promote their norms and values through technical standards even if they are not recognized internationally. Standards can have extraterritorial effects by which leading standard setters can potentially affect the normative framework of third parties. One of the most illustrative examples is the EU's General Data Protection Regulation (GDPR), which contains numerous technical standards as normative benchmarks. The absence of a global regulator for data security has led countries to apply their own regulations in the field of data protection. Some of these regulations, however, have global ramifications (Ryngaert & Taylor, 2020). One of which is the GDPR. The GDPR in fact imposes obligations on any party that deals with data collected or targeted in the EU, regardless of its geographical position (Wolford, 2023). In other words, the GDPR ensures that European data transferred to or processed by third countries are treated with adequate data protection standards that are equivalent to the GDPR (Ryngaert & Taylor, 2020). Through such extraterritorial application, the GDPR has affected data protection regulations of third countries, and, more importantly, it has become a source of inspiration for developing a global standard in data security. Although some opposition has been made to the EU norms and standards in the GDPR, many countries with international aspirations have conformed to it. Such compliance is arguably related to third countries' fear of losing access to the EU market and the high sanctions imposed by the EU in case of norm infringements (Ryngaert & Taylor, 2020).

Leading standard setters can also leverage standards to promote the political and ethical values that are ingrained in them. However, countries’ values often clash with each other. For example, China has pushed for increased government control over the internet at the ITU level, which conflicts with the current Western-based stakeholder system (Segal, 2020). Furthermore, there are reports claiming that China has attempted to remove or oppose any mention of democracy and freedom in important documents at the United Nations (UN), as well as suppress human rights concerns related to Chinese technologies at the ITU level (Levin, 2015; Gorman, 2020).

Leading standard setters can also secure greater strategic autonomy and bargaining power through standards. Many strategic infrastructures, from telecommunication to energy, are underpinned by numerous technologies. Countries relying on foreign technologies to enable their infrastructures are more likely to expose themselves to potential (cyber) threats and attacks. As explained before, developers have paramount knowledge of their functioning and vulnerabilities, by which they could potentially tap into secret information or sabotage strategic infrastructures. This implication is allegedly one of the main reasons why some Chinese technologies, above all Huawei and ZTE, have been banned and excluded in the US market and, to a certain degree, in Europe. The 2019 National Authorization Act prohibited procuring telecommunications equipment and services from Huawei, ZTE, and video surveillance technologies from Hytera, Hikvision, or Dahua companies (Acquisition.Gov, 2019).

Being a leading standards setter also ensures greater international recognition and thereby greater bargaining power. Countries are more likely to seek technological cooperation or assistance from leading standard setters. For instance, China's growing role as a tech supplier to some African and Asian countries is very illustrative of China's increased reputation as a technological pioneer. China successfully signed fifty-two agreements on standard cooperation with countries belonging to the BRI as of September 2019 (Olson, 2020).

2.3.1 Great Power Competition over Telecommunication (Standards)

Leading standards setters can exercise great structural and network power through technical standards across various dimensions. However, such power can be expressed only by technical standards that underpin great networks, such as telecommunication standards. Telecommunication standards comprehend, in fact, numerous hardware and software that enable critical infrastructures and networks. Control over such standards secures large economic benefits and high levels of security among various gains.

Against this background, telecommunication has been at the center of great power competition several times. There are many instances across history in which countries compete with each other to control telecommunication for economic and security reasons. In particular, the existing literature shows how the Anglo-German struggle over telegraphy shares powerful analogies with today's competition over 5G and provides important lessons for today's technological competition (Brunnermeier et al., 2018).

In the late 19 century, Guglielmo Marconi developed a radio network (a wireless telegraphic system) with the help of the British Navy. This development provided the British Empire with a monopoly over radio transmissions. Alongside this monopoly, the British Empire also held a 60% share of world undersea cable, assuring British dominance over global telecommunication (Brunnermeier et al., 2018).

To counter such dominance, Germany carried out a series of domestic and international actions. At the domestic level, Germany provided financial support to its industry to reproduce

Marconi's invention and build its own radio network system. Creating an alternative system, however, was insufficient to overthrow British standard dominance. The British Empire, in fact, initially managed to preserve its dominance through the great network power of its standard, which imposed restrictions on all those operators that would not have complied with Marconi's British standard. Given these constraints, international telecom operators refrained from adopting a different system than Marconi's, de facto disregarding Germany's system.

The German system gained influence only after Germany took a series of actions at the international level. Some of these actions included promoting radio technologies in untapped markets such as Africa and Latina America to secure in advance their standards and organizing international conferences on radio networks to build international consensus for its standards. Through such combined efforts, Germany eventually succeeded with the help of the United States in dismantling the British monopoly, giving rise to an Anglo-German duopoly (Brunnermeier et al., 2018).

Over the past ten years, China and other countries aiming to set international standards, such as South Korea, have employed tactics similar to those used by Germany to challenge British dominance in telecommunications. China, like Germany, has worked to gain support for its technologies both domestically and internationally. Domestically, China has set out strong industrial policies, providing substantial financial support and tax credits to companies participating in international standards settings. While internationally, it has signed numerous cooperation agreements under the BRI to promote its standards and to draw on third-world markets (Brunnermeier et al., 2018; Olson, 2020). Parallel to these actions, China has highly protected its high-tech sectors through bans, tariffs, and restrictive regulations in order to favor its national champions and reduce foreign independence.

This brief comparison shows that telecommunication has always been considered a source of great power competition. This type of competition normally unfolds following the creation of a new technology with disruptive effects and when powers competing over that technology portray antithetical systems. For example, 5G is today considered a highly disruptive technology that will transform and enable new global networks and infrastructures, and great powers competing over securing such technology differ institutionally. In broad terms, the US and the EU portray a democratic system with a free market economy; on the contrary, China depicts an authoritarian state with a state-protected market. The potential impact of 5G on the global economy and institutional differences between great powers are some of the main reasons for the great competition behind mobile network standards such as 5G standards. Hence, being a leading standard setter is important not only for the economic benefits deriving from the outcome of standards but also for the values and norms emerging from such standards.

3. Conceptual Framework, Theoretical Elements, and Methods

Explaining power structures in standardization is a complex task that requires conceptual, analytical, and theoretical clarity. Technical standards are grouped into various categories and processes, involving numerous private and public stakeholders who operate at national, regional, and international levels. These processes are influenced by various factors and conditions. To address this complexity, this chapter aims to conceptualize and frame this study analytically. The first section defines the key terms while the second section explains the analytical framework and introduces some theoretical elements. Finally, the last section outlines the multi-method approach used and the reasons behind its adoption.

3.1 Distinguishing Technical Standards: Categories, Processes, and Other Features

Technical standards can be distinguished by category and process (Tassey, 2000). Starting from the categories, standards can be broadly classified as quality or compatible standards. Quality standards set the parameters that certify the quality of goods and services; whereas compatible standards establish the criteria based on which goods and services work together (David&Greenstein 1990; Hart 2010). Compatible standards are among the most studied due to their network effects: the greater the adoption of the standard is, the larger the market opportunity (Farrell and Saloner 1987; Mattli 2001b).

Regarding the type of process, the existing literature distinguishes between formal (de jure) and de facto standards (Farrell & Simcoe; 1996; Mattli, 2001a). De jure standards are the result of recognized standard bodies, such as the International Organization for Standardization (ISO), where various public and private stakeholders come together to set a common standard; by contrast, de facto standards commonly originate from the market dominance of a given technology upon which other technologies are then created (Rühlig &Ten Brink, 2021). In addition, de jure standards[10] are generally mandated by recognized public authorities and/or standard development organizations (SDOs) through a voluntary and consensus-based process. While de facto standards are mostly the result of market forces in which regulatory authorities have little influence (Breznitz and Murphree 2013). These standards come into existence when a critical mass uses a specific technology (Grewal 2008). Industrial coalitions or single private companies are the main players in market-driven processes (Van de Kaa & Greeven, 2017).

These two processes, de jure and de facto, do not entirely cover the extremely heterogeneous standard-setting ecosystem that has emerged in the last decade. Today there are more than one thousand SDOs that differ from each other in many ways (Updegrove, 2003). Scholars have devoted particular attention to formally recognized and consensus-based SDOs since their outcome obtains greater public legitimacy (Baron et al., 2019). These organizations differ from each other in terms of their membership, voting procedures, and licensing terms (Baron & Spulber, 2018).

SDOs can be classified by three types of memberships: SDOs made up of national standard bodies (e.g. SAC, ANSI); SDOs formed by firms and/or industry associations; and SDOs composed by both public and private actors, including government agencies, universities, and industry groups (Schneiderman, 2015). As far as the voting procedure is concerned, most of these SDOs foresee a majority voting based on consensus, which implies that there is no objection against a technical specification of the standard. Therefore, consensus does not imply unanimity but rather the absence of qualified disagreement (Baron & Gupta, 2018). When there

[10] The de jure element makes sure that the outcome of standards is approved and recognized legitimately at the international level

is a lack of consensus and a deadlock originates from it, a qualified majority is generally used to approve a standard.

In addition, most of the SDOs require stakeholders to disclose their patented technologies under fair, reasonable and nondiscriminatory terms (FRAND) to avoid that patent holders could ask for disproportionate compensation,. As Gupta argues , the implementation of FRAND terms in SDOs, such as the 3GPP, prevents SEP holders from “denying implementers access to the technology” and “ensur[ing] that SEP holders get fairly compensated for their contributions to the standard” (2017:12). FRAND terms, which are generally set prior to the standard-setting process, is an important policy to prevent monopolistic activities by patent holders whose technology becomes essential to the standard (Bekkers et al., 2002; Lamely&Shapiro, 2007).

The existing literature also makes a distinction between SDOs with low or high thresholds of approval. SDOs with a low threshold of approval, which are generally characterized by limited participation, guarantee a fast decision-making process over standards. However, since its limited participation, their standards do not enjoy the same authoritative degree as SDOs with a high threshold of approval (Murphree, 2014). This is also why SDOs, especially those with a low approval threshold, seek cooperation with other formally recognized SDOs. As Blind (2011) argues, SDOs with lower threshold approval tend to submit their standards to the additional approval of broader and more inclusive SDOs. Consequently, many formal SDOs have specific policies dealing with standards developed by limited and less formalized bodies (Baron&Pohlman, 2013; Baron et al., 2014).

Finally, standards can be developed nationally, regionally and internationally. Today, they are mostly developed internationally; however, national and regional standards are still important sites of standard development as their technical specifications can be promoted internationally at a later stage (Mattli, 2001a; Mattli&Büthe, 2003). Furthermore, standards developed at the international level are commonly voluntary unless they are included as a technical base in national or regional regulations (Murphree, 2014).

3.1.1. Telecommunication Standards

This study focuses on the three latest mobile network generation standards—3G, 4G, and 5G—that are compatible (technology) standards set in internationally recognized SDOs[11]. In broad terms, these generational standards guarantee compatibility and interoperability among technology devices across different industries and jurisdictions. In other words, they make sure that we can communicate efficiently across different continents.

The last generation of telecommunication standards is simply the improved version of the previous ones in terms of a set of specific criteria such as latency, speed and coverage. Each of these standards comprises numerous "inter-related standard [technical] specifications [...] incorporating thousands of interdependent inventions reflected in the many thousands of declared patents to these technologies" (Baron, 2019:6). Therefore, even though these standards are often considered as a single monolithic technology, they are made of numerous technical specifications[12]. The patented innovations that are embedded in the standard become standard essential patents (SEPs).

More standards can emerge from the same generation. For example, in the case of 3G mobile networks, three main 3G standards were developed: WCDMA, CDMA2000 and TD-SCDMA. WCDMA and CDMA2000 were the two predominant standards developed at the global level, while TD-SCDMA was an alternative solution developed nationally by China in collaboration with Siemens and eventually promoted internationally with great difficulties

[11] These standards are classified as compatible international technology standards that are generally defined as "a document established by consensus and approved by a recognized body, that provides, for common and repeated uses, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context" (ISO/IEC Guide 2, 2004)

[12] So far there are 10,000 patents declared essential for 2G (GSM), 40,000 for 3G (UMTS), 45,000 for 4G (LTE) standards, and even more for 5G

(Kwaq et al., 2011). Similarly, in the case of 5G, three 5G standards have been adopted internationally so far, two of which emerged within the 3GPP-ITU framework (Nanni, 2021).

As previously seen, one of the reasons for the creation of multiple standards is mostly given by the intention of countries to promote their own endogenous technologies as international standards in order to benefit from greater royalty payments and market shares. This intention, however, also entails some risks if technologies are not sophisticated enough or do not have sufficient political and economic support at the international level (Kennedy, 2006). As the case of China in 3G standards showed, China struggled a lot in promoting its national standard at the international level, reducing only slightly its dependence on foreign (western) technologies (Kwaq et al., 2011).

More recently, the setting of technology standards, above all mobile network standards, have been mostly unfolded at the global level. Given the growing interdependence of the global economy, countries and their industries have prioritized the development of globally developed standards to guarantee technological compatibility (Mattli, 2001b). For example, 5G standards have all been set at the global level. In addition to this, new aspiring standard setters, such as China and South Korea, which have strongly invested in increasing their influence as standard setters, have recognized the importance of shaping standardization directly at the global level, rather than at the national level[13].

To avoid confusion over the multiple mobile network standards, this research focuses only on the three latest mobile network standard generations (3G, 4G, 5G) that have been developed and recognized globally by the ITU-3GPP framework. These have been the

[13] Telecommunication technologies have experienced a greater harmonization of standards over the last decade. While 3G and 4G standards presented respectively three and two variations of standards, 5G is coming out as a globally unified standard (Cihon, 2019), which is one of the main reasons why countries and their industries have been putting large efforts in contributing to the standard. On the one hand, a globally unified standard guarantees a highly compatible technology; on the other hand, it intensifies the competition in the standardization process as the benefits of getting a patented technology recognized as SEP is even higher.

predominant mobile network standards (Kwaq et.al, 2011), guaranteeing the compatibility and interoperability of the largest number of mobile devices, infrastructures, and information systems across the world.

3.1.2 The International Telecommunication Standard Setting: a Complex System

These generational standards have been set by an international public-private driven process between two complementary SDOs, which combines the technical expertise of private stakeholders with the regulatory supervision of public stakeholders across various levels (Mattli, 2001a). These two SDOs are the International Telecommunication Union (ITU) and the Third-Generation Project Partnership (3GPP), which differ in status and membership.

The ITU is an interstate treaty-based organization whose membership comprises 193 member states, sector members, standard organizations, and universities. The 3GPP instead is a public-private transnational organization constituted by seven national/regional SDOs whose membership comprises national and regional regulatory bodies, telecommunication vendors, and operators. These seven SDOs come from different parts of the globe to develop common standards and endorse them as their official national or regional standards. The members of the 3GPP are ARIB (Japan), CCSA (China), ETSI (Europe), ATIS (United States), TTA (South Korea), TTC (Japan) and the recent partner TSDSI (India). In brief, while the ITU is intergovernmental and multilateral, the 3GPP is transnational and multi stakeholder.

The work of the ITU-3GPP partnership is established by a shared timeline that sets the main guidelines and requirements for the development of a new standard generation (Table 5). This timeline is generally approved by two important conferences, the World Radio Communication (WRC) and the World Telecommunication Standardization Assembly (WTSA), which convene every 4 years (Savage, 2019).

Table 5

ITU's IMT requirements

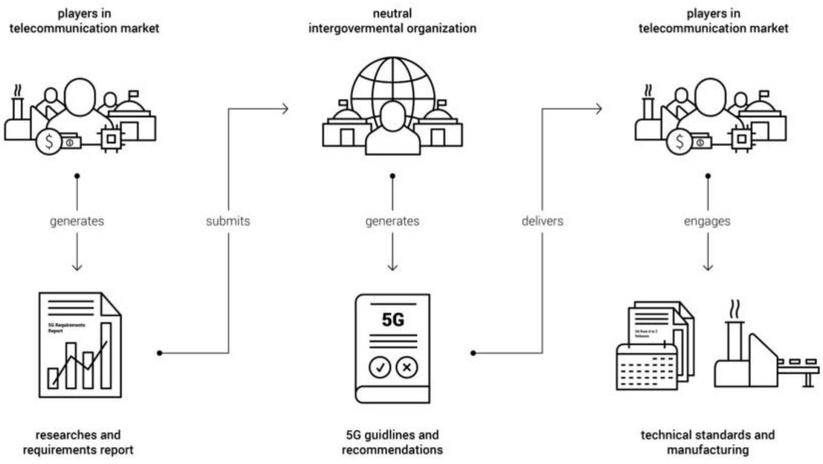
Standard Generation	Label	Description
3G	IMT-2000 (2000)	International Mobile Telecommunications 2000 is a worldwide set of requirements for 3G standards
4G	IMT-Advanced (2012)	International Mobile Telecommunication Advanced is a worldwide set of requirements for 4G standards
5G	IMT-2020 (2015)	International Mobile Telecommunication 2020 is a worldwide set of requirements for 5G standards

Through a hybrid institutional theoretical lens, the ITU-3GPP partnership can be analyzed as a complex system in which agency and authority are dispersed across various stakeholders and different levels of governance (Abbott&Faude, 2021). While the 3GPP develops the technical specifications of standards, the SDOs constituting the 3GPP transpose these technical specifications into national and regional standards, which are then eventually recognized by the ITU in the form of voluntary recommendations (Shao, 2020).

More specifically, this process unfolds through four main steps: first, private stakeholders operating under the 3GPP framework propose studies with new potential technological solutions. Second, these studies are submitted to the scrutiny of the ITU that generates guidelines and requirements accordingly. Third, based on this set of guidelines and requirements, private stakeholders start to compete and cooperate with each other over setting the best technological solution under the 3GPP framework. Specifically, in this process private stakeholders produce technical specifications (TS) that are eventually published in the form of technical releases. Fourth, these technical releases are subsequently approved as regional or international standards respectively by the ITU and the regional standard development organizations under the 3GPP (Baron & Gupta, 2018; Shao, 2020) (Figure 1).

Figure 1

Simplified Standard Setting Process for Generational Standards



Note. This figure was produced by Vince Ming Pu Shao to represent a simplified description of the 5G standardization workflow. From Shao, V.M. (2020, February 13). 5G: the Complicated Relationship between ITU and GGPP. Medium. Retrieved 10 May 2022, from https://medium.com/swlh/5g-the-complicated-relationship-between-itu-and-3gpp-719938f42b8

Thus, the work of the ITU-3GPP is delegated ex ante and validated ex post by both states through the ITU and the seven national and regional SDOs constituting the 3GPP. Therefore, although the private driven work of the 3GPP is performed independently, its outcome also depends on the inter-state regime of the ITU and the public-private SDOs constituting the 3GPP (Baron & Gupta, 2018; Shao, 2020). Based on these considerations, this research examines the ITU-3GPP as a single standardization process, which will be also referred to as the international telecommunication standard setting.

3.2 Different Perspectives on Standardization: Technological Determinism against Political Economic Arguments

The process by which standards are set in SDOs is called standardization. To distinguish standards from other similar rules of practice such as norms, standardization refers exclusively to the process by which the technical specification of a (mobile network) technology is created (Feng, 2003). This process occurs within the working and study groups (WG/SG) of SDOs, where stakeholders cooperate and compete to determine the best technical specifications for the standard.

For instance, in the 3GPP, working groups (WG) are divided into three technical study groups (TSGs), each of which represents a distinctive functional segment: radio access networks (RAN), service & system aspects (SA), and core network & terminals[14] (CT). In these working groups, decisions over technical specifications are generally made through consensus, which implies no opposition rather than unanimous agreement. If no consensus can be reached, the elected chair of the WG decides to take a vote. In the 3GPP, "a super-majority of at least 71% is required for the selection and inclusion of a technical proposal into a standard." (Gupta, 2017:12). At a later stage, the outcome of the WGs is presented to their respective TSGs which convene four times a year to discuss and approve the work of their WGs. As described in the previous section, these meetings result in the approval of the final technical specifications that are eventually converted into formal standards by the organizational partners of the 3GPP in line with the ITU requirements (Gupta, 2017).

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[14] A functional segment defines an aspect of compatibility within the standard "that is independent from the choice of another functional segment of the same standard". For example, the selection of a coding method for a data exchange system is done independently of the selection of a data transmission connector, as long as they are compatible (Weiss & Sirbu, 1990)

The nature of standardization and its outcome is a central debate in the literature. Two broad sets of arguments can be distinguished in the political science literature: the technological (instrumental) and political-economic perspectives (Peng, 2003). The technological perspective draws on functional, world society, and regime theories; in contrast, the political-economic view is based on conflict and structural power-based assumptions (Table 6).

The technological perspective argues that standardization is essentially a technical problem solved by a collaborative engineering process (Meyer & Rowan, 1977; Peng, 2003). This perspective assumes that engineers share a common goal: setting the best technical standard (Peng, 2003). Sharing a common goal is made possible thanks to the autonomy of engineers in SDOs, in which they are put in the condition to clearly "separate the political from the technical aspects" (David&Shurmer, 1996:794; Schofer, 1999). According to this perspective, economic and political forces are considered as exogenous factors that do not interfere with standardization, which is exclusively driven by technical considerations (Hawkins,1996; Peng, 2003).

On the contrary, the political-economic argument argues that several political and economic forces are present in standardization, turning standardization into a social problem rather than a technical one. As Cargill (2011) personally observed throughout his work, stakeholders in the standard-setting process promote technological solutions that are motivated by different corporate and national interests which transcend the mere technical aspects of technologies. According to this argument, standardization is driven not only by technical considerations but also by the competing interests of stakeholders embedded in the different technological solutions proposed for the standard.

As Gadinis specifically argues, standardization is not only shaped by the technical expertise of companies but also by the policy-making agenda of countries in which companies operate (Gadinis, 2015:8). In line with this argument, the outcome of standardization is rather "a form of codified power that reflects the values and the interests of those groups with the greatest access to and influence within standards-setting" (Busch&Bingen, 2006). As Russell argues, "stories about standards are necessarily about power and control—they always either reify or change existing conditions and are always conscious attempts to shape the future in specific ways" (Russell, 2012:80).

The technological-driven argument provides valuable insights into the standardization process. Standardization is, in fact, to a large extent the result of an engineering process driven by consensus and contribution. Its overarching goal is to ultimately guarantee compatibility and interoperability between products and services across the world. This perspective, however, also has some shortcomings. Focusing on shared values and goals does not explain how a collectively produced outcome, such as the setting of a common standard, is agreed upon when stakeholders have diverging values and interests. More precisely, it fails to explain the potential conflicts that may result from stakeholders with diverging preferences in the standard-setting process. For this reason, this study attempts to integrate the technology perspective with the political-economic one, highlighting the tension between the global need to set common standards and the political-economic logic of countries and their industries in international standardization. In particular, for the purpose of this study, standardization is mainly seen as a competition incorporating preferences that reflect different political and economic interests and values. As an ISO document confirms, "standards are never neutral. They reflect the strengths and innovations of those who develop them" (Blind&VonLaer, 2021).

3.2.1. Game Theory Models: Coordination Problems and Distributional Outcomes

The differences between the technological and the political economic arguments on standardization can be further explained by game theory models that focus on coordination problems and solutions (Mattli & Büthe, 2003; Schmidt et al.,1998). Game theories conceive stakeholders as players in games in which their individual payoff depends not only on their individual choices, but also on what the other players do. In other words, players take decisions in relation to what the other players might do. There is, therefore, a strong interdependence that shapes players' possible moves in the game (Hemenway, 1975:101).

Despite their differences, both arguments agree on the assumption that standardization is essentially a coordination problem over reaching consensus on a common standard; however, they disagree over the nature of this coordination (Mattli & Büthe, 2003). The technological-based argument on standardization resembles a pure coordination game. In this type of game the prevailing goal of players is to reach a common standard regardless of whose technological solution will be chosen because all the players will be better off with than without a standard. As Snidal argues (1985), there is no disjuncture between the collective interest of reaching a common standard and the personal interest of each player. Therefore, the choice over which technical solution is chosen as the standard is not conflictual as no player expects a special advantage of one standard over the other (Schmidt et al.,1998). In light of this, the coordination problem can be simply solved by providing players with information on their respective moves, which is a function that is generally guaranteed by SDOs. Once players solve the coordination problem and reach a common standard, it is in the interest of each player to comply, since no player has an incentive to defect (Schmidt et al.,1998).

The political economic argument on standardization is more closely associated with the battle of the sexes games (BoS), in which there are two pareto optimal equilibria that represent a situation in which no single player can be made better off without making someone else worse off (Weiss, 1993). In this kind of game, the goal of players is also to reach a common standard, namely a pareto optimal equilibrium, as it produces the highest total payoffs; however, this time players disagree over which technological solution (pareto optimal equilibrium) will be chosen as a common standard, since these solutions imply different relative gains. A common standard, in fact, produces overall the largest gains, yet these gains are relatively distributed according to the technological solution that is chosen as standard. Thus, players share a collective interest in reaching a common standard as it produces the highest payoff; yet, this collective interest is also affected by the personal interests of each player in promoting the standard that provides him or her with the greatest gains. In this case, coordination is reached if one of the two players persuades the other player to accommodate his or her interest on the second-best preference, establishing the pareto optimal equilibrium which provides him or her the greatest gains (Schmidt et al.,1998).

Both game theory models are positive-sum games in which successful coordination between players can produce a higher overall payoff. In the context of a pure coordination game, payoffs are conceived in absolute terms, while in the battle of the sexes they are considered in relative terms in relation to the influence of players. More empirically, countries and industries agreeing on a globally recognized standard would produce absolute gains. These gains, however, would then be distributed relatively to the capacity of countries and their industries to shape the standard-setting process. Hence, international cooperation over a common standard produces gains to all countries (which is indicative of a Pareto improvement), yet the distribution of these gains is established relatively to the industrial power of countries in the process. These distributions are commonly balanced in favor of the more powerful countries (Cowhey, 1990; Krasner 1991).

Between the two game theory models, the existing literature suggests that the battle of sexes game is more consistent in explaining the process by which standards are set globally (Mattli & Büthe, 2003; Schmidt et al, 1998). Countries and industries involved in the setting of international standards have always been aware of the greater value of having a globally compatible standard on the basis of which other technologies are developed and used across the world. Driven by this underlying motive, they have set up international SDOs, such as the ITU, aimed at developing common standards. At the same time, however, given the distributional effects of standards, countries and industries have also competed with each other over the promotion of their own patented technologies as international standards. As Drezner similarly argues, countries and industries' priority is to create standards as "obvious public goods"; however, the process by which these standards are set is often the result of significant "conflicts and disagreements", given by the distributional implications of standards (Drezner, 2004: 490). Against this background, the countries and industries with the largest number of patented technologies incorporated into the standard become the players with the greatest payoffs.

Importantly, for the purpose of having a globally recognized standard two main preconditions are necessary. The first precondition is having a certain level of cooperation among the major powers, such as the US and China, in the international system. As Drezner argues (2007) a great power concert is a necessary (and sufficient) condition for effective regulatory regimes such as international standardization. The second necessary precondition, which draws on functionalist premises, is having an institutional framework in which various stakeholders decide to cooperate and compete with each other. This institutional framework is represented by the ITU-3GPP framework in which technological powers through their industrial capacity set globally recognized standards.

Table 6

Different Perspectives on Standardization

Perspective	**Theories**	**Values and Interest**	**Game Theory Models**	**Payoff Matrix**
Technological driven perspective	Functional and world society theories	Generalized values and interests	Pure coordination model	Absolute gains

Political Economy perspective	Conflict and power-based theories	Self-oriented values and interests	Battle of the Sexes	Relative gains

3.3. Multiple Layers and Players in Standardization: State and Corporate Power

As previously seen, the setting of international standards is a complex and multilayer system in which agency and authority are diffused among different stakeholders operating at various levels (Garcia et al, 2015; Gratz, 2019). Thus, to possibly analyze power dynamics in such complexity, it is necessary to also consider private stakeholders such as companies as well as disaggregate the state into its different domestic regulatory agencies that participate in the politics of global economic governance, such as international standards (Kreienkamp & Pegram, 2019; Slaughter, 2004; Slaughter 2009).

In international standardization, these stakeholders can differ from each other in terms of their nature, role, interest, and contribution. According to Garcia et al. (2015), stakeholders can be located at three different levels that overlap each other: the industrial level, the governmental level and the standard setting level. The industrial level consists of a network of companies whose primary goal is to set standards as closely as possible to their market interests. The governmental level is instead constituted by a network of regulators and policymakers that are mainly interested in the functional as well as strategic implications embedded in standards. Lastly, the standards-setting level is made of standard development organizations (SDOs) that represent a synthesis of the two previously described levels, bringing together industrial and governmental stakeholders. Therefore, its outcome is mostly the result of the influence exercised by industrial and governmental stakeholders, engineers and bureaucrats.

Precisely in the context of mobile network technologies, the main stakeholders contributing to standardization are big private corporations such as telecommunication manufacturers and mobile operators. Indeed, these stakeholders possess the highest level of knowledge and expertise in the sector. Some of the most important stakeholders have been Qualcomm (US), Ericsson (EU), Nokia (EU), and, more recently, Huawei (China) and Samsung (South Korea).

More broadly, six main industries can be identified at the ITU-3GPP level by clustering private stakeholders by nationality (or headquarter location): the US industry, the European industry, the Chinese industry, the South Korean industry, the Japanese industry and the Taiwanese industry. These have provided the largest contribution to the standardization of generational standards over the last decades (Pohlmann et al., 2020).

Within these industrial blocks, stakeholders are primarily driven by their market interests, so they might have different preferences about the same standard. Despite this, the adoption of any of their technical contributions to the standard produces an overall benefit to the national industry to which they belong (Rühlig, 2020, Becker et al., 2022). Practically, Nokia and Ericsson, which belong to the European industry, might have different preferences over which patented technology should be adopted as a standard given the distributional benefits of SEPs. Despite these plausible differences, the inclusion of any of their patented technologies would eventually benefit the European economy and industry as a whole, assuming that their technologies carry European values and interests.

The technical contribution of public stakeholders such as governmental bodies is instead limited yet essential (Pohlmann et al., 2020). Governmental bodies mostly play supervisory and regulatory roles throughout the technical process (Garcia et al., 2005). Despite this, several studies suggest that governmental bodies either directly or indirectly shape the technical work of SDOs, by delegating authority to private stakeholders and promoting government-industry alliances (Abbott & Snidal,2009; Drezner, 2008, Mattli, 2001b; Kim et.al, 2020). In particular, great powers and their governmental bodies are supposed to promote and influence standardization, by trying to align international standards as closely as possible with their national interests (Blancato, 2019; Cihon, 2019). As Drezner argues, "even on [technical] issues in which there are large zones of agreement, such as standardization of technical protocols, the great powers will manipulate private forms of authority to achieve their desired ends" (2004: 479). Although it is difficult to measure such influence, the role of governments in standardization has arguably become more evident, especially, with the emergence of new technologies with geostrategic implications.

As for SDOs, they provide the institutional framework that brings together industrial and regulatory stakeholders. In the case of mobile network technologies, the ITU-3GPP provides the international framework in which global standards are developed. This process is characterized by the cooperation and competition of different stakeholders across different levels (Garcia et al., 2005). While standards are technically set by experts and engineers, policymakers influence them to pursue their political and economic interests (Malkin, 2022).

Based on these theoretical premises, changing power structures in international standardization, are measured by the direct and indirect contributions of industrial and governmental stakeholders to the process. This is informed by the international political economy (IPE) literature that defines and measures global power structures by integrating corporate power with state power (Starrs, 2013; Schwartz, 2019). State and corporations "are not subordinate to each other, but juxtaposed and intertwined; they use each other to increase their respective power positions" (Babic et al., 2017).

This implies, for example, that China's capacity to shape standardization in generational standards is mediated by the technical contribution and expertise of Huawei and the regulatory influence of the China Communication and Standard Associations (CCSA), which operates under the direction of the Ministry of Information Industry (MII). Similarly, the capacity of the EU to shape standardization is given by the contribution of its industry stakeholders, such as

Eriksson and Nokia, and the regulatory power of ETSI. In this context, stakeholders can also be perceived as institutional entrepreneurs who provide outputs that take into account countries' domestic regulatory framework and thereby their political-economic interests (Nanni, 2021).

In light of this, more scholars assume that countries' tech champions operating in the standardization of key strategic technologies contribute to determining power structures in the global economy (Hyun, 2022; Telenau, 2021). As Becker and et al argues, "From a corporate perspective, having a patented technology included in an internationally recognized standard brings royalties, whereas from a state's perspective, this same aspect brings industrial advantage" and power (Becker et.al, 2022:5). To put it simply, governments and private companies work together as "partners" to gain more influence in the international standard-setting process in order to export their national technology and standards. This allows them to reap the rewards of these standards (Padula & Pizetta,2022). So, this study assumes that the contribution of private and public stakeholders in international standardization represents an extension of states' ability to shape standardization (Malkin 2022). As Babic et al. argue (2017), "states use corporations and are dependent on them to create geopolitically relevant transnational ownership ties."

3.3.1. Framing Power Structures in Standardization: Standard Setters and Standard Takers

Drawing on previous discussions, this study starts by adopting a structural power-based perspective to analyze power shifts in standardization. According to this perspective, standardization is defined as an international regime whose outcome is a structural adaptation of power relations and interests (Krasner, 1982; Padula & Pizetta, 2022). Although international regimes are somewhat autonomous in their actions, this perspective considers them as an intervening variable that influences stakeholders' related behavior and desired outcomes (Krasner, 1982).

Based on this perspective, outcomes resulting from standardization can be divided into two extremes: countries as (leading) standard setters and countries as standard takers. Standard setters supply and export their technology and standards abroad through their international recognition (Kim et al., 2018). In general terms, they are able to use standardization to project their political and economic interests at the international level (Voo, 2022).

On the other hand, standard takers tend to demand and import foreign technologies for different reasons such as a lack of technical expertise. They use standardization either to align their economic and productive structure to international standards or more commonly to protect their domestic market from international competition. Standard takers pay substantial licensing fees making them highly dependent on standard setters, which are in a favorable position to set market and technological trajectories.

Countries and their industries can fall anywhere between being standard setters and standard takers. A country's position on this spectrum may vary depending on the technology and standard being considered. This means that a country can be a standard setter for certain technologies while being a standard taker for others.

Power shifts in standardization are caused by the changing position of countries along these two extremes. Importantly, the position of countries along the spectrum is determined by the capacity of their public and private stakeholder, regulatory bodies and industrial players, bureaucrats and engineers to shape the standardization process of a specific technology in SDOs.

Recent studies have observed changing power shifts in international standardization regimes around technical standards (The Atlantic, 2021). Changing power shifts have been particularly noted in telecommunication. To explain and interpret these power shifts, this study examines the conditions that may turn countries into leading standard setters in the next section.

3.4. Theoretical Expectations: Drivers behind a Leading Standard Setter

Thus, this study views standardization as a coordination (social) problem with distributional outcomes, implying power shifts determining winners and losers, namely standard setters and takers. To explain these power shifts, which reflect countries' capacity to shape standardization, this research attempts to build an analytical framework based on four theoretically grounded conditions, each of which draws on a different theory (Figure 2). These conditions, rather than inferring causality, provide a direction to the analysis, which, at this point, aims to explain under which conditions a country's preferred pareto equilibrium is reached, more practically, under which conditions countries turn into leading standard setters based on the mediated capacity of their stakeholders.

The first condition draws on functional theories that argue that participants in a social structure act in relation to their function (Elster, 2003; Kingsbury et al., 2009; Turner&Maryanski, 1979). In the context of standardization, the function of stakeholders is to agree on a common standard, which ideally reflects the best technological solution among many alternative technologies (Meyer&Rowan, 1977). Since functional approaches suggest that the best technological solution is chosen as a common standard regardless of stakeholders' own interests, the capacity of countries to shape standardization depends on the level of innovation of their industries (Blind, 2006; Blind & Gauch, 2009). In relation to this theoretical expectation, the existing literature agrees on the great importance of innovation in standardization; yet, it disagrees over the extent to which it influences standardization. Some scholars argue that being a great innovator is a sufficient condition for playing an influential role in standardization; others, instead, argue that it is necessary yet not sufficient (Suarez, 2003; Mattli&Büthe, 2003; Rühlig, 2020, Weiss,1991). As the literature suggests, there have been standard battles in which suboptimal technologies have been set (De Nardis, 2014; Drezner 2004) . Against this background, the first condition expects that a technological power that is a great innovator might be a necessary or sufficient condition to have a great capacity to shape standardization, and therefore be a leading standard setter.

The second condition draws on (structural) neorealist explanations that argue that countries' power distribution determines the outcome of international regulatory regimes through their political and economic capacity and preferences (Cowhey, 1990; Krasner, 1982; Krasner, 1990). According to this approach, the outcome of a common standard reflects the relative economic power of countries and their industries within the standardization process. On this theoretical expectation, the existing literature suggests a strong relationship between the countries' economic power and their ability to shape transnational voluntary regimes, such as the telecommunication standard settings (Bach&Newman, 2014; Blind&Von Laer, 2021). However, it disagrees over whether this economic power is a necessary or sufficient condition. Some scholars argue that economic power is a sufficient condition to drive standardization (Cowhey, 1990; Krasner, 1990). Other scholars, instead, find out that economic power is a necessary factor in the standardization process, but it might not be sufficient in determining the capacity of stakeholders to shape the standard-setting process (Mattli&Büthe, 2003). Drawing on these insights, the second condition proposes that a technological power with a large (digital) economic power might be a necessary or sufficient condition to be a leading standard setter.

The third condition draws on liberal domestic theories that explore the importance of domestic institutional arrangements in influencing global governance settings such as international standard settings (Bach, 2010; Katzenstein, 1978; Moravcsik, 1997). Mattli and Büthe assume that a high institutional complementarity between the domestic standard system of countries and the international standard-setting "plays a critical role in placing domestic firms in a first or second mover position when standardization becomes global" (2001:4). In the same vein, Cihon (2019:25) argues that "timely information" and "effective institutional knowledge", which are affected by the extent to which domestic institutions mirror international standard bodies, are key factors for successful influence in the standard setting process. Although the existing literature recognizes that institutional complementarity plays an important role in affecting the influence of stakeholders in the standard-setting process, it is not clear whether it is a necessary or a sufficient condition (Mattli&Büthe, 2001). In light of this, the third condition posits that a technological power with a highly complementary domestic institution might be a necessary or sufficient condition to be a leading standard setter.

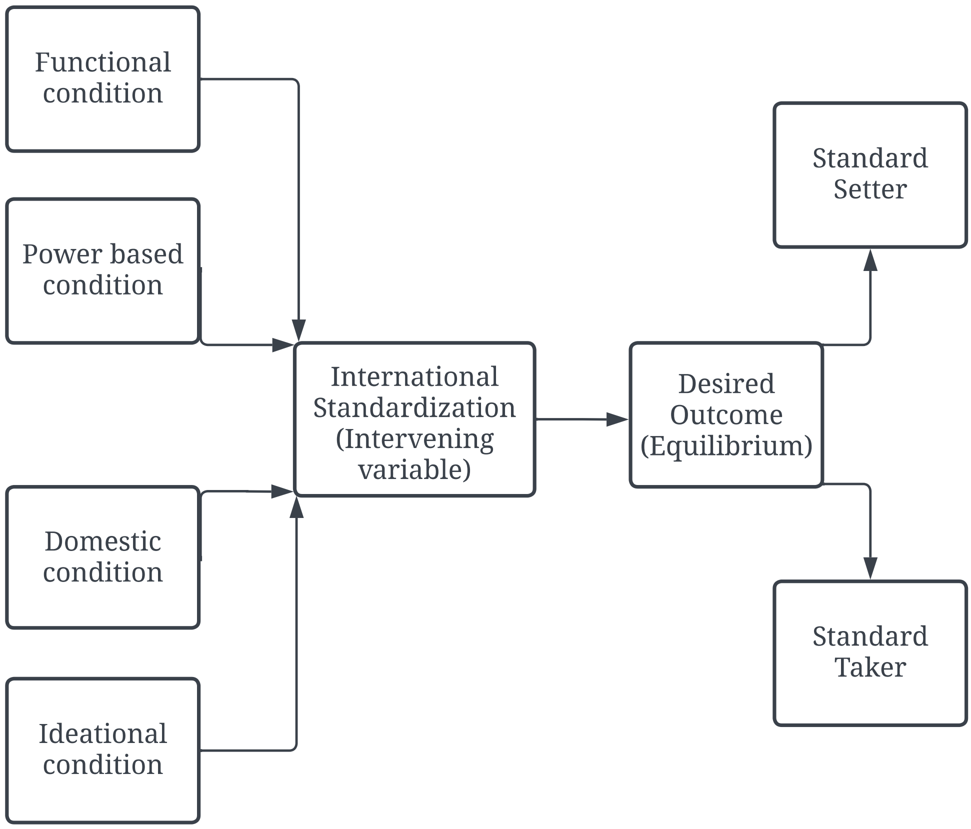
The fourth plausible condition builds upon social constructivist theories that elevate ideas and beliefs to the level of neo utilitarian and rational approaches in international relations (Katzenstein, 1978; Katzenstein, 1996:537). Ideas are defined as "mental constructs held by individuals, sets of distinctive belief, principles and attitudes that provide broad orientations for behavior and policy" (Tannenwald: 2005,15). The constructivist literature defines four typologies of ideas: ideologies or shared belief systems, normative beliefs, cause-effect beliefs, and policy prescriptions (Tannewlad: 2005:16). This research focuses on the last category, policy prescriptions, which are specific policy ideas associated with national strategies and policy programs.

According to constructivist scholars, ideas are not superior to power explanations or independent from it. Their argument is rather that power in its various forms presuppose ideas that affect the way in which power is exercised (Wendt, 1999: 135). In light of this, Wendt suggests inquiring into the "discursive conditions" that presuppose material explanations (Wendt, 1999: 135). Based on these assumptions, some constructivist scholars argue that countries' power and interest are also shaped by the substantive ideas held by policymakers in governmental plans, programs and strategies (Cohen, 2009). Goldstein et al. argue that policy ideas exercise this influence in two ways: they set roadmaps for political changes and they make sure that countries bind to these changes in the future (1993).

In the context of standardization, constructivist approaches suggest, therefore, that the power shifts in standardization, which is given by capacity of technological powers in shaping standardization, might be also explained by the policy ideas held by national policymakers in relation to international standards. In particular, there are different sets of policy ideas about the role of governments (and their equivalent regulatory bodies) in promoting international standardization, which might have an effect on the capacity of their respective countries and industries to shape standardization. In some countries, policy ideas frame regulatory bodies as granters, subsidizers, educators, and promoters of standards; while in other countries policy ideas are more limited. Those countries whose policy ideas envisage a wider role of their regulatory bodies with respect to standards might exercise a greater influence on international standardization. The existing literature is divided on the explanatory power of ideational factors, and implicitly, on the effects of policy ideas. Some scholars argue that “substantive ideas held by policymakers and advisers are decisive or necessary elements of explanations" (Odell, 1985: 85). Other scholars are more reluctant or simply ignore to recognize that ideas are as significant as material and power factors (Lake et al., 2006). Considering this debate, the fourth condition suggests that a technological power that is a standard-focused policymaker might be a necessary or sufficient condition to be a leading standard setter.

Figure 2

Analytical Framework



3.5. Research Design: Multi-Method Approach, Assumptions, and Structure

To address and test the analytical framework developed above, this study adopts a set-theoretic multi-method approach that combines a fuzzy set qualitative comparative analysis (QCA) method with a case-oriented process tracing (PT) analysis, combining cross-case level with within case-level analyses (Table 7). QCA is a set-theoretical approach that draws on qualitative and quantitative methods (Ragin, 1987, 2008; Rihoux & Ragin, 2009), by combining "the in-depth knowledge of case studies with the inferential power of large/medium number of cases" (Chatterley et al., 2014.3). More precisely, QCA conceives social phenomena as sets in which cases have different levels of memberships. Second, it analyzes social phenomena as complex combinations of different sets. Last, and more importantly, it identifies the necessity[15] and sufficiency of conditions for a specific outcome through set relations (Oana et al., 2021: 29).

This method is grounded on Boolean algebra and its fuzzy extension which allow for the set theoretic operations, and more precisely, the creation of truth tables as well as the minimization process (Mello, 2020: 83). While the Boolean algebra limited QCA to using crisp sets based on dichotomous categories that indicated respectively the presence or absence of a condition or an outcome, the introduction of the fuzzy set extension has allowed for further differences in membership degree in the analysis (Ragin, 2000).

QCA is based on three methodological assumptions: conjunctural causation, equifinality, and asymmetric causation. Conjunctural causation reflects a setting in which the outcome of a phenomenon of interest is generated by specific combinations of conditions. Equifinality, instead, describes a setting where different paths made of individual conditions, or a combination of conditions lead to the same outcome. Lastly, causal asymmetry implies that the multiple solutions of the outcome can usually not explain the absence of that outcome, which requires a separate analysis (Mello, 2020: 28-30).

The QCA analysis is structured into three parts (Oana et al., 2021): the pre analytical moment, the analytical moment, and the post analytical part. The pre analytical part consists in the theoretical framing and the measurement and calibration. More precisely, this part deals with (a) the identification of an outcome of interest with potential variations across time, (b) the identification of conditions and cases according to the existing literature, as well as (c) the calibration of conditions and of an outcome through externally conceived rules based on theoretical and empirical knowledge, which leads to the creation of the truth table (all the

[15] In brief, necessity refers to a condition that is always present when the outcome occurs, while sufficiency means that whenever a condition is present, so is the outcome (Oana et al., 2021:91)

calibrated conditions). The analytical moments instead address the analysis of necessity and sufficiency. This part identifies the multiple combinations of conditions that produce an outcome of interest through which the minimization process is performed. More specifically, the minimization process indicates all the multiple paths that lead to a specific outcome. Finally, the post-analytical part is dedicated to the diagnostics and robustness analyses, and the extent to which the results relate to the selected cases and the theoretical expectations.

Throughout the QCA analysis, two similar sets of parameters of fit are used to respectively evaluate the empirical relevance of necessary and sufficient conditions. More precisely, these sets of parameters indicate the extent to which set relations deviate from a perfect set relation either in terms of necessity or sufficiency. For necessary conditions, the set of parameters include: necessity consistency (Cons.Nec), necessity coverage (Cov.Nec), and relevance of consistency (RoN). The consistency parameter measures the extent to which the empirical evidence is in line with a set relation. As a rule of thumb, the consistency rate above which a condition can be considered necessary or sufficient is respectively 9.0 or 8.0. If the consistency rate is met, coverage and relevance of consistency (RON) are considered to assess the extent to which the condition is empirically important. Coverage expresses the difference in size between the condition and the outcome sets; whereas the RON parameter assesses the degree of trivialness, by controlling that a condition is not highly present for the negation of the outcome. Both parameters should be above 0.6. Sufficient conditions are evaluated to a similar set of parameters that include: consistency sufficiency (incluS), proportional reduction in inconsistency (PRI), coverage sufficiency (CovS), and unique coverage CovU). Unique coverage considers the cases that are covered only by one set of conditions. The same thresholds are applied to the parameters of sufficient conditions (Oana et al., 2021).

The QCA analysis, which is rather used for explorative means, is followed by a comparative case-oriented process tracing analysis that identifies and compares the causal mechanisms of two typical cases for each sufficient path and a set of coverage deviant cases that are omitted by the QCA results (Beach, 2017). In particular, this research adopts George and Bennett's approach that defines process tracing as "the use of histories, archival documents, interview transcripts, and other sources to see whether the causal process a theory hypothesizes or implies in a case is in fact evident in the sequence and values of the intervening variables in that case" (George and Bennett, 2005: 206). For the process tracing analysis, most typical cases are selected in order to further assess the causal mechanisms that connect the sufficient paths to the outcome; whereas, coverage deviant cases are chosen to understand and explain cases that are full members of the outcome, but are not explained by any sufficiency paths. So, while typical cases are analyzed to understand if causal mechanisms identified in the cases can be further generalized; deviant cases are analyzed to identify potentially omitted theoretical elements (Oana et al., 2021: 186-192). These cases are selected through visual inspection of the xy plots, their parameters of fit, and a specific R function which provide the most suitable cases in terms of consistency and coverage. More specific methodological considerations on the PT analysis are presented in the second empirical chapter.

Table 7

Multimethod Approach

Qualitative Comparative Analysis (QCA)	**Process Tracing (PT)**
Explorative	Evalutative
Cross-case analysis	Within-case analysis
Identifying and detecting conjunctions instead of testing for theorized patterns/conjunctions	Tracing (and testing) mechanisms triggered by conjunctions

The literature showed that factors shaping standardization are often subject to other factors' influence, which goes against the assumption of correlation-based approaches. To address this issue, the study adopted a configurational approach (QCA) to analyze various combinations of conditions and their degree of necessity and sufficiency. QCA was only used as a starting point for the analysis, as it does not determine whether conditions are causal or operate simultaneously. Instead, it serves as an exploratory tool to identify the set of conditions that potentially trigger the sufficient causal mechanisms that produce the outcome of interest. After the QCA analysis, the study employed a process-tracing method to identify the mechanism and test the theoretical claims generated by the combinations of conditions.

4. Qualitative Comparative Analysis (QCA): Conceptualization, Calibration, and Analytical Results

Drawing on the QCA structure illustrated above, this chapter conceptualizes, measures, and calibrates the membership of cases in relation to the outcome and conditions. In sum, the QCA dataset of this study contains one outcome and four conditions. These are operationalized with quantitative and qualitative indicators calibrated by recording or direct methods (Ragin, 2009). Thresholds for inclusion and exclusion of case sets are justified by identifying gaps in the raw data, carrying out case study analysis (De Block&Vis, 2019), or by creating imaginary cases for full membership and full non-membership (Basturo and Speer, 2012). Different degrees of case set membership are established by creating coding schemes that provide verbal explanations.

The outcome and the four conditions represent the dataset's basic level sets. Each basic level set is further divided into three or four secondary level sets, based on which the overall membership score of the basic level case sets is established. The overall membership score can be established in three different ways: the classical approach, the substitutability approach, and the family resemblance approach. The first approach considers the minimum value of the calibrated secondary level sets; the second approach takes the maximum value of the secondary level sets; while the third approach takes the value of the secondary-level sets in combination, by considering the extent to which cases are sufficiently similar to be part of the basic level set (Oana et al,2021:55). In the following sections and subsections, the study operationalizes individually the outcome and the four conditions of the dataset (Table 8). Based on them, the last section illustrates the analytical results of the QCA, providing the most consistent sufficiency paths and related interpretations.

Table 8

Dataset Including Conditions and Outcome

Dataset	Conditions 1 (Functional)	Conditions 2 (Power-based)	Conditions 3 (Domestic)	Conditions 4 (Ideational)	Outcome
Basic level Set	Great ICT innovator	Large economic power	A highly complementary domestic configuration	A standard-focused policymaker	Leading Standard setter
Indicators	Share of GDP on R&D Level of technological competitivenes s	Share of ICT manufacture Share of ICT added vale	Institutional configuration of domestic standard bodies	Governmental declarations	Share of SEPs, contribution, participation, and leadership positions in SDOs
Data	OECD database (quantitative)+IMD ranking (quantitative)	OECD's Trade in Value Added (TiVA)	Domestic standard bodies websites (qualitative)	Domestic standard bodies websites + related governmental bodies (qualitative)	IPlytics Platform database+ other datasets (quantitative)
Calibration	Fuzzy set/Direct method/ Minimum value	Fuzzy set/Direct method/Minimum value	Fuzzy set/Recoding method	Crisp set/ Recoding method	Fuzzy set/Direct method/ Family resemblance

4.1 Outcome: What Is a Leading Standard Setter?

The outcome of the QCA analysis is constituted by the basic level set, a leading standard setter. A leading standard-setter is a technological power that has a great capacity to shape standardization. The capacity to shape standardization is generally conceptualized as the ability of countries and their industries to "translate their R&D into international standards" (Blind&VonLaer, 2021:15). In other words, it is the capacity to turn countries' industrially produced outputs into international standards (Blind&VonLaer, 2021:4; Lerner & Tirole, 2015). Similarly, Kennedy (2007) conceptualizes the capacity to shape standardization as the ability to gather consensus around a set of technological solutions. From a more technical perspective, this is defined as “the ability to build broad consensus across the [standardization] ecosystem [and] drive an end-to-end design[16]” (Qualcomm, 2019). Consensus is assumed to be “always partial, transitory, and possibly forged through extra-scientific factors”, despite the inherent technical nature of standardization (Hass, 2019).

Drawing on this literature, this research defines the capacity to shape standardization as the ability of technological powers to promote their industrially patented technologies into the international standard. As some standard experts pointed out in their interviews[17], this capacity consists in turning their “own interests”, in the form of a patented technology, into a “collective interest”, namely a standard essential patent. Thus, the extent to which technological powers build consensus around their interest-embedded technologies is a determinant factor for having a great capacity to shape standardization and being a leading standard setter. This capacity is mediated by the ability of its stakeholders to develop SEPs, participate and contribute actively to the standard-settingg process, and hold leadership positions in working groups. The greater this ability, the greater the capacity of technological powers to include their patented innovations in the international standard, thereby becoming a leading standard setter.

4.1.1 Measurement

The basic level set, a leading standard setter, is further constituted by four secondary level sets: top patent holder, large participation, high standard contribution, and numerous leadership positions. These secondary level sets are respectively operationalized with four indicators: the share of declared standard-essential patents (SEPs), participation, standard

[16] Driving an end-to-end design means being able to standardize a technological solution, which entails more technical specifications, from the proposal phase to the approval phase across numerous study and working groups
[17] Interview conducted during my research abroad at the Global Governance Center in Geneva in 2021

contributions, and leadership positions in SDOs working groups (WG), respectively by stakeholder's country of origin and standard generation. Each of these indicators captures a distinctive property of the set leading standard setter.

The first indicator, declared SEPs, consists of the share of patented families that national and regional industries declare essential for a specific standard. Declared SEPs do not fully reflect the real share of SEPs that are eventually included in the standard. Most of the time SEPs declarations are filed as standard-essential patents in standard development organizations without any third-party approval or while still pending (Baron & Pohlmann, 2019). Therefore, their status can change after their declarations, as some might not be essential during the standardization process. In addition, even when the standard is set, there is no systematic analysis that establishes the degree of essentiality of a declared SEP. According to some studies, only 30% of all declared patents are estimated to be essential (Pohlmann, 2021). Despite these shortcomings, SEPs declarations are still considered one of the best sources to assess SEPs' industrial ownership and more broadly the influence of countries in the standard landscape. This claim is further validated by the fact that telecommunication is one of the sectors with the highest level of matching between declared SEPs and specific standard documents, which implicitly indicates that there is a high degree of matching between declared SEPs and (real) SEPs (Baron & Pohlmann, 2018). Despite SEPs useful indication, other indicators are required to provide a full picture of the capacity of technological powers to shape standardization.

The second indicator, participation, measures the level of attendance of engineers and corporate representatives in the SDO working groups (WG), by stakeholder's country of origin[18]. More precisely, the indicator considers the level of participation in the RAN working

[18] The share of engineers and market representatives attending the radio access network (RAN) working group (WG) of the 3GPP

group, which is the WG with the highest level of participation of experts. In aggregate terms, this should indicate the extent to which each national industry participates and commits itself to standardization. Given this interpretation, the second indicator provides a further assessment of technological powers' capacity to shape standardization (Pohlmann, 2021; Rühlig, 2021; Weiss, 1991).

Although the second indicator captures the level of commitment to the standardization process, it does not measure the level of contribution of each national industry to the development of the standard. For this reason, the third indicator looks at the share of standard contribution by stakeholders' country of origin. Standard contributions are technical proposals submitted by various private stakeholders, above all firms, in standard development organizations (SDOs). In the case of the 3GPP, private stakeholders submit standard contributions, which can take different forms, to various study groups. Although it is very difficult to assess the real contribution of these standard contributions, they are generally considered a suitable indicator for assessing the overall influence of national industries in SDOs, and thereby the influence of technological powers in the standardization process. As Pohlmann argues, the approval of technical contributions can be indicative of "how much share and influence firms have in the development of a standard such as 5G" (Polmann, 2020: 24).

The fourth and last indicator instead takes into account the share of leadership positions, namely chairman and vice chairman positions held in the 3GPP by stakeholder's country of origin and standard generation. In the 3GPP, these positions are held by corporate and organizational representatives. Those who hold a leadership position can exercise a great influence in the standardization process, by overseeing and managing the decision-making process. For example, if no consensus is reached around a technical specification, the chairman plays a decisive role in promoting or disregarding that technical specification (Blind&Von Laer, 2021). In addition, leadership positions in SDOs require not only human and financial capital but also managerial and technical skills (Spring et al., 1995). As a matter of fact, when electing leadership positions voters tend to give great importance to the technical and material capabilities of the firm/country whose candidate is representative of. Given this implication, the share of leadership positions can also be very indicative of the capacity of technological powers to shape standardization.

4.1.2 Data

The data on SEPs declarations, attendance share, and technical contributions respectively per country origin and standard generation draw on the available studies published by the IPlytics platform database, which is one of the most comprehensive databases on SEPs and standard contributions. The IPlytics Platform integrates in a systematic way various SEPs declaration databases and matches them to worldwide patent information and worldwide standard and contribution databases. This matching provides detailed information by standard generation, technology groups, current owner, status, and other relevant categories.

Focusing on telecommunication standards, the IPlytics database compiles declared patents by cross-correlating declared SEPs with ETSI and 3GPP standard data. Since patented technologies can be essential across different standard generations, the same SEPs declaration can be recounted for each generation. The database also collects standard contributions submitted to the 3GPP. These technical proposals are submitted, reviewed, and voted on in various WG constituting the 3GPP. This data is very helpful to analyze the influence of countries especially when their respective industrial stakeholders do not publish or disclose their SEPs in SDOs databases. In addition to the IPlytics Platform, I retrieve further data from the study of Bekkers et al. (2020), which provides a comprehensive data analysis on the patent landscape related to the time frame corresponding to the development of 3G standards, which was not (publicly) accessible at the IPlytics Platform.

As far as leadership positions are concerned, data are retrieved from the 3GPP database. In particular, the data focus on the share of leadership positions held by stakeholders in three specific time intervals that correspond to the examined telecommunication generation.

4.1.3 Calibration

The basic level outcome, leading standard-setters, is a fuzzy set made of four secondary sets. The overall membership score of the basic level set can be established in three different ways: the classical approach, the substitutability approach, and the family resemblance approach. The set, leading standard setters, follows a family resemblance approach, whereby the combined values of the individually calibrated indicators of the secondary level sets determine the membership scores of the QCA cases (De Block&Vis, 2019). These indicators are calibrated through a direct method that establishes three relevant set membership thresholds: the threshold for full membership (1), the crossover point defining the difference in kind (0.5), and the threshold for nonfull membership. I justify the location of the qualitative thresholds that determine the membership scores of these indicators, by identifying gaps in the raw data and considering case-specific knowledge and expert views.

The first secondary level set, a top patent holder, is operationalized with the share of declaring SEPs. Technological powers whose industries hold a patent share equal to or above 20% obtain a set membership of 1, classifying cases as top patent holders. Case study analyses show that leading standard setters over telecommunication generations have held a patent share above 20%. The crossover point is fixed at 14%. This value corresponds to the median and is located in a notable gap in the data. The threshold for non-full membership is fixed at 7% with no holding patent share.

The second secondary level set, a large participation (participator), is measured by the share of participation of individuals in SDOs. Technological powers with a share of 15% are considered full members of the subset. According to case-specific knowledge, 15% is considered to be a high level of participation over the last standard generations, which has been reached only by influential standard players. The crossover point that establishes the differences in kind is located at 12%, which corresponds to a notable gap in the raw data. The exclusion anchor is set at 6%.

The third secondary level set, large standard contribution, takes as the base variable the share of standard contribution. Technological powers that hold a share equal to and above of 20% obtain full membership. This value is located in relation to a large gap in the raw data, above which cases hold the largest majority of standard contributions. The point of indifference is located at 10%, which corresponds to the median and a notable gap in the raw data. Full nonmembership is fixed at 5%.

The fourth secondary level set, numerous leadership positions, is operationalized on the basis of the number of chairman and vice-chairman positions held in the SDO. The threshold for full membership is set at 5 leadership positions. This value is chosen with the help of experts that suggest assigning full membership above that value. The crossover point and the threshold for nonfull membership are located respectively at 3 and 0.

Following the family resemblance approach, leading standard setters are technological powers that are sufficiently similar in relation to four secondary level sets. In other words, leading standard setters are technological powers that have at least three of the four defining properties of the outcome (Table 9 in Annex I).

4.2 Condition One: What is a Great (technological) Innovator?

The first condition is formed by the basic level set, a great innovator which focuses on the relationship between innovation and standardization. Innovation is a broad term that can be defined in different ways. In general, scholars associate innovation with the creation of new knowledge, mostly in the form of new goods and services (Kotey & Sorensen, 2014). Private stakeholders, such as firms, generate most of this knowledge; however, public stakeholders such as regulatory bodies also play an important role (Freeman, 1987; Watkins et al., 2015). Drawing on this literature, a technological power that is a great innovator is defined as a great knowledge creator and technological enabler. This can vary according to two different dimensions: the amount of resources devoted to R&D and the level of technological competitiveness of countries. The level of technological competitiveness is further divided into three subfactors: the degree of expertise, openness and preparedness in creating and adopting new technologies.

4.2.1 Measurement and data

The basic level set, a great innovator, is formed by two secondary level sets: a large R&D investor and a high technological enabler that are operationalized respectively with two indicators: the domestic expenditure of countries on R&D expressed as a percentage of gross domestic product (GDP), and the level of technological competitiveness of countries that is based on the degree of expertise, openness and preparedness in creating and adopting new technologies. R&D expenditures are indicative of countries' investments in innovation; whereas the level of technological competitiveness arguably measures the extent to which countries turn these R&D investments into tangible innovations. These two indicators can be respectively seen as proxies for measuring the R&D inputs and outputs of countries and their industries.

There are several studies that demonstrate a positive link between R&D and the ability to produce standard-essential patents (Shapiro and Varian, 1999). Similarly, the level of technological competitiveness of countries ideally reflects their capacity to produce and adopt new technologies that might become standards (Shapiro and Varian, 1999). Variations in R&D expenditures and technological competitiveness are therefore likely to affect the capacity of technological players to shape standardization.

The data of these indicators are retrieved from the OECD database and the IMD World Digital Competitiveness ranking (WDC). The OECD database collects data according to the OECD methodology for R&D statistics (as presented in the OECD Frascati Manual). The GDP expenditure on R&D includes all the R&D spending carried out within an economy on a yearly basis. The R&D data expressed as a percentage of GDP is chosen over the R&D data that is expressed in absolute terms to allow better cross-country comparisons.

The IMD World Digital Competitiveness (WDC) annual ranking analyzes the level of technological competitiveness of countries, by combining hard data with survey data that are retrieved both from the private and the public sectors across three major pillars: knowledge, technology, and future readiness. Knowledge refers to the level of expertise of countries in building new knowledge; technology looks at the overall context that enables digital innovation; while future readiness considers the level of preparedness in adopting new technologies. These three blocks are further divided into factor-specific subcategories.

4.2.2 Calibration

The first condition, a great innovator, is a fuzzy set that is composed of two secondary-level sets. The overall membership score of the basic level set is established through a classic approach that takes into account the minimum value of the two individually calibrated secondary level sets: a large R&D investor and a high technological enabler. These sets are calibrated through a direct method that establishes three relevant set membership thresholds: the threshold for full membership (1), the crossover point defining the difference in kind (0.5), and the threshold for nonfull membership. I justify the location of the qualitative thresholds that determine the membership scores of these indicators, by identifying gaps in the raw data and considering case-specific knowledge.

The first secondary level set, a large R&D investment, is operationalized on the basis of the GDP expenditure of technological powers on R&D. Mobile network standards, such as G standards, are not developed on a yearly basis, but rather they are the result of an iterative and contributive process that can take more years; therefore, the value used to assign membership degrees is represented by the average GDP expenditure on R&D by country in a specific time range, namely the years in which the largest part of the standard is developed. Based on these considerations, technological players with a GDP expenditure on R&D that is equal to or higher than 2.5 percent get a membership score of 1, which classifies cases as large R&D investors. The cross-over point is fixed at 2 percent. The threshold for nonfull membership is located at 1.5.

The second secondary level set, a high technological enabler, is measured with the IMD digital competitiveness index. This index consists of a ranking that assesses the digital competitiveness of countries on a score that goes from 0 to 10. The value used to assign membership degrees is represented by the average score of a country in the time period that corresponds to a standard family. The values of the EU countries, which are considered as an unitary player, are further aggregated. The qualitative thresholds are set as follows: technological powers with a score higher than 7.5 are considered full members of the set, a great technological competitiveness. The crossover point and the threshold for full exclusion are set respectively at 7 and 5, in line with the qualitative explanations of the index. By adopting the classical approach, technological powers not only have to be full members of the set large R&D investor but also to the secondary level set a great technological enabler to be a full member of the basic level set, a highly innovative ecosystem (Table 10 in Annex I).

4.3 Conceptualization: What is a Large Economic Power?

The second condition is constituted by the basic level set, a large economic power, which focuses on the nexus between economic power and standardization. Economic power is commonly associated with the industrial capacity of countries to produce, buy and sell goods and services (Whalley, 2009). Countries can exercise this power unilaterally or collectively through coercion or persuasion. For example, countries with a great economic power at the international level may exercise their power, by threatening to restrict markets, increase trade barriers, or hampering investments (Whalley, 2009). In the context of standardization, economic power is expressed by the economic size and value of industries in the standard setting process, through which industries can socially and economically persuade other competing industries to adopt their technological solutions (Weiss&Sirbu, 1991). In this case, the economic size and value of the ICT sector of technological powers is taken as a sector reference since it includes most of the technologies that are standardized at the 3GPP/ITU level. In light of this, a technological power with a large economic power is a great ICT manufacturer and value adder.

4.3.1 Measurement and data

The second basic set, large economic power, is made of two secondary level sets: a great ICT manufacturer and a high ICT value adder. These are operationalized with two indicators: the ICT gross output percentage of the world total ICT gross output by country/region, the ICT added value percentage of world total ICT added value by country/region. The first indicator measures the total economic activity of technological powers in the ICT sector, which is equal to the value of GDP plus intermediary consumption; the second indicator assesses the ability to generate additional value to the ICT sectors, by measuring the value of gross output minus the value of intermediate consumption. These two indicators are indicative of the economic power of technological powers in the ICT sector, which is the sector that includes most of the mobile network technologies that are standardized at the ITU/3GPP level. These indicators are chosen, by drawing on studies that show a positive correlation between the economic power of industries and the incorporation of technical specifications into standards, especially in the case of ICT technologies (Weiss and Sirbu, 1991).

The data are taken from two databases. Data on ICT gross output and added value are retrieved from the OECD's Trade in Value Added (TiVA) database that includes a collection of economic indicators for the years 2005-2016. Data on ICT gross output and ICT value added refer respectively to two categories: computer and electrical equipment (D26T27) and information and communication technologies (D58D63). Although this database might exclude some telecommunication technologies such as mobile core networks or service providers, it is, to my knowledge, the publicly accessible dataset on ICT technologies with the most comprehensive and consistent data across time and country.

4.3.2 Calibration

The second condition, a large economic power, is a fuzzy set calibrated with a direct method. The overall membership score is established by considering the minimum value of the two calibrated secondary levels sets: a great ICT manufacturer and a high ICT value adder. Therefore, a technological power that is a large economic power needs to be simultaneously a great ICT manufacturer and a high ICT value adder. The location of the qualitative thresholds of each set is established by identifying gaps in the raw data and considering case-specific knowledge. The reference value for the assignment of membership scores is represented by the average value of a given indicator by country or set of countries and standard family.

The first secondary level set, a great ICT manufacturer, is operationalized with the ICT gross output percentage of the world total ICT gross output by country. A technological power whose industry holds a percentage equal to or above 15 obtain full membership. Cases with this score are classified as great ICT manufacturers. The crossover point is set at 11. This value coincides with a notable gap in the raw data. The threshold for full nonmembership is set at 2, below which cases cannot be considered members of the set, a great manufacturer.

The second secondary level set, a high ICT value adder, is measured by the ICT added value percentage of the world total ICT added value. A technological power whose industry holds a percentage equal to or above 20 obtains full membership. Cases with this score are classified as great manufacturers. The crossover point is set at 15. This value coincides with a notable gap in the raw data. The threshold for full nonmembership is set at 5, below which countries cannot be considered members of the set, a great manufacturer (Table 11 in Annex I).

4.4 Condition Three: What is a Highly Complementary Domestic System?

The third condition is constituted by the basic level set, a highly complementary domestic system, which focuses on the role of domestic institutions in influencing the outcome of international regimes. Studies show that countries with a domestic standardization body, which is complementary to the international standardization regime, have a greater capacity to shape standardization. Complementarity between domestic and international institutions provides competitive advantages to industries. In line with this, technological powers with a highly complementary domestic system have a domestic institutional framework that is largely matching the international standard setting regime. In this case, the ITU-3GPP is based on a public-private framework; therefore, technological powers whose institutional framework relies on a similar public-private configuration are considered highly complementary to the international standard-setting.

4.4.1 Measurement and Data

This condition is operationalized by analyzing the institutional configuration of domestic standard bodies. These standard bodies can vary in terms of their institutional nature across three dimensions: standard bodies can be private-driven, public-private driven, or state-driven. For example, the US system has been characterized by a private-driven system; by contrast, the Chinese and the Korean ones have long been state-driven; whereas, the European one has been mainly public-private driven. The institutional configuration of countries' standard bodies is considered correspondingly to the time frame in which each standard has been developed. I retrieve the data from various SDOs websites such as ETSI, ANSI, and SAC and various policy papers.

4.4.2 Calibration

This condition is a fuzzy set that is calibrated through a recoding method that groups the qualitative data into four qualitative thresholds. Membership scores are established on the basis of a coding scheme that verbally explains the location of the qualitative thresholds. Technological powers whose standard domestic body has a public-private driven system are considered full in (1). Countries that have a private-driven system are considered more in than out (0.67); countries with a state-driven system are considered more out than in (0.33); and countries with a different configuration are considered fully out. The crossover point is located at 0.67. (Table 12 in Annex I).

4.5 Condition Four: What is a Standard-Focused Policymaker?

The fourth condition is formed by the basic level set, a standard-focused policymaker, that focuses on the relationship between the policy ideas of national policymakers and international standardization, assuming that the discursive power of ideas is as important as "the control of material resources and structural power" (Nelson&Tallontire, 2014: 482). In particular, there are different sets of policy ideas about the role of national and regional regulatory bodies in standardization. In addition to their primary function of standard enforcer, policy ideas can conceive regulatory bodies as granters, subsidizers, educators, and promoters in order to increase the international footprint of their respective industries in standardization. Policy ideas that conceive regulatory bodies as granters, subsidizers, educators and/or promoters can translate into a set of policy actions that include the provision of research grants, tax breaks, information exchange, and public private initiatives (Garcia et. al, 2005). All these measures might provide a competitive advantage to industrial stakeholders in the setting of international standardization. Drawing on this literature, a standard-focused policymaker is defined as a technological power that promotes policy ideas that attribute to its regulatory body the role of granter, subsidizer, educator, and promoter in support to its industry in international standardization.

4.5.1 Measurement and Data

This condition is assessed qualitatively, by focusing on the policy ideas that are included in the legislative proposals, industrial plans and programs that are issued by national and regional regulatory bodies with regard to international standards. More precisely, a standard-focused policymaker is assessed on the basis of four policy areas, namely: R&D grants, subsidies and tax breaks, professional training courses, and public-private initiatives. Each policy area is associated with a specific role: the provision of R&D grants conceives the role of regulatory bodies as granters, subsidies and tax breaks as subsidizers, education grants and information exchange as educators, and, lastly, private and public initiatives as promoters. These policy areas and roles can overlap each other and vary across cases and time. Data are mainly retrieved from national and regional regulatory bodies as well as ministerial institutions responsible for issuing industrial plans and programs relative to international standardization. Some of these plans are, for instance, the EU Standardization strategies 2022 and China Standard 2035.

4.5.2 Calibration

The basic level set, a standard-focused policymaker, is a fuzzy set. The thresholds for inclusion and exclusion are set through a coding scheme. Technological powers whose policy ideas conceive the role of their regulatory bodies as a granter, subsidizer, educator and promoter obtain a membership score of 1 and get classified as a standard-focused policymaker. Technological players that instead cover three of the four policy ideas get a membership score of 0.67. Lastly, technological powers with policy references to two or one or none of the policy areas get respectively a membership score of 0.33 and 0 (Table 13 in Annex I).

4.6 Analytical Results

The analytical results of the QCA show all the possible relations between sets in terms of necessity and necessity on the basis of three parameters of fits: consistency, coverage, and relevance of necessity (RoN). The QCA results show that there is no single condition that can be considered necessary. All the conditions have in fact a consistency rate below the recommended threshold set at 0.9. The first condition, a great digital innovator, has a consistency rate of 0.8. The second condition, a large ICT economic power, has a slightly higher consistency rate of 0.83. While the two remaining conditions, a highly institutional complementarity and a standard-focused policymaker have respectively a consistency rate of 0.8 and 0.7.

There is, however, one combination of two conditions that can be considered as necessary for the outcome. This combination of conditions, which is defined as SUIN conditions, are: a great digital innovator and a large ICT digital economic power. This combination has a consistency rate above 0.9, and a coverage rate above 0.6. The relevance of necessity of this combination is, however, lower than 0.6. The literature argues that sets lack empirical consistency under a 0.6 threshold.

Similarly, to the analysis of necessity, there is no condition that can be considered sufficient for the outcome, as no single condition reaches a consistency rate above 0.9. A large digital economic power is the condition with the closest consistency rate to 0.9, with a consistency rate of 0.87. The other conditions instead score lower consistency rates around 0.7.

When assessing sufficiency in terms of multiple conditions in conjunction, however, the conservative solutions given by the minimization process of the truth table reveal three sufficiency paths for the outcome. Two paths are respectively constituted by three conditions and one path by four conditions. The first path is made of a great digital innovator, a large ICT economic power, and a highly complementary institutional system; the second path consists of a great digital innovator and a large ICT economic power, and a non standard- focused policymaker; the third and last path results from a non great digital innovator, a large ICT economic power, a non highly complementary system, and a standard focused policymaker. The first path includes the following cases: China 5G (2016-2020), EU 5G (2016-2020), EU 4G (2008-2015), EU 3G (2000-2007), Japan 3G (2000-2007). The second path covers: US 5G (2016-2020), US 4G (2008-2015), Japan 4G (2008-2015), US 3G (2000-2007). The third path, instead, is represented only by one case, namely: China 4G (2008-2015) (Figure 3).

Figure 3

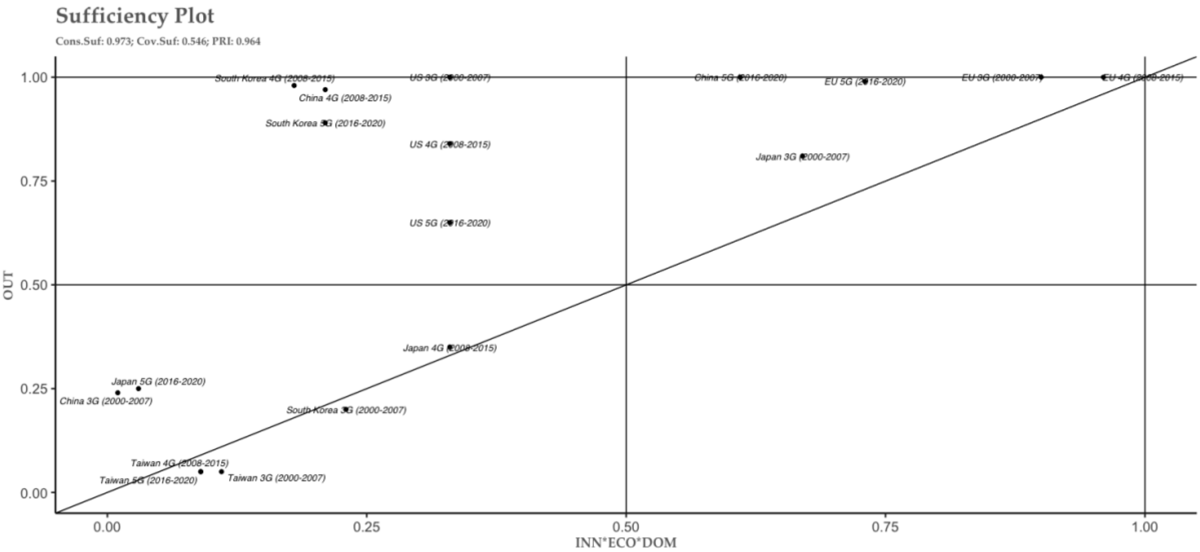
Sufficiency Paths and Parameters

```
M1: INN*ECO*DOM + INN*ECO*~POL + ~INN*ECO*~DOM*POL -> OUT

                      inclS   PRI   covS   covU
-----------------------------------------------
1       INN*ECO*DOM   0.973  0.964  0.546  0.243
2      INN*ECO*~POL   0.921  0.886  0.393  0.090
3 ~INN*ECO*~DOM*POL   0.903  0.806  0.148  0.074
-----------------------------------------------
                 M1   0.945  0.928  0.710

                      cases
--------------------------
1       INN*ECO*DOM   EU 4G (2008-2015); China 5G (2016-2020),EU 5G (2016-2020),EU 3G (2000-2007),Japan 3G (2000-2007)
2      INN*ECO*~POL   US 5G (2016-2020),US 4G (2008-2015),Japan 4G (2008-2015),US 3G (2000-2007); EU 4G (2008-2015)
3 ~INN*ECO*~DOM*POL   China 4G (2008-2015)
```

This study focuses specifically on the first two sufficiency path, which meets to a sufficient degree the parameters of fit for consistency and coverage. The first path has sufficient consistency and PRI rates higher than 0.9, plus sufficient and unique coverage rates respectively at 0.5 and 0.2 (Figure 4).

Figure 4

First Sufficiency Path Plot



Note. Produced with QCA R package created by Oana et al, 2022.

Similarly, the second path has sufficient consistency and PRI rates, respectively at 0.9 and 0.8, and sufficiency and unique coverage rates at 0.4 and 0.1 (Figure 5). The third path has sufficient consistency and PRI similar to the previous paths (0.9; 0.8); yet, it has sufficient and unique coverage rates far from the required threshold suggested by the QCA literature (Figure 6). Thus, according to the parameters of fit, the first two sufficiency paths are those with the strongest 'explanatory power'.

Figure 5

Second Sufficiency Path Plot

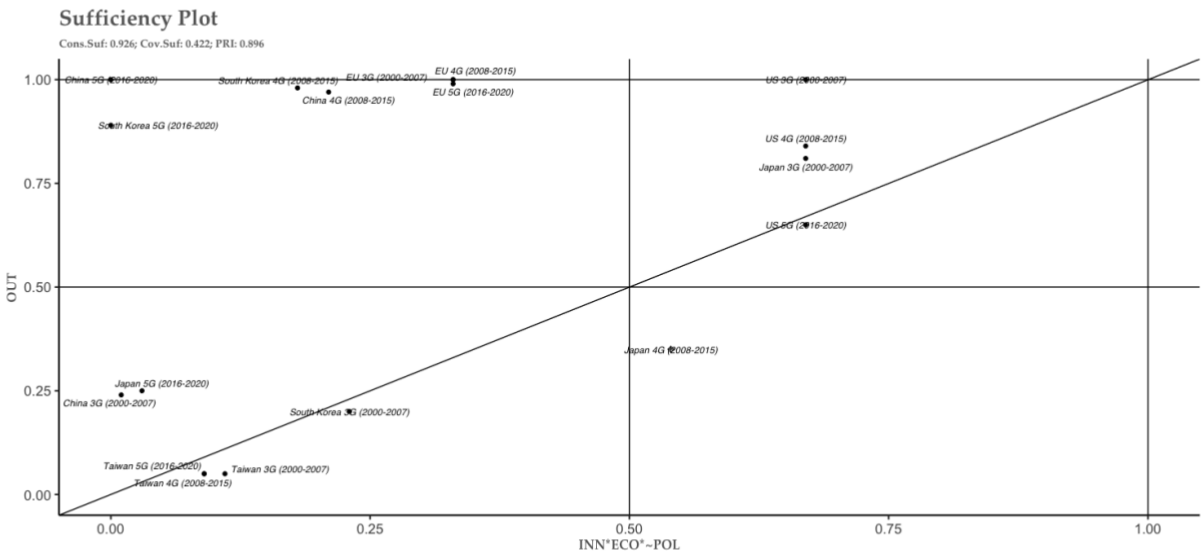
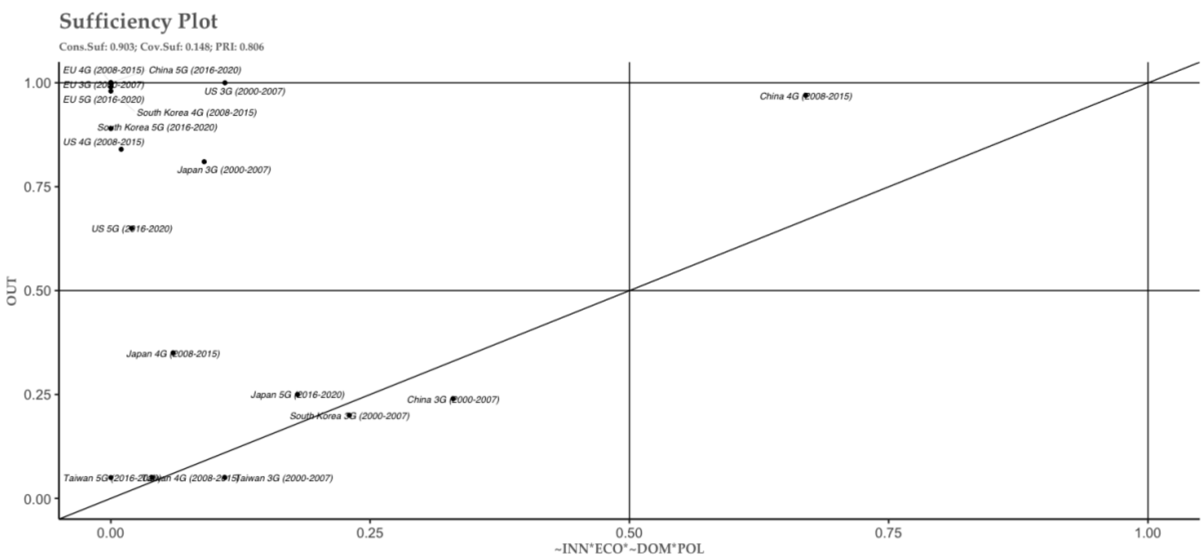


Figure 6

Third Sufficiency Path Plot



4.7 Interpreting the Analytical Results

Two primary interpretations can be derived from the analytical results: an outcome-oriented and a condition-oriented. The outcome-oriented interpretation suggests that power structures have changed due to the rise of new leading standard setters, which have caught up with traditional standard setters. These are China and South Korea, whose capacity to shape standardization has significantly increased over the three latest mobile network generations, leapfrogging from a standard taker position to a standard setter one in less than a decade. This capacity is reflected by the large participation, increased SEPs, technical contributions and leadership positions in the setting of generational standards.

So, power structures in telecommunication standards have tilted towards new aspiring standard setters. In this power shifts, traditional standard setters, are still influential powers. In particular, the US and EU countries are still considered leading standard setters in telecommunication standards, which reflect their great influence in the process. However, they are no longer the only dominant standard setters. Thus, the result suggest that traditional standard setters have not really been replaced yet by new aspiring standard setters; but rather they have rather seen their dominant position challenged and shrunk over time. Put differently, power shifts in standardization can be seen as the natural consequence of China's and South Korea's rise as technological powers rather than the result of the US's and EU's power decrease in standardization. Different is the case of Japan, which is no longer a leading standard setter compared to the previous generations. This will be further discussed in the conclusive chapter.

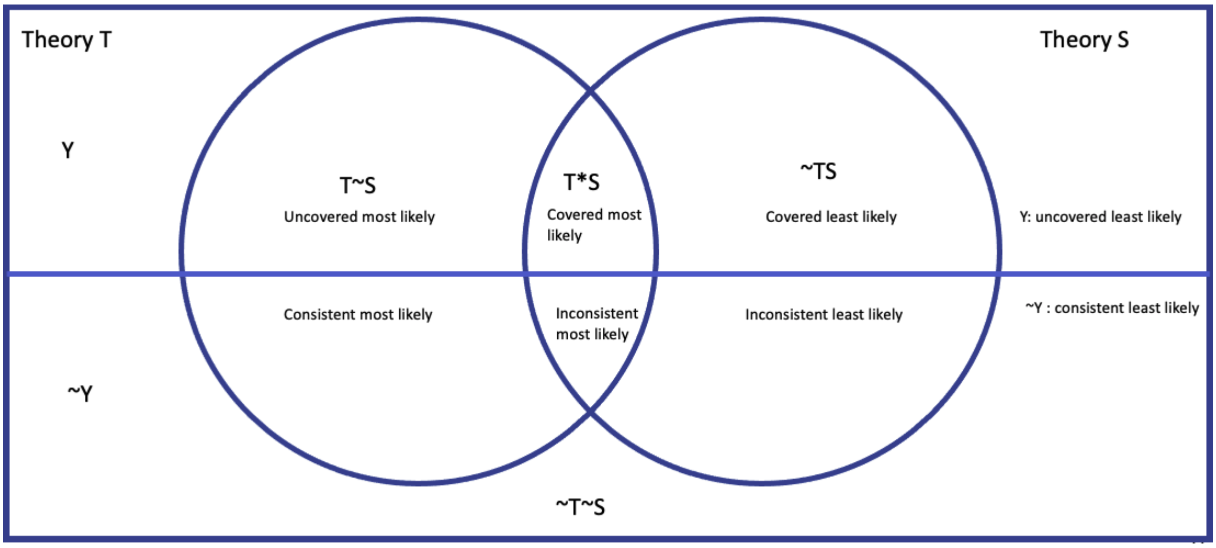
The condition-oriented interpretation focuses on the plausible sufficiency paths, suggesting that technological and economic capabilities are essential to shape standardization. However, when technical and economic capabilities are roughly equalized between countries, having a highly complementary domestic system seems to provide a competitive advantage in becoming a leading standard setter. This is further evidenced by the fact that China and South Korea have become members of a highly institutional system parallelly to becoming leading standard setters, suggesting the competitive advantage provided by government-industry coordination. By contrast, the US relative decrease in standardization might also be explained by its private driven, hand-off approach, to standardization. As in the case of the outcome-oriented interpretation, this will be further discussed in the conclusive chapter.

4.8 The Analytical Results in Relation to the Theoretical Expectations

This section reexamines the theoretical expectations based on the empirical results of QCA analysis, by identifying the theoretical elements that are supported or not by the results (Oana et al., 2021; Ragin,2000). More precisely, it focuses on the extent to which theoretical expectations conform with the empirical results, by showing the percentage of cases that are covered most likely, uncovered least likely, and covered least likely according to each theoretical expectation. Cases covered most likely are cases in which the empirical results meet the theoretical expectations (T*S). Cases uncovered least likely are cases in which the results do not match with theoretical expectations (T*~S); whereas cases that are covered least likely are cases in which the results are not explained by any theory (~T*~S). The level of coverage between theories and empirical results takes also in consideration the level of consistency (Ragin, 2000) (Figure 7).

Figure 7

Theory Evaluation Scheme



Note. Readapted from Oana et al, 2020

Functional theories argue that innovation drives standardization. Given this explanation, being a great innovator is expected to be an influential component for shaping standardization. The empirical findings of the first condition are largely consistent with the functional proposition: 72% of the cases [19] are covered most likely. 18%[20] of the cases are instead uncovered most likely, suggesting different paths for the outcome of interest. While the remaining 10%[21] of the cases is covered least likely, which suggests a need to further expand the theoretical framework.

Power-based theories suggest that standardization is a function of countries' economic power distribution. Therefore, technological powers that are large economic powers are expected to be influential players in the standard setting. Even in this case, the analytical results are to a large degree consistent with this argument. Indeed, 80% of the cases[22] fit in the intersection of covered most likely. The remaining 20% of cases[23] fall under the category of covered least likely and uncovered most likely.

Domestic theories explain that domestic institutions affect the ability of companies or industries to shape standardization. More precisely, it posits that a highly complementary domestic institution provides a competitive advantage to companies pitching their patents in international standardization, thereby determining the capacity of countries as leading standard setters. The analytical results support to a certain extent these theoretical elements. 54% of the

[19] China 5G (2016-2020) US 5G (2016-2020) EU 5G (2016-2020) US 4G (2008-2015) EU 4G (2008-2015), US 3G (2000-2007) EU 3G (2000-2007) Japan 3G (2000-2007)
[20] South Korea 5G (2016-2020) and South Korea 4G (2008-2015)
[21] China 4G (2008-2015)
[22] China 5G (2016-2020), US 5G (2016-2020), EU 5G (2016-2020), China 4G (2008-2015), US 4G (2008-2015), EU 4G (2008-2015), US 3G (2000-2007), EU 3G (2000-2007), Japan 3G (2000-2007)
[23] South Korea 5G (2016-2020) and South Korea 4G (2008-2015)

cases[24] are covered most likely. 28% of the cases[25] fall under the category of covered least likely. While the remaining 18% of the cases[26] is considered uncovered most likely.

Ideational theories propose that policy ideas affect the way in which regulatory bodies play a role in supporting companies or industries in international standardization. More precisely, a standard-focused policymaker is expected to promote policy ideas that are conducive to research grants, tax breaks and other policy actions. The analytical result shows that this argument slightly matches with the empirics: 45% of the cases[27] belong to intersection covered most likely; 36% of cases[28] are covered least likely; and 19%[29] are uncovered most likely.

Going back to the main research question, the analytical results show that there is no single theory that fully explains what turns countries into leading standard setters, but rather it is a combination of theoretical elements. Taken individually, functional and power-based explanations seem to be the most consistent. However, they do not explain on their own the outcome of interest. Indeed, analytical results demonstrate the innovation-driven outcome of standardization; yet, as power-based explanations argue, results also show that this outcome is also dictated by the distribution of (economic) power within the process. This is in line with the literature strand that argues that innovation and economic power are critical (yet not sufficient) factors for playing an influential role in the standard setting (Krasner, 1991; Mattli&Büthe, 2003).

Results also show that domestic factors have less explanatory power. This is the case when technological powers have very different levels of innovation and economic power,

[24] China 5G (2016-2020), EU 5G (2016-2020), EU 4G (2008-2015), EU 3G (2000-2007), Japan 3G (2000-2007)
[25] US 5G (2016-2020), China 4G (2008-2015), US 4G (2008-2015), US 3G (2000-2007)
[26] South Korea 5G (2016-2020) and South Korea 4G (2008-2015)
[27] China 5G (2016-2020) EU 5G (2016-2020) China 4G (2008-2015) EU 4G (2008-2015) EU 3G (2000-2007)
[28] US 5G (2016-2020) US 4G (2008-2015) US 3G (2000-2007) Japan 3G (2000-2007)
[29] South Korea 5G (2016-2020) South Korea 4G (2008-2015)

producing a significant gap between countries regarding their technical and material capabilities. By contrast, when these capabilities are roughly equal between technological powers, the complementarity level of domestic institutions seems to become a decisive factor in providing a competitive advantage in standardization. Finally, results show that ideational theories are theoretically less consistent. This could be related to the fact that policy ideas require some time before they turn into concrete policy actions (Table 14).

Evaluating the theoretical claims of single conditions provides a general assessment of theories in terms of their explanatory power. However, this type of evaluation does not really investigate the plausible causal mechanisms that are triggered by single or combined conditions. In particular, it does not explain how causal conjunctions might work with each other (Ragin 2000; Ragin, 2008). In light of this, the following chapter attempts to theorize and possibly test the presence of causal mechanisms that are given by the most consistent sufficiency terms, by conducting a case-oriented PT analysis. This will be done in the next chapter.

Table 14

Summary of Theory Evaluation Results

Theory	**Uncovered most likely T~S**	**Covered most likely TS**	**Covered least likely ~TS**	**Uncovered least likely**	**Consistent most likely T~S: ~Y**	**Inconsistent most likely TS: ~Y**	**Inconsistent least likely ~TS: ~Y**	**Consistent least likely**
Functional	18%	71%	10%	0%	58 %	0%	0%	42%
Power-based	10%	80%	0%	10%	10%	0%	0%	90 %
Institutional	18%	54%	28%	0%	15%	0%	0%	85%
Ideational	19%	45%	27%	0%	57%	0%	0%	42%

5. Second Empirical Analysis: Tracing the Process of Most Typical and Deviant Cases

The QCA results confirm a power shift towards new aspiring standard setters like China and South Korea. These power shifts reflect changes in the capacity of technological powers to shape standards that are given by the contribution of their respective public and private stakeholder to international standardization regimes such as the one analyzed, namely the 3GPP and the ITU. According to the QCA analysis, different sets of sufficiency paths explain these changes. In the following analysis, this study focuses on the most consistent sufficiency path by exploring the two most typical cases, China 5G (2016-2020) and EU 5G (2016-2020). These two cases are then compared with two other cases, US 5G (2016-2020) and South Korea (2016-2020), which represents respectively a most typical case for the second sufficiency path and a coverage deviant case for a potentially omitted path. These cases are selected visually by analyzing the xy plots (Figure 4,5,6) and by using an R function that identifies the most appropriate cases in terms of typicality, deviance, and irrelevance based on their consistency and coverage (Table 15). In addition to that, cases have also been selected, considering the accessibility of case-related data.

Table 15

Case study selection

Sufficiency paths	**Cases**
Most typical cases- 1 path Tech+Market+Instituional	China 5G (2016-2020) EU 5G (2016-2020)
Most typical cases- 2 path Tech+Market	The US 5G (2016-2020)
Deviant cases-3 paths Tech+Instituional	South Korea 5G (2016-2020)

More precisely, this chapter is divided into three sections. The first section further explains why a process-tracing analysis within the selected cases is necessary for the research under study and how the analysis is conducted in compatibility with the QCA results. The section outlines the possible theoretical mechanisms triggered by the sufficiency paths. The third section tests the theorized causal claims and mechanisms against the selected cases, by tracing their process and identifying empirical evidence. The last section attempts to draw some conclusions on the causal mechanisms' consistency and validity and to offer insights for theoretical improvements ideally.

5.1. Why is Process Tracing Necessary?

QCA cannot distinguish between scope and causal conditions nor conveys information about the causal mechanisms triggered by individual or combined conditions. In light of this, this study resorts to a process tracing (PT) analysis to flesh out, trace, and refine the theoretical mechanisms linking the sufficiency path to the outcome (Beach & Rohlfing, 2018). According to the literature, there are two main types of PT analysis. The first type tries to explain an outcome in a specific case, by identifying the mechanisms that are sufficient to explain the outcome either deductively or inductively; while the second type tests whether a postulated causal mechanism is present or not in a specific case (Pedersen & Beach, 2010). Studies can employ both types of PT for their analyses.

This study mainly adopts a PT analysis that tests the presence or absence of specific parts of a theorized causal mechanism. More precisely, for the purpose of this study, PT is employed as "a theory-testing manner, with the emphasis being a structured empirical test of whether there is evidence, suggesting that a hypothesized causal mechanism exists between the found conjunction and the outcome" (Beach, 2017). This type of PT analysis is used when there is "a robust correlation between X and Y has been found with other methods, but we are unsure whether there is an actual causal mechanism linking the two" (Pedersen & Beach, 2010: 5).

By confirming or disconfirming the existence of causal mechanisms that presumably connect the sufficiency paths to the outcome, this analysis attempts to discern scope conditions from potential causal conditions. Scope conditions are required for an outcome to be present, but do not have any explanatory power since they do not trigger any causal mechanisms (Falleti & Lynch, 2009). In addition, the study attempts to understand whether a sufficiency path made of different conditions produces an outcome that results from either a single mechanism or a sequence of mechanisms. In other words, it tries to understand whether conditions triggering mechanisms operate simultaneously or in sequence (Beach, 2017). Based on the empirical results, the study finally attempts to possibly refine the theoretical framework of how conditions and their expected causal mechanisms work with one another (Beach & Rohlfing, 2018).

5.1.1. How is Process Tracing Performed

This PT analysis is performed by conceptualizing and operationalizing the expected causal mechanisms that are triggered by the sufficiency paths. Causal mechanisms can be defined in different ways. In this study, causal mechanisms are defined as a "theorized system that produces the outcome through the interaction of a series of parts that transmit causal forces from *X* to *Y"* (Beach, 2017). More precisely, causal mechanisms are made of a series of parts that are necessary to the mechanisms and that can be further deconstructed into entities and activities. Entities are the actors that undertake activities in a specific part of the mechanism; whereas activities represent the causal forces that are produced through the mechanisms (Pedersen & Beach, 2010).

In the conceptualization process, the entities are referred to as nouns and the activities as verbs recalling the potential causal force. The parts of the mechanism are measured through observable empirical implications that are expected to appear in the empirical analysis. To perform a robust PT analysis, the observable implications that assess the expected parts of the causal mechanism need to meet a relatively high degree of certainty, uniqueness, and feasibility (Pedersen & Beach, 2010). A "certain" implication means that if the expected implication is not present within the analyzed case, then the postulated mechanism fails the empirical test; while a "unique" implication implies that the expected mechanism does not overlap with other theorized mechanisms (Pedersen & Beach, 2010). As Gerring and Seawright suggest "[…] researchers are well advised to focus on a case where the causal effect of one factor can be isolated from other potentially confounding factors" (2007:122). Lastly, a feasible implication instead refers to the availability of the empirical data: if they can be gathered and measured (Table 16).

Table 16

Methodology

Methodology and method	**What?**	**Why?**	**How?**
Process tracing analysis	Process tracing as testing the presence or absence of causal mechanisms triggered by condition	1)To discern scope conditions from causal conditions 2)To understand whether conditions operate sequentially or simultaneously 3) To refine theorized mechanisms	1)Conceptualize parts of mechanisms according to entities and activities 2)Operationalize based on empirical implications (certain, unique, feasible)

This study draws mainly on qualitative and some quantitative data to unravel and trace the theorized mechanical processes. Data integrate primary and secondary sources. Primary sources consist of statistical data, governmental declarations, industrial plans, recorded panels, and interview transcripts. Interviews were conducted primarily with industrial and academic profiles for confirmative purposes. These few interviews were conducted during my research abroad in 2022. Secondary sources draw on policy papers and journal articles focusing on the political economy of technology standards referring to telecommunication standards (Table 17).

Although PT is a useful tool to confirm or disconfirm plausible causal mechanisms, it is important to recall that the same condition can trigger different mechanisms with multiple effects on the outcome (Illarim, 2011). In light of this, as the existing literature suggests, this PT analysis provides evidence exclusively to the mechanisms it attempts to trace (Pedersen & Beach, 2010). In addition, caution is exercised when attributing causal power to a condition even if solid evidence is found for the theorized mechanisms.

Table 17

Data Selection

Type of Source	Primary Source	Secondary Source
Definition	First-hand information	Secondary-hand information, analysis, and commentary
Type of data	Statistical data, governmental declarations, industrial plans, recorded panels, newspapers, and interview transcripts (for confirmative purposes)	Policy papers, journal articles both from the west and east
Examples	Number of patents held by countries, China Standard Strategy 2035, stakeholders' opinions	(Western) Think tank policy papers and Political Economy and Telecommunication policy journals

5.2. Unpacking Theoretical Mechanisms: Conceptualization and Operationalization

The QCA results produced different sufficiency paths to explain a leading standard setter. These sufficiency paths are made of a set of conditions that might trigger either single or multiple causal mechanisms. In fact, conditions can be connected to the outcome through various constellations of mechanisms. In addition, they can go from a simple sequence, whereby one condition triggers another, to more complex conjunctions of sequences (Beach & Rohlfing, 2018).

Since detailed causal mechanisms have yet to be fully developed, this analysis starts by formulating the plausible causal mechanisms of each condition, by drawing on the main theories that underpin that condition. It does so by identifying and unpacking the causal mechanisms of each condition into parts, entities, and activities. These theorized mechanisms are then empirically tested against a set of established observable implications that are linked to the activities performed by the entities of the causal mechanism. Based on this analysis, this study attempts to show what type of mechanisms, single or multiple, connects the conditions to the outcome, and whether these mechanisms work simultaneously or sequentially. It might also provide further information about conditions' explanatory power and mechanisms.

5.2.1. Theorizing the Causal Mechanisms of the First Path

The first sufficiency path comprises three conditions: a great technological innovator, a large market power, and a highly complementary system. The first condition, a great technological innovator, draws mainly on functionalist and regime theories, which in the context of standardization suggest that standards are the result of the best technical solution and therefore of the most technologically advanced stakeholder. As Spulber argues, SDOs unanimously choose the most efficient technology despite competing preferences among participants (Spulber, 2016). Therefore, technological primacy is expected to determine standards' outcomes and distributional effects.

According to the QCA results, this theoretically grounded condition is consistently necessary and part of the first sufficiency path. Innovation is indeed a function of countries' technical knowledge and expertise, which according to the literature, are prerequisites for playing an influential role in standardization (Hallstrom & Boström, 2010). What is not clear yet is the causal mechanism, single or multiple, which connects a great technological innovator to a leading standard setter contributor. To do so, the study unpacks the mechanism of the first condition, by discerning plausible parts, entities, and activities, as follows below.

The first condition plausibly triggers one single causal mechanism that can be divided into three interconnected parts. A great innovator is a technological power (country or set of countries) that invests large resources into Research and Development (R&D). Devoting large resources to R&D should enhance industries' technical knowledge and expertise, which translates such increased knowledge into innovations. To protect these innovations, industries should patent their technological inventions in domestic and international patent offices and SDOs. Industries with international aspirations commonly declare patents as SEPs to secure the economic benefits they could generate if recognized as part of a global standard. When standardization occurs at the intentional level, holding large portfolios of granted SEPs should put industries in the condition to be leading standard setter, reflecting technological power's capacity to shape standardization.

In the empirical analysis, the study expects for the first part to find evidence of a large investment of countries' GDP in R&D devoted to standardization (training, research activities, infrastructure). Next, it expects, respectively, for the second and third part of the mechanism, a large number of patents filled in domestic and international SDOs and recognized SEPs for telecommunication standards. These data are retrieved from databases and reports such as IPlytics and integrated with qualitative data (Table 18).

Table 18

Condition One: Theorized Mechanism

Mechanism	First Condition: Great Innovator

Parts	Part 1	Part 2	Part3
Label	R&D → Innovation	Innovation→Patents/SEPs	(Granted) SEPs→ Standard contributor
Description	R&D investments allow industries to create innovations	Innovations are secured by being filed in patent offices and international SDOs	Patents that are granted as SEPs puts industries in the condition to be a leading standard setter
Empirical Observations	Large (public and private) R&D investments	A great number of patents filled in (domestic and international) patent office and SDOs	A great number of recognized SEPs

The second condition, a large economic power, draws on power-based theories that argue that the outcome of standards reflects the power distribution of actors in terms of their economic and market power (Krasner, 1991). Standards are therefore determined by the power relations that are established by the most influential actors (Bishop, 2015; Drezner; 2005). QCA results show that economic power is an essential condition to form a sufficiency path for the outcome of interest: two of the most consistent sufficiency paths include economic power. This is mostly in line with the existing literature. As Rühlig argues (2022), "larger economies and big companies have a higher impact on international technical standards than smaller markets and small and medium-sized enterprises (SMEs)". Similarly, Weiss and Sirbu argue that "the size of the firms in the coalition supporting a technology [is] a significant determinant of technological choice in the standards decisions" (Weiss&Sirbu, 1990). Also for this condition, however, the plausible causal mechanisms linking economic power to being a standard setter needs to be further theorized.

The second condition might prompt two causal mechanisms that can be further divided into two parts respectively. A large economic power is here defined as a country (or set of countries) whose industry is a large manufacturer and value adder of ICT technologies that are closely associated with telecommunication standards. Countries with a large industrial base and an established manufacturing sector commonly possess large material resources that can be used to access and participate in international SDOs, which are inclusive but simultaneously very costly (Rühlig, 2022). Participation in SDO consists of attending numerous meetings in working groups and dealing with business travel and financial expenses. According to a study conducted by the British Standard Institute, it takes approximately three years to develop a national standard and probably even longer for international standards, which includes a larger number of stakeholders and meetings (BSI, 2011). For instance, on average, the ISO has seven standard meetings daily (Büthe&Mattli, 2011). In light of this, participation in international standardization commonly implies high financial costs that only large economies and big companies can afford. As Sell argues, large companies have the ability to shape intellectual property rights and standards in their favor due to their material resources (Sell, 2003). So, the material resources, which potentially derive from the economic size of technological powers, should allow their industries to participate regularly in standardization, putting them in the condition to pitch their technologies solutions and thereby become a leading standard setter (Table 19).

The second causal mechanism assumes that great economies hold large financial revenues from large market shares that give their industries significant market power. Market power is defined as the capacity to influence prices and (potentially) manipulate the supply and demand of technological products or services (Strange, 1975). When new technologies are offered on the market, prices are a determinant factor; therefore, choices over standards might also depend on the prices of the technologies that are embedded in that standards. The industry, which can provide the most competitive international prices thanks to its market power, might have a greater capacity to incorporate its technology into the standard. As Sturgeon argues, holding large market shares should put industries in a better position to lobby for their technologies and influence the choice of standards (Sturgeon, 2002) (Table 20).

The study proposes for each mechanism two observable implications. In the first mechanism, the analysis expects to find evidence on large ICT industries or big companies that possess great material resources, such as financial revenues, that ensure participation in international standardization. The second part of the first mechanism expects great participation at the ITU-3GPP level. In the second mechanism, the first part expects empirical facts about large market shares in technologies related to G standards, which can come from domestic or international market shares. The second part instead expects competitive prices in technologies related to G standards from the leading standard setter. Differently from the QCA data, where it was more difficult to find coherent data across different cases and time frames, the selected data on market shares are specifically related to mobile network standards (RAN,Core, Terminal).

Table 19

Condition Two: Theorized Mechanism

Mechanism	Second condition: large economic power	
Parts	Part 1	Part 2
Label	Material resources→ (international) participation	(International) participation→ standard contributor
Description	Large economic powers have financial resources that allow industries to participate in international standardization	International participation puts industries in the condition to learn from and contribute to standardization

Empirical Observations	Large economic sources and financial revenues	Great participation in international SDOs

Table 20

Condition Two: Theorized Mechanism

Mechanism	Second condition: large economic power (2 mechanism)	
Parts	Part 1	Part 2
Label	Material resources→ market power (competitive prices)	Competitive prices→ standard contributor
Description	Market power allows industries to offer competitive prices	Competitive prices provide industries with greater lobbying capacity in standardization
Empirical Observations	Large market shares	Competitive international prices

The third condition, a highly complementary domestic system, draws on institutional theories that analyze the relationship between domestic institutional arrangements and global regulatory frameworks (Stephan&Parizek, 2019). More particularly, it explores how domestic standard systems might influence the capacity of industries to shape international standardization depending on their institutional configurations. Domestic institutions that show high complementarity with international organizations are more effective in externalizing the domestic preferences of industries at the international level (Mattli&Büthe, 2003).

The QCA results identify the third condition as part of the first sufficiency path. This is in line with the existing literature, which has provided empirical evidence about the relationship between institutional complementarity and competitive advantage in standard settings (Mattli&Büthe, 2003; Rühlig&Ten Brink, 2021). The QCA results, however, do not directly assess the plausible causal mechanisms that connect the condition with the outcome. In fact, it identifies the condition as a member of the sufficiency path, but it does not provide explanations about its plausible causal mechanisms.

Therefore, this study attempts to trace and analyze two theorized parts of the plausible causal mechanism, drawing on Mattli and Büthe's theoretical framework that focuses on two dimensions within the institutional configurations of countries: the level of institutional coordination and organizational hierarchy between institutions and industries (Mattli&Büthe, 2003).

The former affects the flow of information within national standardization systems; whereas, the latter shapes the degree of cohesion in internationalizing national preferences. The level of information coordination varies from a low-level consensus system in which actors compete with each other intensively to a high-level consensus system in which actors agree on a single national standard. The more a system is based on the principle of market competition, the more industries will be unwilling to share information as they perceive that information as a private asset. By contrast, the more a system is consensus-driven, the more industries will be open to sharing their information through institutional mechanisms that reduce transaction costs (Mattli&Büthe, 2003).

The degree of organizational hierarchy instead affects the capacity of aggregating the preferences of all private actors and projecting them onto the international level. Even in this case, the more centralized the system is, the more cohesive preferences will be at the international level. By contrast, the less centralized the system is, the lower the capacity to aggregate preferences between competing forces and sponsor them at the international level (Mattli&Büthe, 2003).

Based on these theoretical premises, the causal mechanism is divided into two parts: a domestic system based on high coordination between public and private stakeholders should ensure that governments and industries work jointly in developing a specific standard. A centralized organizational hierarchy instead should ensure that this standard is pitched at the intentional level in a univocal way. This can also be defined as the ability to speak with one voice (Rühlig&Ten Brink, 2021). Speaking with one voice can be critical to providing a competitive advantage in international standardization in an arena characterized by competition and contestation.

By tracing these theorized mechanisms, the study expects to find evidence for the first theorized part on institutional coordination mechanisms or public-private initiatives related to telecommunications technologies. As for the second part, the study expects to gather evidence from industries' capacity to speak with one voice in international standardization.

Table 21

Third Condition: Theorized Mechanism

Mechanism	Third condition: institutional framework	
Parts	Part 1	Part 2
Label	Coordination→ one voice	One voice→standard contributor
Description	High coordination between public and private stakeholders allows exchanges of information and preference convergence	Converging consensus between domestic stakeholders allows to act with one voice at the international level which provides a competitive advantage in shaping standards
Empirical Observations	Public-private partnerships and initiatives	Evidence of 'one voice' actions in international standardization

5.3 Assessing the Most Typical Cases of Sufficiency Path One: China 5G and EU 5G

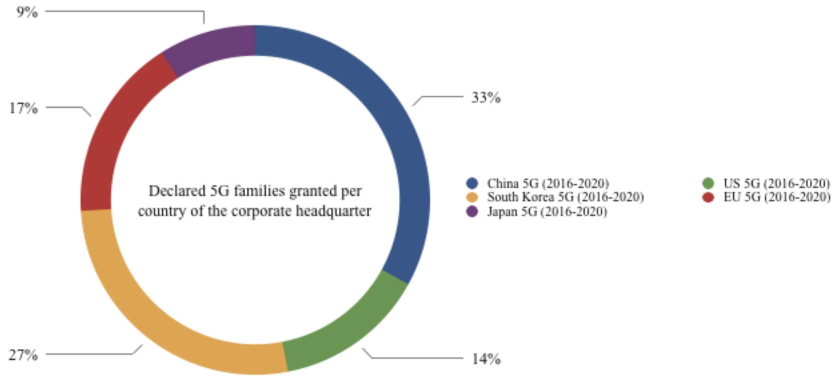
In this section, the study tests the causal mechanisms theorized above, by assessing the empirical observations associated to the parts of the causal mechanisms within two case studies, China 5G and EU 5G. The case study analysis starts by assessing China's position in standardization and testing the theorized mechanisms that might explain China's great capacity to shape standardization. To further test the consistency of these mechanisms, the study also analyzes the case of EU 5G, drawing comparisons with two other cases, US 5G and South Korea 5G, which belong to two different sufficiency paths.

5.3.1 Assessing China as a Leading Standard Setter

China is among the leading standard contributors to 5G mobile network technologies on the basis of different indicators. One of the most indicative one is China's significant number of patented technologies declared SEPs. When aggregating the shares of 5G SEPs by country's origin of the patent holder, China holds the highest number of applications, accounting for approximately one-third of the total share of SEPs applications. South Korea follows closely with 27%. European countries, the US, and Japan instead lag a bit behind, following respectively with 17%, 14%, and 9% (Pohlmann et al.,2022) (Figure 8).

Figure 8

Declared 5G families (granted) per Country of the Corporate Headquarter

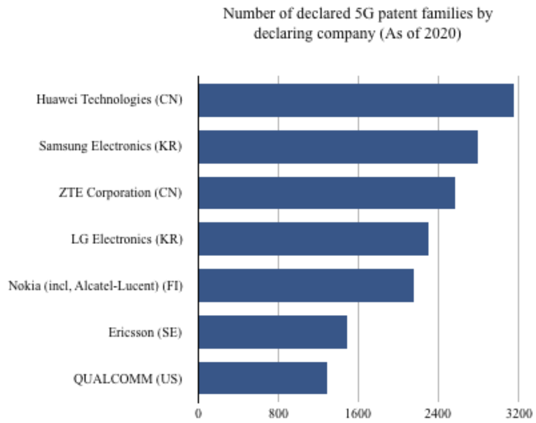


Note. Own elaboration. Data are retrieved from IPlytics Reports on SEPs. More specifically from the series of reports on "Who is leading the 5G patent race" authored mostly by Tim Pohlmann and other experts. https://www.iplytics.com/blog/. Full bibliography in the reference list.

At the company level, Huawei, China's national tech champion, holds the largest portfolio of SEPs as of 2020. According to IPlytics data, Huawei leads in terms of SEPs declarations, followed by Samsung, ZTE Corporation, LG Electronics, and Nokia, Ericsson and Qualcomm (Figure 9).

Figure 9

Number of Declared 5G Patent Families by Declaring Company



Note. Own elaboration. Data are retrieved from IPlytics Reports on SEPs, https://www.iplytics.com/blog/

However, China has in aggregate terms a lower grant rate compared to other technological power such as EU countries and South Korea. As the aggregated number of 5G family shows, European companies have the highest grant rates with 66% followed by South Korean and US companies, which are also the industries with the highest percentage of internationally registered patents. This is probably indicative of their greater technological quality (Pohlmann, 2020) (Table 21).

Table 21

Patent Declarations and Filling

Country of Origin of the Patent Owner	Declared 5G Families	Thereof filed at least the at the USPTO, EPO or PCT	Thereof at Least Granted in one Office
Chinese Companies	6,234	73.74%	25.57%
Korean Companies	5,119	89.65%	62.63%
European Companies	3,211	91.25%	66.33%
US Companies	2,591	87.96%	44.31%
Japanese Companies	1672	83.31%	50.06%

Note. Reproduced from IPlytics Reports, https://www.iplytics.com/blog/

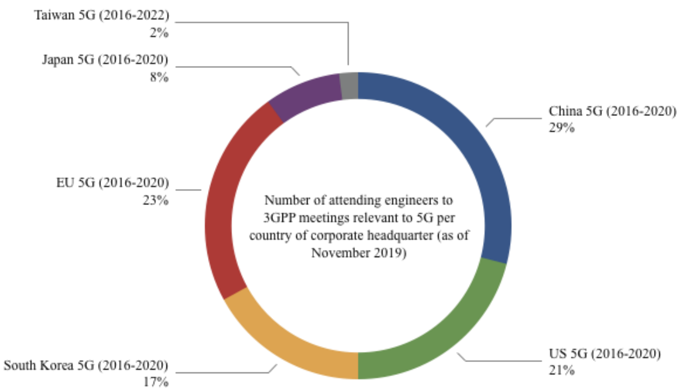
It is important to note that SEPs can differ in terms of their essentiality vis a vis the standard. SEPs can consist of a significant contribution or just a tiny improvement to the standard, implying that counting SEPs only partially reveals who leads the standard setting. As Gu explains, technology standards such as 5G can be seen as a tree composed of a trunk, branches, and leaves (Gu, 2019). The technologies essential for the tree’s trunk are much more valuable than those essential for a leaf. This implies that the essentiality of technologies should also be measured depending on the part they cover in the tree, namely their position and added value to the system.

Experts also argue that industries that hold a portfolio of technologies that cover the entire tree, namely those that cover an end-to-end system, play a leading role (Qualcomm, 2019). Huawei and other companies, such as Nokia and Samsung, have been among the first to hold a portfolio of SEPs covering an entire end-to-end system (Gu, 2019). Huawei’s “vertically integrated" structure covers an entire stack of telecommunication products at a large scale (Voo, 2021). Thanks to such capabilities, China has been one of the first countries to test 5G technologies in its territory. It currently has one of the largest 5G networks in the world, which is expected to account for 40% of the global 5G market by 2025 (5G observatory, 2020; GSMA, 2021). This has also contributed to China's increased technological reputation and influence in the international standard-setting process.

China's capacity to shape standardization also derives from its increased participation in 3GPP's working groups (WG), which reflects China's increased R&D investments and technical knowledge in standardization. China is the country with the greatest participation in 3GPP's working groups when it comes to aggregating the participation of engineers by companies' nationality. As statistics show, China's share of participants as of November 2019 accounted for approximately 30 % followed by the EU and the US with 24% and 21% (IPlyitics, 2019)(Figure 10).

Figure 10

Share of Participation by Country/Region

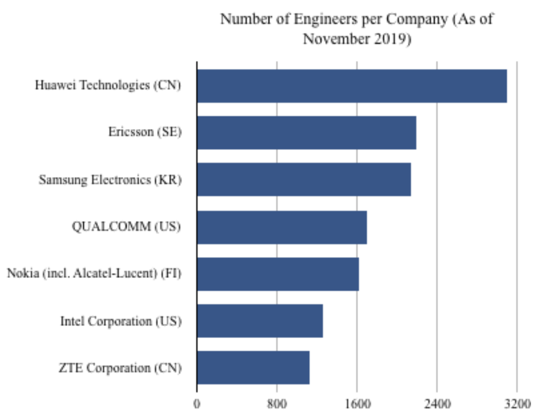


Note. Own elaboration. Data are retrieved from IPlytics Reports on SEPs, https://www.iplytics.com/blog/

At the company level, Huawei is the leading company in terms of attending engineers to 3GPP's 5G meetings with more than 3000 individuals as of November 2019. Ericsson (SE), Samsung (KR), and Qualcomm (US) follow respectively with approximately 2000 engineers (Polhmann et al, 2020)(Figure 11).

Figure 11

Number of Engineers per Company



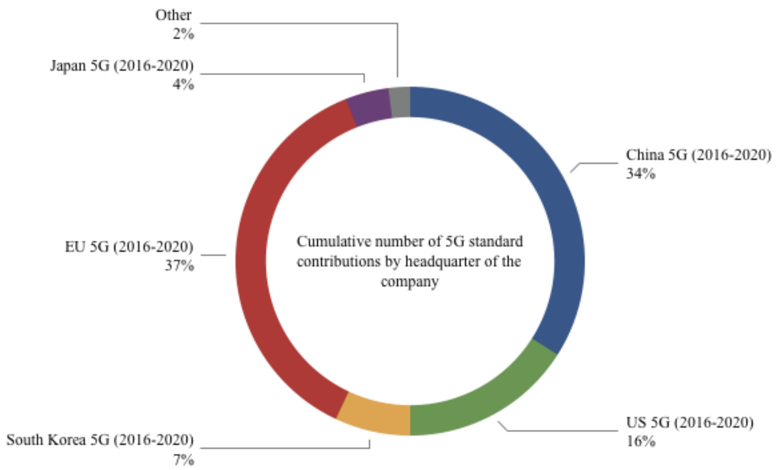
Note. Own elaboration. Data are retrieved from IPlytics Reports on SEPs, https://www.iplytics.com/blog/

China’s increased participation has raised diverging opinions. Some observers argue that China’s increased participation in 3GPP’s working groups is a strategy to exert pressure through their massive presence rather than their qualitative contribution. For this reason, China’s participation is seen as a risk to the quality of the decision-making process. Other observers, who are more optimistic, argue instead that China’s increased participation is a physiological consequence of China’s greater role in global economic governance. In addition, by being an economic superpower, China’s participation in global standards is seen as a good sign to preserve economic integration and technological compatibility. This argument, however, might be contested when analyzing China’s compliance with international standards. Contrary to what is expected from a globally integrated China, China’s adoption level of international standards is still relatively low (Teleanu, 2021). According to a report conducted by the US-China Business Council in 2020, only one-third of China’s national standards issued by SAC are in full or partial compliance with international standards (US-China Business Council, 2020).

China’s increased capacity to shape standardization is also reflected in its active role in providing technical contributions to the 3GPP and the ITU. China’s increased participation has also led to greater technical contributions to SDOs' working groups. As recent statistics show, China is the country whose industry has the second highest number of standard contributions with a share of 34%, which is slightly below the EU which leads with 37% (Pohlmann, T., & Buggenhagen 2022) (Figure 12).

Figure 12

Cumulative Number of 5G Standard Contributions to 3GPP

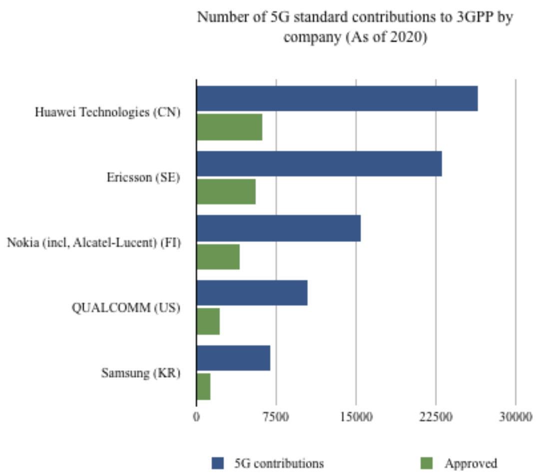


Note. Own elaboration. Data are retrieved from IPlytics Reports on SEPs, https://www.iplytics.com/blog/

At the company level, Huawei is the corporate entity with the highest number of provided and approved technical contributions. Two European companies, Nokia and Ericsson, follow suit (Polhmann et al., 2020). In relative terms, however, Huawei has a lower acceptance rate of technical contributions than European companies, which might be in line with the argument that China's contribution is more quantitative than qualitative. Despite this, although it is difficult to assess the qualitative impact of technical contributions to standards, most observers generally convene on the increased quality of China's contribution over the last three generations (Polhmann et al., 2020; Rühlig, 2022)(Figure 13).

Figure 13

Cumulative (and Approved) Number of 5G Standard Contributions to 3GPP by Company



Note. Own elaboration. Data are retrieved from IPlytics Reports on SEPs, https://www.iplytics.com/blog/

China has also played a leadership role in various working groups at the 3GPP and ITU levels, which is another indication of China's leading contribution to 5G. China's industry has held various chairman or vice chairman positions in 3GPP's working groups over the period concerning 5G, accounting in total for 6 influential positions (Table 22). These positions strategically cover all the main working groups, which are indicative of China's industrial presence along the entire supply chain of telecommunications technologies and infrastructures (Gu, 2019).

Table 22

Leadership Positions in 3GPP's Technical Study Group (2019-2021)

TSG	Position	Person	Company	Nationality
RAN	Chairman	BERTENYI, Balazs	Nokia Corporation	EU
RAN	ViceChairman	HAYES, Stephen	Ericsson Inc.	USA
RAN	ViceChairman	NAGATA, Satoshi	NTT DOCOMO INC.	JP
RAN	ViceChairman	XU, Xiaodong	China Mobile Com. Corporation	CN
SA	Chairman	MAYER, Georg	HUAWEI TECHNOLOGIES Co. Ltd.	CN
SA	ViceChairman	NAKANO, Yusuke	KDDI Corporation	JP
SA	ViceChairman	KIM, Laeyoung	LG Electronics Inc.	SK

SA	ViceChairman	SCHUMACHER, Greg	Sprint Corporation	USA
CT	Chairman	MORAND, Lionel	Orange	EU
CT	ViceChairman	AGHILI, Behrouz	InterDigital Communications	USA
CT	ViceChairman	ACHTER, Johannes	Deutsche Telekom AG	EU
CT	ViceChairman	AI, Ming	CATT	CN

Note. Own elaboration. Data are retrieved from 3GPP website, https://www.3gpp.org/

Huawei and China Mobile have been among the most active Chinese players. For example, China Mobile has held a vice chairman position for two consequent terms (2017-2021) in the RAN working group that undertakes the largest technical development in the 3GPP and, for such reason, is one of the most important working groups. Most declared SEPs and technical contributions are associated with RAN technologies, such as 5G antennas, which provide critical technologies to connect users to networks through radio waves (IPlyitcs, 2019). Another fact that reflects China's increasing footprint is that the number of chairman positions held by Chinese companies has increased threefold from 3G to 5G.

China has also been very active at the ITU level (Gamito, 2018). China and its companies have been one of the most prominent participants in the ITU Study Group 13 (SG13), which is responsible for developing standards for next-generation networks, including 5G. In particular, China has submitted significant contributions to SG13 on topics such as network slicing, network orchestration, and cloud computing and has been a key contributor to the development of the International Mobile Telecommunications-2020 recommendations (IMT-2020) (Teleanu, 2021). As statistics show, China submitted 830 technical documents to the ITU in 2019, accounting for more than the three following countries combined: the US, Japan, and South Korea (KAN, 2021).

In addition, the ITU has been led up until recently by Houlin Zhao, the first Chinese official to be elected as ITU's Secretary General, serving for two mandates (2014-2022) approved by the ITU Plenipotentiary Conferences. According to some observers, this has further facilitated China's technological proposals and initiatives, such as China's digital silk road, the digital component of China's Belt and Road Initiative, which also includes a standardization scheme (Voo, 2021). China's increased presence and leadership position has further contributed to elevating China's influence in global telecommunications standards in shaping the direction of 5G development.

China's growing presence and influence in international standardization also finds confirmation in some anecdotal evidence, which should be further expanded by observing working groups or carrying out interviews with relevant stakeholders. One of the first Chinese successes in 5G standardization revolves around 3GPP's selection of Huawei's home-grown coding method for 5G data transmission, better known as "polar codes". This coding method was considered a "direct challenge" to the US-produced coding method "LDPC", which was backed by western stakeholders such as Qualcomm, Samsung, Nokia, and Intel (GU, 2019). As Wang Xuezhi, a telecommunication expert, argues, "Huawei-backed Polar Code entering the 5G standard has a symbolic meaning. This is the first time a Chinese company has entered a telecommunications framework agreement, winning the right to be heard". He also explains, however, that "this accomplishment cannot be exaggerated as many global telecom giants still have the loudest voice" (APCO, 2019).

Another example of China's contribution relates to the development of the Non-Standalone (NSA) 5G standard, in which Chinese companies played a leading role. The NSA 5G standard was adopted by the 3GPP in 2017 to allow network operators to deploy 5G services more quickly and effectively by leveraging existing 4G infrastructure. The first 5G services that are provided today rely mainly on this standard (Techblog, 2020).

Some evidence of China's increased influence can also be traced to the appointment of chairman positions, which are elected for two-year mandates by competing industries in the

3GPP. In a very competitive election in 2019 for the SA chairman position, one of the main 3GPP working groups, participants cast more votes for the representative of Huawei, George Mayer, than for that of Qualcomm, Eddy Hall. Observers argued that this decision resulted from technological and reputational considerations, which further substantiated the argument on China's increased technical and social capabilities in international standardization (Gu, 2019).

This anecdotal evidence also illustrates China's great contribution to 5G standards and its increased capacity to build consensus around its homegrown technologies. Certainly, Chinese companies' active involvement in 5G standardization within 3GPP and ITU has contributed to driving the development of key 5G technologies and has positioned China as a key player in the global race to develop and deploy 5G networks. However, it is important to note that the development of 5G standards is also underlined by cooperation and collaboration. While China and Huawei have played a leading role in the development of polar codes, NSA 5G standards, and other vital technologies within 5G, it would be inaccurate to conclude that China is the only 5G standard contributor and setter. In addition, the competition over the selection of alternative 5G technologies, such as in the "polar codes" case, is seldom a straightforward battle between Huawei and Qualcomm, China and the US. The outcome of standards is the result of collective decisions involving many competing companies, organizations, and countries contributing to the selection of the standard's best technical specifications. It is also demonstrated, however, that this collective effort is led and shaped by the most influential players, one of which has been China and its industry. In the following section, the study attempts to explain China's increased capacity to shape standardization.

5.3.2 Explaining China as a Leading Standard Setter

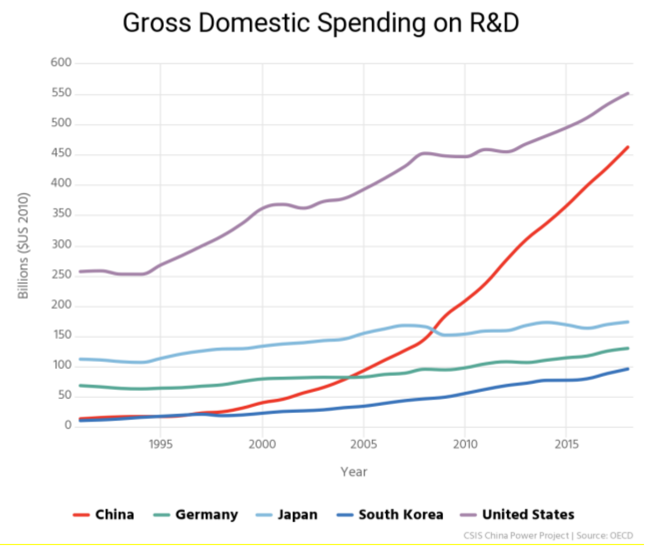
Ample quantitative and qualitative evidence demonstrates China's great capacity to shape the 5G standard settings. Although there are other very influential players in the process, it is substantially argued that China is a leading technological power in developing 5G standards (Pohlmann & Buggenhagen, 2022; Gu, 2022). This is striking, considering that China's position in standardization has shifted from being a standard taker to a standard setter in generational standards in less than a decade. As the QCA results show, this shift results from a combination of three conditions, each of which might trigger a sequence of single or multiple mechanisms, which are analyzed below.

5.3.3 Analyzing China as a Great Innovator

The first condition relates to China's innovation capabilities and its effects on standardization through the mechanism theorized in the previous sections, which revolves around R&D, patented innovations and SEPs. China's level of innovation has increased significantly over the last decade because of different factors. One of these factors has been the increasing amount of funds and investments devoted to R&D. According to OECD statistics, China's R&D expenditure in 1991 was approximately 0.7 % of its GDP, far below the average of industrialized countries such as the US, which accounted that year for 2.5 % of its GDP (OECD, 2022). By 2020, China's GDP spending on R&D more than tripled, accounting for 2.4% of its GDP (World Bank, 2022). In absolute terms, for the same year, China was the country with the second largest R&D spending with more than 450 billion dollars (nominal constant year), preceded only by the United States with a spending of approximately 550 billion dollars (OECD, 2022). Strikingly, China's R&D expenditure experienced a 35-fold increase from 1991 to 2018 (China Power Project, 2022) (Figure 14).

Figure 14

R&D Spending per Country (1995-2015)



Note. This graph was created by China Power Project based om OECD data. Retrieved from https://chinapower.csis.org/china-research-and-development-rnd/#:~:text=China's%20spending%20on%20R%26D%20continues,percent%20of%20GDP%20in%202019.

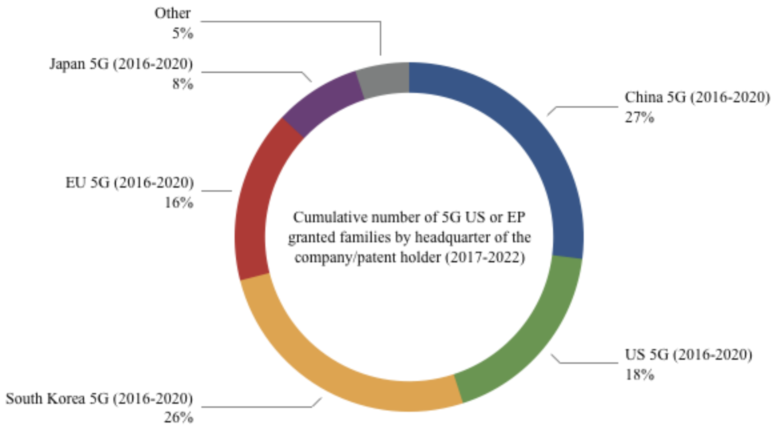
More specifically, according to the Chinese National Bureau of Statistics, electronic products, including information and communication equipment, attracted most of the R&D funding, accounting for approximately 36 billion dollars in 2019 (National Bureau of Statistics, 2019). In addition, at the company level, Huawei has been at the forefront of R&D spending. Huawei's R&D spending accounted for 14 billion dollars in 2017, far exceeding those of Nokia and Ericsson which stopped approximately at 5 billion each (Gu, 2019, Jiang 2018). It is likely that China's spending on R&D will further increase in the coming years. As the 14th Five-Year Plan for National Informatization states, China seeks to increase its R&D spending by more than 7% during the perioded plan, targeting a much higher percentage of spending than had been established in previous Five-Year Plans (Mallapaty, 2021).

China's increased technical capabilities are also confirmed by the European tendency to perceive China as a "thriving R&D hub" (European Business Confidence Survey, 2022). According to the European Business Confidence Survey of 2022, China's R&D and innovation environment is viewed as more favorable than the worldwide average by 40% of respondents. Importantly, this view has increased and been consistent over the year (European Business Confidence Survey, 2022). This trend is mostly related to China's numerous collaborations, which bring together national champions, start-ups, scientists, and researchers in a large innovative ecosystem (Merics, 2022). China's market size and demand for innovative products are other reasons. Instead, those respondents viewing China's innovation ecosystem negatively attribute the decision to the lack of IPR protection in China, which would increase the risk of seeing European technologies being copied (Merics, 2022).

The high spending on R&D expects countries and their industries to experience a greater number of innovations, which are empirically observed in patents filed in world patent offices. Patents encourage innovations by guaranteeing that countries and companies that invest time and money into developing new technologies can potentially reap the benefits of their inventions. During the period related to 5G standardization, China's filed patents have gradually increased at the international level. Statistics show that 73% of Chinese 5G innovations have been filed by at least one international patent office among USPTO, EPO or PCT. This rate is lower than European and US stakeholders, which accounts respectively for 91% and 87% of internationally filed patents, but has increased compared to previous generations (Pohlmann et al., 2020). In addition, as seen before, China has a relatively lower rate of granted patents by one of the above-mentioned international patent offices compared to European and Korean counterparts (Pohlmann et al., 2020). However, when considering the cumulative number of 5G patents family that are granted by the US or EU patent office, China leads with a 27%, followed very closely by Korean patent holders at 26% (Pohlmann, T., & Buggenhagen, 2022) (Figure 15).

Figure 15

Patents Granted by US or EP Patent Offices by Nationality of Patent Holder



Note. Own elaboration. Data are retrieved from IPlytics Reports on SEPs, https://www.iplytics.com/blog/

The increased number of internationally filed patents by Chinese stakeholders is indicative of China's increased role in generational standards. Internationally patented technologies provide a legal protection for patent holders across different jurisdictions and secure potential economic benefits, showing China's inclination toward expanding its commercial interests and normative rules by filing SEPs at international patent offices, which are then pitched at the international level as global standards.

The empirical evidence gathered within this case analysis suggests a strong connection between innovation capabilities and standardization influence. The QCA results, however, established innovators as a necessary condition rather than a sufficient one. This relates to the fact that technological capabilities might depend on other factors. As briefly anticipated, the innovation capabilities of China has also been linked to China's economic and institutional aspects. This will be further addressed in the conclusion.

5.3.4 Analyzing China as a Large Economic Power

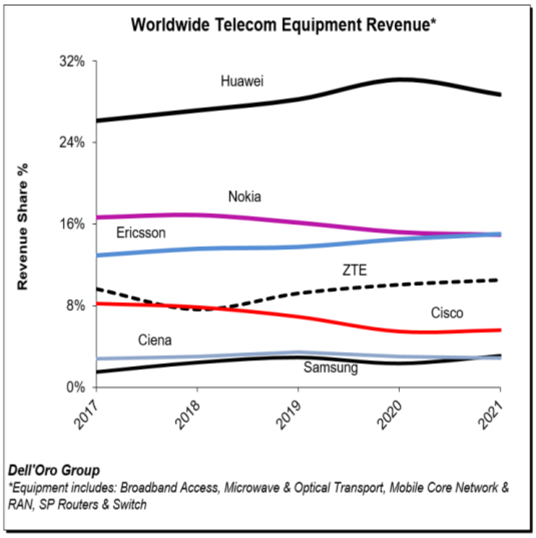
The second condition-centered mechanism expects to find within case evidence about China's material resources in the form of economic and market resources and revenues, which should trigger two parallel mechanisms: provide Chinese stakeholders with the financial capabilities to participate in international standardization and enable stakeholders to set competitive prices through which they can further shape the outcome of standards. In the following paragraphs, the study shows why China is a large economic power and empirically analyzes the mechanism that emerges from such a condition.

China has shifted from a manufacturing-driven industry to an innovation-driven industry over the last decade. Many studies claim that such a shift has been mainly driven by the ICT sector, which has the highest productivity level (Zhang & Chen, 2019; Li & Wu, 2018). China's ICT sector has increased significantly over the years, accounting for approximately 40% of China's GDP in 2021 (Yi, ChinaBrifieng, 2022).

In light of this, China has been considered a major player in the global technology industry in the last few years. It praises many leading technology companies in the global telecommunication industry (Merics, 2022). According to statistics, two of the top seven telecommunication manufacturers, which are highly engaged in the global market, are Chinese, namely, Huawei and ZTE. More precisely, Huawei held approximately 30% of the total telecom equipment market as of 2018, increasing its market share by 8% since 2013 (Pongratz, 2020; Pongratz, 2022).

Figure 16

Worldwide Telecom Equipment Revenue Share by Company (2017-2021)

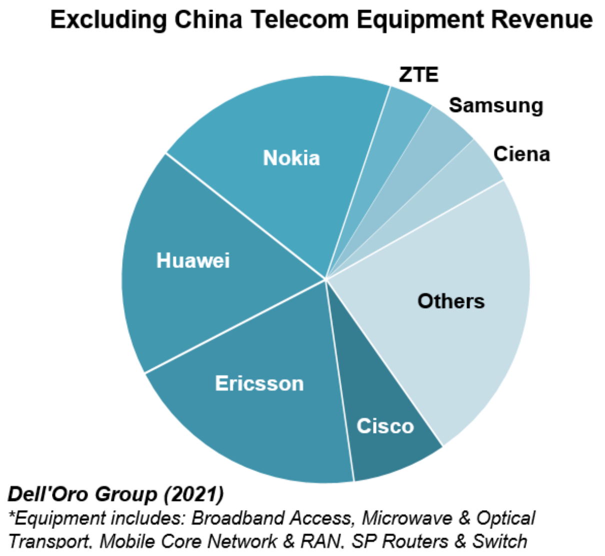


Note. This graph was created by Stephan Pongratz Dell'Oro Group. Retrieved from https://www.delloro.com/key-takeaways-2021-total-telecom-equipment-market/. See Reference list

During the same period, the market share of European players, such as Nokia and Eriksson, slightly decreased until 2018, when their market share stalled. When aggregating the global market share of telecommunication equipment by region, China's global market share accounted for more than 40% as of 2018. The EU industry followed the Chinese one, holding approximately 30% of the global market share (Figure 16). Focusing on international shares, the playing field is more balanced with Ericsson, Nokia, and Huawei holding respectively 20% of the global market in 2021 (Figure 17). Despite this, China remains one of the largest global suppliers given its domestic market size and huge installed base worldwide (Council of Foreign Affairs, 2021).

Figure 17

Worldwide Telecom Equipment Revenue Excluding China's Domestic Market



Note. This graph was created by Stephan Pongratz Dell'Oro Group. Retrieved from https://www.delloro.com/key-takeaways-2021-total-telecom-equipment-market/

China has represented the greatest domestic market for telecommunication equipment over the last few years. According to statistics, China's telecommunication infrastructure counts half of the world's 4G base stations (Council of Foreign Affairs, 2021) and approximately 1.4 million 5G base stations as of 2021. In addition, China already recorded more than 450 million 5G connections in 2021, which are forecasted to cover half of the world's mobile 5G connection in the coming years according to GSM intelligence (GSM, 2021).

China's economic productivity and market leverage provided China and its stakeholders with great financial revenues generated by global and domestic markets. Huawei's revenue from telecommunication technologies was four times greater than Nokia's or Ericsson's in 2019 (Foreign Policy, 2021). Similarly, Chinese mobile operators, such as China Mobile, which can count on millions of users, obtained in aggregate terms the highest 5G revenues in 2020, which are expected to increase up to 10 billion dollars in the following years (Weissberger, 2022). These significant revenues sound even more remarkable if we consider that the combined revenues of US and European operators obtained only half of the Chinese operators' total revenues in the same year (Weissberger, 2022). More recent governmental data show that the combined business revenue of China's telecommunication sector rose to approximately 230 billion dollars in 2021, according to the Ministry of Industry and Information Technology.

These statistics briefly reveal China’s increased financial resources, which have arguably put their stakeholders in a better position to shape standardization for three reasons. First, greater financial resources allowed Chinese stakeholders to invest more in international participation in international standard settings. Large resources were devoted to international standardization by China and its stakeholders. Consequently, Chinese stakeholders' participation level at 3GPP and the ITU level has increased significantly over standard generations. China is today the most represented player within the 3GPP with 178 members if we do not consider the EU in aggregated terms, which accounts for more than 200 members. The US follows with almost 100 members (3GPP Global Membership, 2020).

Second, large financial power put Chinese stakeholders in the position to set competitive prices for their products and thereby offer more attractive packages, which can be a determinant factor to increase further China’s market share and its capacity to pitch its patented technologies at the international level. According to a European Council of Foreign Affairs study, “Chinese vendors have priced their products around 10-30 % more cheaply than the competition on global markets”. In particular, Huawei has been one of the vendors with the most aggressive prices abroad. However, Ericsson managed on some occasions to outbid Huawei in its home market in China in 2019 (Gu, 2019), which is also indicative of Europe’s industrial competitiveness. This has presumably become more difficult over time since China’s government has ordered Chinese mobile operators to prioritize Chinese manufacturers for their telecommunication infrastructures, conceding only a small slice to foreign vendors (Foreign Affairs, 2020).

It is evident that China and its stakeholders have increased their capacity to shape standardization also thanks to the financial resources derived from its economic and market power, which has increased China's participation and market competitiveness. The empirical evidence also shows that the mechanisms triggered by economic power are also connected to innovation capabilities. Material resources have also allowed China and its stakeholders to increase its technical expertise through R&D investments, which vice versa has contributed to its economic power. This interconnection will be further discussed in the conclusive section when trying to refine the theorized mechanisms.

5.3.5 Analyzing China with a Highly Complementary (Domestic) System

Technological capabilities and economic power trigger mechanisms essential to increase countries' capacity to shape standardization. However, according to the first and most consistent QCA path, they are not sufficient. The first sufficiency path also considers institutional complementary in its equation, which triggers a mechanism that presumably facilitates the projection of countries' indigenous innovations as international standards. The following paragraphs describe China's standardization approach toward institutional complementarity. Subsequently, it analyzes the empirical findings against the theorized mechanisms.

China's domestic standardization system has evolved parallel to its economic and technological growth over the last two decades. This evolution can be traced by some historical moments and events in China's political and economic development. The first moment corresponds to China's opening-up process in the late1970s. Since then, China has started to conceive international standards as a fundamental means to promote China's integration into the global economy. Among various institutional improvements, this required the creation of an organization that could coordinate China's national standardization system and represents China's position internationally. For this reason, China's State Council established the China

Association for Standardization (CAS) in 1978, which has operated since then under the auspices of the State Administration for Market Regulation (SAMR). During this period, China's national standardization system was primarily state-driven, an institutional characteristic in contrast to the US and European standardization systems, which were primarily private-driven or public-private-driven.

China's decision to join the World Trade Organization (WTO) in 2001 arguably represented another moment that prompted a change in China's institutional approach to standards. China's decision to join the WTO and its binding regulatory regime obliged China to comply with international standards and, above all prevent the use of national standards as trade barriers. To meet WTO accession criteria, China has taken concrete steps toward adapting its national standards to international standards and guaranteeing intellectual property rights. These steps were legally enforced in 1989 by China's Standardization Law, which constitutes China's normative basis for standardization.

As a result of such changes, China reduced its national mandatory standard significantly by the end of 2000, adopted various international standards such as ISO 9000, and increased its presence in international standardizations, becoming in particular a member of the Council of the International Organization for Standardization in 1983. Despite China's progress in standardization in these years, China's influence in international standardization was still low. Among various factors, this was also related to its state-driven standardization system, which was not really conducive to innovation and complementary to the international standardization system (Wei, 2020).

In the early 2000s, China's participation in international standardization continued to increase; however, this was not followed by a greater capacity to promote its indigenous technologies as international standards. China's influence still lagged behind those of advanced countries, as China's 3G technology (TD-SCDMA) showed in those years. China's 3G failed to spread commercially because of various factors, including the technical superiority and market influence of Europe's WCDM standard as well as the US's CDMA 2000 standard (Wei, 2020; Voo, 2021).

According to experts, however, China's 3G failure provided China with important lessons in the following decade. On the one hand, China recognized the importance of market power, early commercialization, and creating a value chain for the promoted technology; on the other hand, it realized the need to reform China's national standardization system (Wei, 2020). As some observers argued, China "has little control over international technical standards. That is why we must reform our management system to win control of international technical standards" (Shuchun&Hanchuan, 2020).

The need to change China's standardization system was officially discussed in China's 11th fifth-year plan in 2006, which underlined for the first time the importance of changing China's standards ecosystem to increase the influence of Chinese companies and experts in international standardization. Following this plan, SAC also set out a five-year plan specifically on standardization. This plan set the ground for creating a standardization system that would increase the role of the private sector, shorten the standardization cycle, and increase participation and leadership positions at the international level.

It was clear that China's standardization system had not met yet its growing technological capabilities. As Zheng Weihu, President of China Nationa Insititute of Standardization, argued in relation to the SAC plan, "innovations are not contributing to the progress of the industry as a whole through standardization, because there is no voluntary standardization run by private entities in China, and business enterprises do not have the means to convert their innovations into though private and industry innovations" (Zheng, 2006).

The SAC plan was normatively substantiated by the Reform Plan for Deepening Standardization, which was issued by China's State Council in 2015. This reform plan called for a fundamental reorganization of China's standardization system that culminated in the revision of the Standardization Law (of 1989) in 2018. The Standardization Law in 2018 draws on China's standardization past failures as well as on western domestic standardization best practices. China sought the advice of the major standard organizations, including US's ANSI, Germany's DIN, France's AFOR, and UK's BSI. This mix of failures and lessons has turned China's mostly state-driven system into a hybrid system, combining public control and market processes (Seaman, 2019). More precisely, there are five typologies of standards that fall under two broad categories, namely state-led and market-led (Seaman, 2019).

The new standardization system has been seen as a "partial liberalization" of the standards system. This liberalization dealt with two issues. First, it reduced the number of mandatory standards, which were not conducive to innovation. According to the National Center for Standards Evaluation (NCSE, 2019), many industry and local standards have been abolished or become voluntary following the reform. Second, and more importantly, the role of the private sector has increased significantly. For instance, introducing association standards, which resemble US standard models, provides greater space for industries that develop standards in line with market needs and technical requirements. In addition, the standardization law has set a framework that provides successful companies in international standardization with rewards. Central and regional governments are said to be providing annual stipends of up to one million yuan (US$155,000) for companies leading in the development of standards within key SDOs (Pop et al., 2021).

However, China's domestic standardization system is still subject to government control. The government still has a "steering role" when it comes to standardization (Seaman, 2019). Some industrial experts argue that “the system cannot be changed directly from a state-driven one to a purely market-driven one; the government is not in the habit of completely giving up control.” Others say that eventually “most of the work is reportedly driven by experts from the private sector, while state institutions maintain the formal, overall leadership” (Telenau, 2021: 23). In addition, plans, such as Made in China 2025 and more recently Standardization 2035, foresee a greater role of the private sector, encouraging companies, social organizations, and universities to participate in international standardization activities. Despite the state component, China’s changing approach to standardization has increased its level of domestic complementarity to the international system, by rethinking the role of state entities and prioritizing those of companies. In addition, China’s standardization 2035 plan has recently foreseen a greater shift to international complementarity. According to recent recommendations coming from China’s standardization plan, standards will be further divided into two parts: those of national relevance and those of global importance. Those of global importance is set to be developed by joint partnerships between institutions and industrial associations (Ouline for National Standardization Development, 2021).

As explained below, the theorized parts of the causal mechanism triggered by China’s complementarity also present some evidence. The mechanism is expected to observe a high level of institutional coordination between private and public stakeholders in China’s standardization system and collective action at the international level. This is manifested in the several joint initiatives between the Chinese government and the Chinese industry, which are established to create coordination mechanisms to exchange expertise and build consensus.

China’s most important coordination mechanism concerning 5G is the IMT 2020 (5G) Promotion Group. This promotion group was established in 2013 by three powerful Chinese ministries, namely the Ministry of Industry and Information Technology (MIIT), the National Development and Reform Commission (NDRC), and the Ministry of Science and Technology

(MOST). It was based on the international IMT promotion group issued by the ITU, calling upon an "all-government and all-industry" Chinese alliance to develop and deploy 5G (Triolo, 2020:20).

More precisely, this alliance involved the largest players of China's telecommunication ecosystem, including major research institute under the MIIT such as the Chinese Academy of Information and Communications Technology (CAICT), the three largest Chinese operators (China Mobile, China Telecom, China Unicom), mobile device makers (Xiaomi, Oppo, Vivo), and mobile equipment manufacturers (Huawei and ZTE). Other Chinese companies such as Lenovo and Universities (Shanghai and Jiatong) also contributed to the group (Triolo, 2020).

Experts argued that this coordination initiative enabled China to develop, test, and build networks on a large scale and in particular become a leading contributor of patented technologies allowing the Chinese industry to hold key SEPs for 5G (Triolo, 2020). In particular, Triolo explains in relation to international standardization that China's promotion group "has served as a unified platform for channeling China's considerable participation in and contributions to the global standard-setting processes for 5G under the 3rd Generation Partnership Project" (2020:22). On a similar note, Rühlig argues that China's promotion group put Chinese stakeholders in the condition "to boost the reputation of standardization proposals as collective ones, rather than just the interests and solutions of an individual company". This was further confirmed by one of its interviews with a Chinese stakeholder who said that "in earlier years, we were not very coordinated and came to international standard-setting unprepared. We had five Chinese companies with five different ideas. […] From your perspective, this might sound normal because private companies compete in the West over standard-setting. But we were a latecomer. We had no influence. […] The [IMT 2020 (5G)] Promotion Group has helped us a lot. We discuss all aspects beforehand and come up with a good and consistent solution and can show how our proposals support not only the interest of a single company but the entire 5G ecosystem" (Rühlig, 2022).

In addition, the theorized mechanism finds evidence also in the many Chinese technical committees and working group that mirror the work of international working groups at the ISO or ITU level. Committees that do so bring together public and private stakeholders to exchange information and gather consensus on standard proposals that are proposed in a second stage at the international level. According to SESEC, approximately 900 China's technical committees mirror ISO/IEC technical committees or working groups that also deal with 5G technologies. For instance, China's technical committee 260 (TC260) on information security mirrors one of the ISO/IEC working groups on information security, cybersecurity, and privacy, namely the ISO/IEC JTC1/SC27 (US-China Business Council, 2020). The mutually coordinated development of domestic and international standardization has been further promoted by publishing translations of domestic standards into foreign languages. According to statistics, China has published 721 foreign language versions of Chinese standards of 2019, (SAC, 2020). These are some of the actions planned by China to participate in international standardization activities and raise its voice effectively.

Interestingly, China had also signed several bilateral and standardization agreements with more than 50 national and regional standardization organizations. Thanks to this, it also participated and contributed to the work of domestic and regional standard bodies such as the European Committee for Electrotechnical Standardization (CEN/CENELEC) and the Pan American Standard Commission (COPANT). In addition, it also established 12 joint research centers in China to promote technical and knowledge sharing on global standardization issues (SAC, 2020).

China's domestic standardization system has changed over the last decade consequently to China's economic rise and political aspirations, against the background of its political and economic reforms (Yu, 2011). Since it acceded to the WTO in 2001, China has gradually set up a system to shape its indigenous technologies in line with international standards as well as a project such technologies as international standards, which has contributed to promoting China's global economic integration and competitiveness. China has done so by reforming its standardization system to enhance greater institutional complementarity between its domestic and international standardization systems.

Although it is difficult to assess the impact of China's public-private initiatives and mirror committees on international standardization, the empirical evidence provided above illustrates China's great effort in coordinating private and public stakeholders at the domestic level to increase its standard capacity at the international level. As the within-case analysis has shown, coordinated public-private partnerships and mirrored working groups have favored China's capacity to shape standardization. This evidence suggests that China's shift from a main standard taker to a standard setter can be also attributed to its institutional changes and initiatives which are functional to China's economic growth and increased innovation capabilities.

5.3.6 Drawing Conclusions on China as a Leading Standard Setter in 5G

The empirical analysis shows that the empirical observations theorized for each condition have been reasonably met. The empirical analysis shows that China's increased innovation capabilities have contributed to China's standardization capacities, by holding greater amounts of internationally filed patents and SEPs proposed to the international standard setting. The results also indicate that China's increased revenues derived from its economic and market power provided large investments into R&D as well as laid out financial resources for China's stakeholders to participate more actively in international standardization, which is also functional for acquiring more technical expertise. Parallelly, China's market power allowed its industrial stakeholders to offer competitive international prices and thereby gather consensus around its technologies in international standardization. Empirical evidence finally reveals that China's national standardization system provided China's industry with a competitive advantage in international standardization, by establishing coordinated public-private partnerships and mirrored committees. Thus, the PT analysis substantiates the first sufficiency path, providing evidence of the presence of the theorized mechanisms.

Furthermore, the empirical analysis suggests that the conditions forming the sufficiency paths trigger multiple mechanisms that work in conjunction. The empirical results demonstrate that China's role as a technological innovator is connected to China's considerable economic power, which contributed to China's increased innovation through R&D investments and participation. In addition, China's institutional complementarity with international standardization is linked to China's economic and technological growth. Indeed, the need to protect and externalize China's technologies and standards arguably shifted China's standard system towards institutional complementarity. At the same time, the analysis suggests that a great coordination between domestic stakeholders benefits the countries' innovation and economic system by exchanging information and needs. However, what is not clear yet is which triggered mechanisms might be more consistent, which would provide further information about conditions' potential explanatory power. To do so, the study analyzes another typical case of the first path and two cases belonging to other sufficiency solutions.

5.3.7 Assessing and Explaining EU (countries) as Leading Standard Setter

As previous statistics showed, European countries have also been leading standard setters in mobile network standards. This influence is mainly given by the big contribution of two European tech companies, Nokia and Ericsson, among the largest patent holders in 5G technologies. In aggregate terms, European countries also praise the industry with the largest technical contributions to the 3GPP standard setting and leadership positions as of 2020.

Similarly to China 5G, the EU's great capacity to shape global standards has resulted from its economic and market leverage, innovation capabilities, and coordinated public-private partnerships.

The European industry held global market shares in telecommunication equipments equal to the Chinese one, guaranteeing substantial resources to R&D and standardization activities (Pongratz, 2022). Public funds have further supported private resources devoted to innovation: a report by the European Commission estimates that the European Union has invested over 700 million dollars in 5G R&D projects between 2014 and 2018. These amounts are relatively low compared to other countries such as South Korea: Seul invested over 1.5 billion dollars in 5G research and development in the same period (New York Times, 2014).

Despite smaller public support, the European industry has been the most represented region at the 3GPP level during the 5G standardization period. Some experts, however, have raised concerns that the presence of EU industrial stakeholders has decreased in standardization compared to previous generations. One reason for such a decline is attributed to the growing footprint of the Asian region, which goes at the expense of European and US industries.

Regarding the institutional configuration, the EU standard framework has highly reflected the 3GPP/ITU framework. As a matter of fact, the 3GPP can be considered as a byproduct of ETSI since it was formed by a project conceived by ETSI itself. While the 3GPP operates independently of ETSI, it is closely tied to the organization and many of its members are also involved in ETSI activities.

Similarly to China, the EU has set different public-private partnerships that have mirrored the technical work of 3GPP and ITU to ensure European interests in setting global 5G standards. One such partnership is the 5G Public-Private Partnership (5G PPP), which is a joint initiative between the European Commission and the European ICT industry (ICT manufacturers, telecommunications operators, service providers, SMEs and researcher Institutions) established in late 2013. The goal of this partnership has been to secure Europe's technological leadership, by reinforcing the European industry's position on global markets and, more importantly, creating a common European approach to the development of 5G networks and services (5GPPP, n.d).

As the Vice President of the EU Commission, Neelie Kroes, said at the Mobile World Congress in 2013 to inaugurate the partnership, "[…] I call on EU industry and other partners to join us in a Public-Private partnership in this area [5G]. An open platform that helps us reach our common goal more coherently, directly, and quickly. European 5G is an unmissable opportunity to recapture the global technological lead. And I hope you will be able to support and join us" (European Commission, 2013). According to the EU Commission, the 5G-PPP put Europe in the forefront of global standardization thanks to the coordinated research work between public and private stakeholders (European Commission, 2016).

This partnership, which is still ongoing, was followed by other plans such as the EU 5G Action plan in 2016, which outlines a set of policy actions to support the development and deployment of 5G networks and services in the EU. In particular, among the proposed actions, the plan set priorities for a coordinated 5G deployment, including spectrum allocation, multi stakeholders trials and efforts to set global standards (European Commission, 2016). As the action precisely states "the EU aims at continuing to influence the technological definition of future communications systems (5G and beyond) and consequently the standards through its advanced research", identifying 5G standards as one of the five priority areas under the Digitising European Industry initiative. More recently, these actions have been reviewed in the EU's Digital Decade plan, which further underlined the importance of shaping global technology standards (European Commission, 2021). In particular, in the field of next generations of networks, the plan referred to the role of shaping global standards to secure Europe's IP leadership and technological competitiveness.

In the same period, the EU concluded bilateral agreements on standardization with technologically advanced countries, such as South Korea, Japan, and ultimately China. The EU-China partnership on 5G in 2015 strengthened cooperation on joint research actions and global standardization for 5G in the 3GPP and the ITU. These agreements also foresaw access and participation in each other's publicly funded 5G activities and cooperation between their two respective industrial associations, the EU's 5G PPP and China's 5G promoting group (European Commission, 2015). Although assessing the impact of such agreements is difficult, it is arguable that building consensus through international agreements might have also contributed to the EU's capacity to shape standardization.

5.4. Other Sufficiency Paths and Mechanisms: Assessing and Explaining the US as a Leading Standard Setter

The QCA also results provided two different solutions for the outcome of interest. The first solution refers to the second most consistent path, which entailed membership in the innovation and economic conditions. The most typical case for this path is US 5G. Instead, the second uncovered solution concerns innovation and institutional complementarity. The chosen case for this solution is Korea 5G.

Starting from the second sufficiency path, the US has been one of the main leading standard setter for 3G, 4G, and to a lesser extent 5G standards. It is the country, along with the EU, with the largest SEPs and leadership positions across the three latest wireless network standards (add table). Qualcomm, US leading tech manufacturer, and AT&T, one of the main US mobile operators, have been at the forefront of these technologies (GSMA, 2018). As in the case of the European countries, the US has faced the rising technological challenge of China and South Korea's powerful industries, which reduced its technological edge and market power.

According to the QCA, the US as a leading industrial standard contributor is the result of combining two conditions, its innovation capabilities and economic/market power. Hence, the US and its industrial players have played a leading role in standardization despite not being member to the third condition, institutional complementary. In fact, the US domestic standard system has been mainly private driven, being characterized by high levels of market competition and theoretically by little public-private collaboration over technological solutions at the domestic level (Mattli & Büthe, 2003). The US standard ecosystem is indeed made of numerous standard development organizations that commonly compete with each other or at least do not coordinate with each other (Mattli, 2001; Seaman, 2019).

According to some observers, the US market-driven system is actually the key source behind US's innovation and leading standard-setting position. There is ample evidence proving that market competition favores innovation (Weiss, 2003). At the same time, however, too much competition might not be good either (Boldrin et al., 2011). In particular, when equally strong economies propose their technologies as global standards, studies have shown that economies with a domestic coordinated system have a competitive advantage in creating large industrial coalitions, which are key to influencing international standardization (Kenndy, 2007; Mattli and Büthe, 2003). So how can the US leading position in standardization be explained?

The US standardization power is primarily explained by its great technology and economic power in previous generations, which have yielded great financial benefits. As seen before, the US has been the country with the highest level of R&D spending in the world in the last decade (OECD, 2019). At the company level, Qualcomm, one of the world's US leading technological innovators, has invested over 75 billion dollars in R&D since its creation in 1985, devoting over 20 % of its revenue since 2006 (Qualcomm, 2021).

In addition, the US has boasted the industry with the highest amount of revenues derived from royalty payments across many digital sectors over the last decade (IP Finance, 2021; RCR Wireless News, 2019), which is indicative of the value and 'essentiality' of its standard essential patents. For example, a study estimated that Qualcomm received 5% of the total profit of each 3G handset based on CDMA standards (Ray, 2011). More recently, in 2019 Qualcomm obtained approximately 5 billion dollars through the licensing of its 4G patents to third companies (Qualcomm, 2019). For the same technology, Huawei estimated revenue of 1.2 billion dollars from patent licensing between 2019-2021 (Reuters, 2022). This amount of IP revenues has been relatively far from those generated by Qualcomm and other European companies; nonetheless, it represents a critical first shift in the IP balance of payments considering that China's industry has been mostly a standard taker in technology standards up until recently.

When looking at aggregate IP data, the US is still the country with the highest IP balance of payments as of 2021 (World Bank, 2021); however, this surplus has started to decrease in the last five years, also because of the rise of new aspiring standard setters, such as China, whose large contribution in international standardization has been conducive to reap larger benefits in the last years (Malkin, 2022). As Malkin argues, "Chinese firms presently do not figure prominently in the collection of rents accruing from SEP declarations, yet, this situation is unlikely to persist indefinitely".

The US's has attempted to contain China's increased influence in standardization by imposing economic sanctions and market bans, such as those placed on Huawei in 2019. However, these have not been so successful. The main reason, as Malkin explains, is that standards include "parts and processes that stem from the proprietary efforts of several firms. This means that royalty payments for standardized products flow to multiple firms, irrespective of the product designer's national origin. Therefore, even if countries comply with US requests to ban Chinese firms from supplying equipment to their telecom networks, SEP royalties would still flow to Huawei and ZTE, regardless of whether their physical technology is used or not" (2020).

The US's intention to prohibit or limit collaborations with Chinese technological players, which de facto would have meant withdrawing the US industry from global standardization regimes, such as the 3GPP, was also soon abandoned in 2019. Indeed, these prohibitions would have further increased China's footprint in global standardization. As the US government stated later in relation to such policy idea, "Reduction in Qualcomm's long-term technological competitiveness and influence in standard setting would significantly impact U.S. national security" since, among various implications, it would have conceded greater space to China and Huawei in global standardization (US Treasury, 2018). Similarly, Wilbur Ross, the US secretary of Commerce, later affirmed that this policy action could have damaged US innovation leadership, encouraging if anything "U.S. industry to fully engage and advocate for U.S. technologies to become international standards" and thereby allowing American companies to continue operate in SDOs with a Chinese growing presence (US Department of Commerce, 2020). This has opened up a discussion about a greater role of the US government in supporting the US industry in the development of international standards, which is critical to preserve US technological leadership.

Historically, the US tended to have a "hands-off approach" to setting global standards, reflecting its long-lasting technological superiority and market competitiveness. The US leadership in innovation and global markets conferred the US industry a "wielding de facto influence" in international SDOs (Voo, 2021: 24). This led the US Government to preserve a hands-off approach, believing that the US industry would continue to play a dominant role in standardization by default, given the sole presence of its industry in the main 5G standardization bodies. However, since the rise of new large economies with standard-setting aspirations, the US's innovation and economic power has no longer guaranteed US leadership in global standard settings, particularly at the 3GPP and ITU (Chen et al, 2018; Voo, 2021). As Voo argues, in a highly increased technological competition with equally strong economies, the US "laissez-faire approach to standards setting perpetuates an inefficient system and leaves too much to chance" (Voo, 2021: 35). Against this backdrop, the US government have started in the last years to reconsider its national standardization system and in particular its approach to the setting of global standards in order to create greater public-private synergies, which is further indicative of the importance of having a highly complementary domestic system.

There have been references to public and private cooperation to increase US influence in international standardization already since 2011. As the US Strategy for American Innovation of 2011 stated, "the vibrancy and effectiveness of the U.S. standards system in enabling innovation depend on continued private sector leadership and engagement [...]. In limited policy areas, however, where a national priority has been identified in statute, regulation, or Administration policy, active engagement or a convening role by the Federal Government may be needed to accelerate standards development and implementation to help spur technological advances and broaden technology adoption" (National Institute of Technology and Standard, 2012:2). The strategy further specified that the US government might undertake this task, by playing various roles such as the role of participant, facilitator, and source provider (National Institute of Technology and Standard, 2012). However, concrete steps towards greater public-private coordination and partnerships have been taken only in the following years.

In relation to 5G, the Advanced Wireless Research Initiative (AWRI, 2021) represented a first step towards a greater US public-private coordination in standardization. The Obama administration launched this initiative in July 2016, a couple of years later than China and South Korea's 5G project, to "maintain US leadership and win the next generation of mobile technology" (The White House, 2016). This group included, under the supervision of the US National Science Foundation, the main US telecommunications vendors, operators, and foreign players such as Nokia and Samsung. The initiative received from the US government a 400 million investment in R&D over seven years to develop and test new wireless networking solutions. Thus, the AWRI initiative arguably demonstrated a stronger government-standard commitment to 5G to effectively coordinate the innovative-driven US industry.

This approach found further confirmation in the US National Strategy to Secure 5G that the Trump administration released in March 2020. The plan establishes how the US government should lead the development and deployment of 5G networks. To preserve US influence, the strategy particularly outlines the importance of holding leadership in setting global standards. More precisely, the strategy states that "the United States Government will work to preserve and enhance United States leadership on 5G in relevant organizations that set standards in concert with the private sector, including but not limited to commercial, academic, and like-minded international partners." This imply that greater governmental efforts are put in federal interagency coordination and participation in international standardization. As the strategy precisely sets out, "the United States will promote and support increased participation by the private sector and ensure that such participation is informed by appropriate public-private coordination" (ANSI, 2020). This strategy has also been complemented by significant public investment to develop 5G technologies. One is the 5G rural fund of 9 billion dollars allocated to the Federal Communications Commission (FCC) in October 2020 for the development of 5G networks and technologies, including funding for standardization activities.

All these US actions aimed at strengthening government-industry relations in the last years have illustrated the importance of acting coordinatively and coherently at the development of international standards. Although the driving force behind standardization comes from the industry, it is expected that the US government will have a greater role in coordinating public-private partnerships and allocating resources for international standardization (Council of Foreign Affairs, 2020). This should also be the case for other disruptive technologies such as IA. Indeed, following the Executive Order on Maintaining American Leadership in AI in 2019, the US National Institute for Standards and Technology announced that it would further promote coordination between federal agencies and the private sector to lead AI global standards (Federal Register, 2019).

5.5. Assessing and Explaining South Korea as a Leading Standard Setter

South Korea has been another influential standard contributor to the development of telecommunications standards, especially in the last two network generations, 4G and 5G. According to the QCA results, such influence has been the result of South Korea's innovation capabilities and institutional complementarity. This implies that the condition of economic power is not necessary, which in turn suggests that the mechanisms triggered by such conditions are not required. When looking more closely at this case, however, South Korea and its industry possess large technical expertise and economic and financial resources given by its presence in key global markets such as the US and Japan (Oh, 2022). In particular, Samsung, South Korea's main technology company, has invested more than 22 billion dollars in 5G technologies and holds important market shares in RAN technologies, which have increased significantly as of 2019 (Gu, 2019). So, South Korea in fact needs to be recalibrated and considered part of the first sufficiency path.

South Korea's approach to standardization recalls some aspects of China's government-industry partnership. South Korea's leading standard contribution is not only the result of its innovative ecosystem but also of its public-private institutional configuration. To secure South Korea's position as a global 5G leader, South Korea's government promoted several cooperative frameworks, involving multiple stakeholders from the public and private sectors, right after the commercialization of 4G technologies.

The first initiative, the 5G Forum, was established in 2013 to constitute a platform for public and private collaborations under government supervision (5G Forum, 2022). The 5G forum above all included government officials, telecommunications vendors such as Samsung and LG, the three main Korean mobile operators (KT, SKT, LGU+), and the Korean standardization body Telecommunications Technology Association (TTA) (5G Forum, 2013). This initiative undertook a public-private investment of approximately 1.5 billion dollars between 2014 and 2020 (Pujol, 2015).

Another important cooperative framework, which complemented the 5G forum, was South Korea's 5G Strategy Promotion Committee, a governmental body established in 2015 with the goal of bringing together public agencies, telecommunication vendors, mobile operators, research centers, and the civil society. This promotion committee met twice a year to discuss government policies, industrial needs, and challenges (Yeo, 2019). Among various actions, the committee devoted great importance to international cooperation and global standardization to promote its indigenous technologies as globally recognized 5G standards (World Bank, 2019).

South Korea was indeed very active at the international level in these years, establishing several international collaborations (Massaro&Kim, 2022). One of which was the agreement between the Ministry of Science and Technology and the European Commission in 2014, which set the ground for collaborations on a global definition of 5G standards (European Commission, 2014). South Korea also formed similar agreements with its regional partners China and Japan (Heo, 2017).

South Korea also took a proactive role in international and transnational organizations. In 2014, it hosted the ITU Plenipotentiary Conference, which represented the very first 5G Global Summit. Hosting such an event conferred great prestige to South Korea, which was the second non-American or European country (after Japan in 1994) to be hosting an ITU plenipotentiary conference (Massaro&Kim, 2022). In addition, it recognized South Korea's increased reputation as a technological power. A year later, South Korea also chaired the ITU Council meeting in Geneva Switzerland for the first time since it joined the ITU in 1952. During this conference, South Korea successfully encouraged selecting and allocating a specific type of radio frequency, the so-called millimeter wave (mmWave), as a 5G globally recognized frequency (Korea IT News, 2015).

During the same period, South Korea have also been actively participating at the 3GPP level through the great contribution of its industrial players, like Samsung. This participation has also been supported by the Korean standardization body, which has been part of the 3GPP since its creation in 1998.

The driving force of South Korea's standardization capacities has come from its public-private solid relationship. As Mr. Lee explained about South Korea's 5G program "the government is a trigger for the private sector." (CNN, 2014). Other industrial Korean experts similarly argued that public-private cooperation was "the key amid intensifying competition among global mobile carriers: it [was] significant for the government and companies to join hands and reach the goal together" (Samsung, 2021).

As seen, South Korea also pursued international collaborations between domestic and international stakeholders (Gao, 2015). As Kwak and other scholars argued, holding collaborative relationships between international partners is also important in influencing global standardization (Kwak et al., 2011). This is also related to the fact that countries are never fully technologically independent. For example, South Korea's 5G ambitions also depended on foreign companies in areas such as microchips, where US companies, such as Qualcomm, have been leaders.

Thus, South Korea's case shows that even in countries with a mature mobile industry, the government's role is critical to promoting successful indigenous technologies abroad. The lessons learned from Korea's experience can offer interesting insights to other latecomer countries that seek to play a greater role in standardization.

5.6 Conclusions

Various conclusions can be drawn from the empirical analysis performed within the selected case studies. First, the case study analysis suggests that the first sufficiency path is consistent in explaining the power shifts that are given by being a leading standard setter, which results from three combined conditions (innovation, economy and institution) that generate multiple mechanisms.

Focusing on the theorized mechanisms, the case study analysis also shows that the empirical evidence has consistently met the empirical observations. In particular, holding large amounts of SEPs, devoting resources to international standardization, and setting up government-industries initiatives have contributed to the capacity of technological powers to shape global standards. There is also some evidence on market power, but the effect of this mechanism has been difficult to assess given the lack of data on international prices.

In addition, the empirical analysis hint that these mechanisms can work both sequentially and simultaneously. The innovation capabilities of countries are mostly derived from their large economy (or market 'company' size), which provides the financial resources to invest in R&D and standard participation. Subsequently, countries increased technological expertise and involvement in global standardization can prompt a change in their domestic institutional configuration by aligning their domestic system or approach as much as possible to the international standardization framework. This has been the case for China, South Korea, some European countries, and arguably the US to preserve its technological leadership. At the same time, institutional complementarity guarantees great coordination between domestic stakeholders, which in turn benefits the countries' innovation and economic ecosystems by establishing a suitable regulatory system (Figure 18).

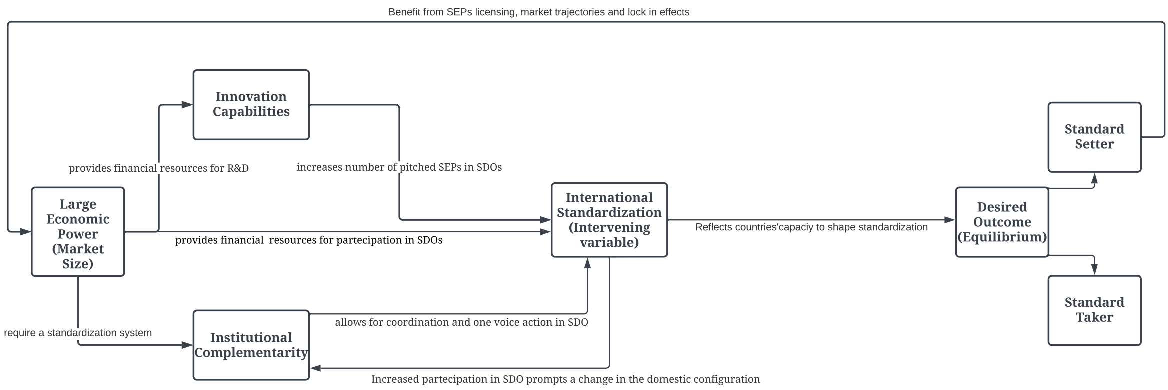
From the case study analysis, the study derives that being a great innovator and having a large economy (or holding big companies) are essential prerequisites for becoming a leading standard contributor. These two conditions are highly necessary, which suggests that they might be considered scope conditions for the outcome. In the case of the US, these two combinations suffice to explain the outcome. As seen, this is plausibly related to the wide economic and technological edge accomplished by the US industry in the past decades and to fewer competitors than nowadays. This, however, needs to be further explored.

The empirical analysis also reveals that the mechanisms triggered by the domestic condition are consistent with the empirical observations. The growing influence of South Korea and China, and the relatively preserved EU position in international standardization suggest that having a highly complementary system that promotes coordinated public-private cooperation provides a competitive advantage. This is further corroborated by the fact that the US, whose capacity has declined relatively to the other technological powers in 5G global standardization, is not a member of the third condition, highly institutional complementarity. In addition, the US's recent actions towards promoting greater government-industry partnerships further indicate the competitive advantages coordination can bring in international standardization.

Based on these considerations, the empirical analysis suggests that institutional complementary (in combination with innovation and economic conditions) has explanatory power. In particular, a highly coordinated institutional configuration positively impacts the capacity of technological powers to shape standardization by building consensus between domestic stakeholders. The case study analysis also suggests that institutional complementarity provides a larger consensus between domestic and international players, another factor that needs further exploration.

Figure 18

Theoretical mechanisms based on the PT results



6. Conclusion and Discussion

Over the past decade, the global political economy has undergone significant structural changes due to the emergence of new world powers that have taken on a more prominent role in shaping international policies, norms, and values. These changes have been particularly noticeable in the realm of technology, which has become a key battleground for nations. Power competition is no longer solely determined by military and economic capabilities, but also by technological advancements.

In the race for technology leadership, setting global technology standards have become a main arena of competition between countries and industries. International standards can exert great structural and network effects, by setting the rules by which state and non-state actors operate in the global political economy (Blancato, 2019; Strange, 1994; De Nardis, 2011). Given this, shaping global technology standards can secure enormous political and economic benefits to countries and industries that own and control such standards. In particular, generational standards like 5G "create a path dependency resulting in huge economic and strategic benefits for the corresponding companies and, potentially, governments" (Voo, 2020).

The outcome of generational standards carries various implications, by creating entirely new ecosystems of applications and infrastructures. In particular, they can generate large distributional effects, establishing who accrues the largest benefits from the licensing of patents or who faces the highest switching costs over different generations (Büthe et al., 2010; Gadinis, 2015). Standards are also embedded with values and norms, establishing which normative framework is globally promoted (Rühlig, 2021). Finally, standards can have important security implications. Those who control the dominant standards might be better aware of standards' technical vulnerabilities and potential backdoors. (In an international standard-setting process, however, hiding vulnerabilities deliberatively is very unlikely given the collaborative and attentive work of working groups and engineers).

In light of these implications, this research aimed to investigate power shifts in telecommunication standards. It tried to do so from a realist perspective that analyzes standardization as a structural adaptation of power relations whose configuration reflects players' capacity to be a leading standard setter, namely having a first mover advantage in standardization, as theorized in the battle of the sexes game. According to the IR/IPE literature, this first-mover advantage can derive from various combinations of conditions that suffice the outcome.

Drawing on this literature, this research specifically focused on power shifts in standardization by explaining under what conditions countries turn into leading standard setters across the three latest generations of mobile network standards (3G, 4G and 5G). Since (international) standardization is a complex process involving various stakeholders across multiple levels of governance, this research assessed leading standard setters by aggregating the contribution of public and private stakeholders to generational standards by nationality or headquarters' position. Identifying stakeholders' nationality or headquarter is a good indicator to illustrate where the political and economic benefits from power shifts in standardization go. The assumption is that while holding SEPs generates economic benefits for a company, the same economic benefit generates an industrial advantage for the country in which the company's headquarters is located (Becker et al., 2022). Based on this analytical consideration, this research focused on changing power shifts in telecommunication standards at a country-level analysis, specifically, those set at the 3GPP-ITU level.

The analysis was conducted through a mixed method approach combining a Qualitative Comparative Analysis (QCA) with a Process Tracing Analysis (PT). While the QCA identified the sufficiency paths for becoming a leading standard setter, the PT analysis examined selected case studies to further substantiate the sufficiency paths and trace their causal mechanism. The research chose QCA considering the multiple factors behind shaping standardization and the multiple outcomes (equifinality) that could originate from them. The PT tracing instead was used to explore more in-depth the presence of conditions and the type of mechanisms triggered by such conditions.

6.1 Findings

The QCA results suggest that the rise of China and South Korea as leading standard setters has resulted in a change in power structures for the three latest telecommunication standards. Traditional standard setters, such as the United States and European countries, have remained leading standard contributors, but their capacity to shape standardization has arguably decreased over the last three standard generations. While the traditional standard setters have tried to preserve their influential positions, new aspiring standard setters have experienced a shift along the (standard) power spectrum from being mostly standard takers to having a greater voice as standard setters. From a theoretical point of view, this means that there are more players with a first-mover advantage in the process of choosing the best equilibrium, namely the most beneficial standard for them. More players guarantee greater international technological compatibility, which is the primary function of global standards, but also generates greater competition since the benefits at stake are higher. In particular, the licensing of SEPs has become one of the most lucrative markets, not only for the potential benefits generated by royalty payments but also for the influence obtained in controlling strategic industrial value chains (Pohlmann&Buggenhagen, 2022).

Power shifts in telecommunication standards are further substantiated by the results of the (selected) case studies. The case study results confirm the leading contribution of China and South Korea as technological powers in the development of telecommunication standards.

China and South Korea, respectively, boast industries with the largest numbers of SEPs, standard contributions, participation, and leadership positions in telecommunication standards. They can count on strong technological companies, Huawei and Samsung, which play a very influential role in the process, covering the entire supply chain of telecommunication technologies. In addition, they have been very active at the international stage, holding various leadership positions at the ITU-3GPP level. Traditional standard setters, above all the US and EU countries, are still influential players, contributing significantly in terms of SEPs and other indicators. For example, EU countries are the technological player with the largest amount of recognized standard contributions. In addition, it is represented by Nokia and Ericsson, two of the most influential tech companies in telecommunication standards. Similarly, the US standard setting power is primarily given by Qualcomm, which is the company with the most leadership position held in the 3GPP, which is indicative of its technological and reputational power.

In general, results show that there are several influential powers, leading standard contributors, in standardization, which makes it difficult to establish which country or company is the greatest standard power. As a recent report by the USPTO states, “there is no country and company that leads in 5G patenting” (USPTO, 2022). This is related to the fact that “it is very difficult to crown a winner, especially when the underlying data is based on [5G] patents that were self-declared and not checked for essentiality or validity” (Pohlmann&Buggenhagen, 2022:6). Although it is difficult to provide an answer to who leads G standards, the results of this study further reveal that there has been a power shift in telecommunication standards given the rise of new players as leading standard contributors.

The research also investigated under what conditions technological powers turn into leading standard setters in telecommunication standards drawing on political economy-grounded conditions. From the QCA analysis the study derived two consistent sufficiency paths. Among these, it focused primarily on the most consistent sufficiency path, which explains a leading standard setter as a result of three conditions: being a great (technological) innovator, a large ICT economic power and having a highly complementary institutional (standard) configuration. This combination of conditions suggest that technical expertise and material economic power are essential conditions, yet they are not sufficient to explain the outcome without having a domestic standard system that fully mirrors the international standardization system.

The PT analysis shed further light on the mechanism triggered by these conditions, suggesting that in some cases, such as for China and South Korea, these conditions have worked sequentially in conjunction. The PT analysis has also revealed that innovation and economic capabilities are rather scope conditions in contrast to the role of domestic institutions in transnational regulations, which is arguably a condition with a greater causal force. Theoretically, this suggests that the equilibrium selection is tilted in favor of the player with great technical expertise, material power, and a complementary domestic system.

6.2 Implications

Power shifts in the development of telecommunication standards toward new aspiring standard setters have some implications. Countries such as China and South Korea will generate greater revenues from patent licensing in the coming years. Although it is commonly very difficult to shift from buyer to seller in technology licensing (Malkin, 2022), companies such as Huawei and Samsung have already experienced greater revenues in terms of technology licensing. US and European companies are still the largest beneficiaries of royalty payments; however, these financial revenues are likely to shrink following the rise of new influential players. This also implies that new aspiring standards will have a greater say in establishing the technological trajectory of new generational standards in line with their interests, which potentially provides them with greater look-in effects.

Assuming that technologies are never neutral, telecommunication standards will also arguably carry more Asian norms and ideas in relation, for instance, to data privacy and security. This is not a problem insofar as global standards are the result of a transparent and cooperative (yet competitive) process, which guarantees a high level of scrutiny of standardized technologies. In fact, there would be much greater risks to standardization if influential latecomers, such as China, had promoted their technologies outside the mandated SDOs[30].What also deserves special attention is to what extent new aspiring standard setters, in particular China, adopt and enforce internationally recognized standards. Data suggest that China is still far from having a high-level compliance, but this might increase given its greater contribution to international standardization (Telenau, 2021).

Overall, the results imply that traditional standard setters are no longer the dominant players in the development of technology standards, more precisely, in telecommunication standards. The last (5G) and possibly new generations of mobile networks will probably distribute gains more equally between traditional standard setters and new aspiring ones, seeing the share of new aspiring standards increase at the expense of those of traditional standard setters. Considering this, it will be interesting to see whether the influence of China and South Korea will further increase and consolidate or if the US and EU countries will manage to resume their previous dominance in defining global standards.

Regarding the conditions, the most consistent sufficiency path suggests that innovation capabilities, economic resources, and institutional complementarity are a successful recipe for contributing effectively to international standardization. This implies that pouring resources into R&D, particularly in the development of specific skills for standardization, is essential for

[30] There is a recent study that shows for example that there is little contribution of Chinese stakeholders to a specific technology related to 5G data security, lawful interception, which suggests that they have working on it indipedently outside the 3GPP context (Becker et al., 2022)

playing an influential role in international standardization. Similarly, providing financial support to players engaged in standardization is also important given the high financial costs required for participating. In addition, the importance of having a complementary institutional framework implies greater coordination between public and private stakeholders in pitching standards at the international level. In light of this, it is likely that greater resources will be devoted to standardization and the development of public-private partnerships.

The recent EU standardization strategy of 2022 is very indicative of such trends. The Commission has launched a 'standardization booster' to create greater synergies between R&D and standards, connecting Horizon 2020 beneficiaries with standardization experts and activities (European Commission, 2023). One of such activity is to organize academic programs and events to promote awareness of standards, share good practices and train future standard experts that are highly demanded. In addition, the Commission is planning to establish a new institutional mechanism through the High-Level Forum to further promote coordination between national and regional standard bodies, strengthen the European approach to international standardization, and preserve European leadership in global standards (European Commission, 2023).

6.3 Contribution

This research aimed to contribute to the political economy literature that analyzes power dynamics in global governance, by focusing on a neglected (yet growing) literature strand that addresses power shifts in the setting of technology standards, in this specific case, the three latest generations of telecommunication standards. This research tried to do so, by providing new conceptual, empirical, and theoretical insights.

The study attempted to further define power shifts between standard takers and standard setters, by describing a standard power spectrum along which countries and industries' capacity to shape standardization may be located. Conceptualizing a standard power spectrum might be important to assess countries' influence in international standardization, whose process and outcome will increasingly affect power structures in global governance. As previously explained, controlling disruptive technologies through standards provide great political power and economic advantage.

From an empirical point of view, the study provided evidence on the rise of aspiring standard setters challenging the dominant position of traditional standard setters. In particular, empirical results reveal that China and South Korea have caught up with the US and EU countries in telecommunication standards, contributing to the literature that studies changing power shifts over international standards (Blind&VonLaer, 2021; Gu, 2022). The study also contributed to the literature explaining changes in the outcome of transnational and multilateral organizations such as SDOs (Bach 2010; Mattli&Büthe 2003), by investigating under what political and economic conditions countries turn into leading standard setters in international standardization and thereby shape the outcome of standards.

Following the QCA analysis, case studies suggested that when technological powers cover roughly the same position along the technological and economic frontier, the mechanisms triggered by institutional conditions, such as greater government-industry coordination, may have explanatory power. This contributes particularly to literature that explains international changes as a result of domestic determinants, such as the institutional complementary theory of Mattli and Büthe (Mattli&Büthe, 2003).

The research arguably also contributed to the literature that studies the relationship between private stakeholders and power dynamics in global governance, by taking as proxies the contribution of companies (and national standard systems) to SDOs for explaining power shifts in standardization (Malkin, 2022; Kreienkamp & Pegram, 2019). More precisely, it contributes to the literature that analyzes the agency of private actors "as an extension of state actors' ability to shape outcomes and structures in the global system" (Malkin, 2022).

6.4 Limitations

This research also presents some limitations as a result of some analytical, methodological, and practical decisions. By establishing a country-level analysis, the research provided a general picture of technological powers' contribution to generational standards; however, in doing so it did not directly address the role and influence of single companies in the development of standards. Since the role and agency of big companies, such as Huawei or Ericsson, greatly influence the standard setting, this analysis may omit important explanations that could have been better extrapolated at the company level.

The explanatory conditions may also present some limitations. The empirical analysis, particularly the PT analysis within the selected case studies, showed that each condition can trigger various causal mechanisms, some of which were not analyzed because of a lack of data and time. In addition, some additional arguments came out from the case study analysis, which might have further contributed to explaining countries' influence as a leading contributor to standardization. For example, countries' industrial reputations and countries' international cooperation on standardization might also have explanatory power. This needs to be further explored.

From a methodological point of view, the multimethod approach (QCA+PT) was helpful to frame the research and identify conditions in terms of necessity and sufficiency. However, it also presented some limitations when conceptualizing and calibrating the conditions. In particular, the way in which the calibration of conditions was conducted might be disputable. Some of the conditions were calibrated by identifying gaps in the raw data since alternative calibration techniques were difficult to apply. In addition, the study would have also benefitted from an ethnographic study given the obscure work of standardization at times. However, this was not possible during the research abroad mostly because of Covid-19 restrictions.

Some limitations also concern the collection of data. The research had to compile data from different databases to cover the entire sets of cases over the time range analyzed, and this might have also affected the analysis. In addition, some data, such as SEPs and royalty payments, were either difficult to access or not available.

6.5 Areas of Further Research

As a result of this study, further research might be conducted on explaining power dynamics in other SDOs or technologies. This would give more evidence to substantiate or contradict the explanations reflected in the sufficiency path. In addition, the growing transnational component of global governance calls for more research on the role of private actors in developing disruptive and strategic technologies such as 5G or AI. Indeed, considering technology as a game-changer factor in altering balances of power, greater attention should be devoted to the role of technology companies and industries in shaping global economic structures. The results also indicate that government-industry coordination and partnerships are crucial for gaining a competitive edge in the technological leadership race. Future studies may further explore variations in these mechanisms by examining their impact on standardization and the overall global economic structure. Finally, the results show that some case studies have not been covered by any sufficiency path, which suggests that some other explanatory conditions need to be explored, such as international cooperation partnerships.

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Acronyms

ANSI	the American National Institute of Standardization
CEN	the European Committee for Standardization
CENELEC	the European Committee for Electrotechnical Standardization
ETSI	the European Telecommunications Standards Institute
FRAND	Fair, Reasonable and Non-discriminatory Terms
ICT	Information Communication Technologies
IEC	International Electrotechnical Commission
IPR	Intellectual Property Rights
ISO	International Organization for Standardization
ITU	International Telecommunication Union
SAC	the Standards Administration of China
SDO	Standard Development Organizations
SEP	Standard Essential Patents
TS	Technical specifications
WG	Working Groups

1. Annex: Tables

Table 9

Outcome

Outcome (Basic level set)	Indicators (Secondary level sets)	Calibration: coding scheme			source
Leading standard setter (O)	Top patent holder (SEP) Indicators: share of SEPs declarations	With a score of 0	0	Not a top patent holder	Iplytics database+ other databases
		With a score of 14	0.5	Neither a top nor not a top patent holder	
		With a score > 20	1	A top patent holder	
	Large participation in the SDO (PAR) Indicators: share of attendance	With a score <6	0	Not a large participator	Iplytics database+ other databases
		With a score of 12	0.5	Neither a large nor not a large participator	
		With a score > 15	1	A large participator	
	High contribution (CON) Indicators: share of Standard Contribution	With a score < 5	0	Not a high standard contributor	Iplytics database+ other databases
		With a score of 10	0.5	Neither a high contribution nor not a high contributor	
		With a score > 20	1	A high contributor	
	Numerous leadership positions (LEA)	With a score of 5	0	Not a numerous leadership position holder	3GPP database
		With a score of 3	0.5	Neither numerous leadership positions nor not a numerous leadership positions holders	

	Indicators: number of leadership positions	With a score of 0	1	A numerous leadership positions holder	

Table 10

Condition 1

First condition (Basic level set)	Indicators (Secondary level sets)	Calibration: coding scheme			source
A great innovator (I)	Large R&D investor (INV)	With a score of 1.5	0	Not a great R&D investor	OECD database
		With a score of 2	0.5	Neither a top nor not a great R&D investor	
		With a a score > 2.5	1	A great R&D investor	
	Great technological enabler (TECH)	With a score < 6	0	Not a great technological enabler	IMD index

		With a score of 6.5	0.5	Neither a great technological enabler nor not a great technological enabler	
		With a score > 7.5	1	A great technological enabler	

Table 11

Condition 2

Condition (Basic level set)		**Indicator (Secondary level sets)**	**Calibration: coding scheme**		**Source**
Large economic power	Large ICT manufacturer	With a score 3	0.33	Not a large ICT manufacturer	OECD's Trade in Value Added (TiVA)
		With a score of 8	0.5	Neither a large manufacturer nor a large manufacturer	
		With a score > 10	1	A large manufacturer	
	Great ICT value adder	With a score 3	0.33	Not a great value adder	OECD's Trade in Value Added (TiVA)
		With a score of 8	0.5	Neither a great value adder nor a great value adder	

		With a score > 10		A great value adder	

Table 12

Condition 3

Condition	**Qualitative Indicator**	**Calibration**		**Source**
Highly complementary system (DOM)	Other configuration	0	Not a highly complementary	Qualitative data: SDO databases and policy papers
	State-driven institutional configuration	0.33	Not so highly complementary	
	Private institutional configuration	0.67	Quite highly complementary	
	Public-private institutional configuration	1	Highly complementary	

Table 13

Condition 4

Condition four	**Calibration**	
A standard-focused policy maker (POL)	0	A technological power whose policy ideas cover one or none of the four roles
	0.33	A technological power whose policy ideas cover two of the four roles
	0.67	A technological powers whose policy ideas cover three of the four roles
	1	A technological power whose policy ideas conceive the role of its regulatory bodies as granter, subsidizer, educator and promoter

2. Annex: Other Figures

Figure 19

Graphical Description of Raw Data

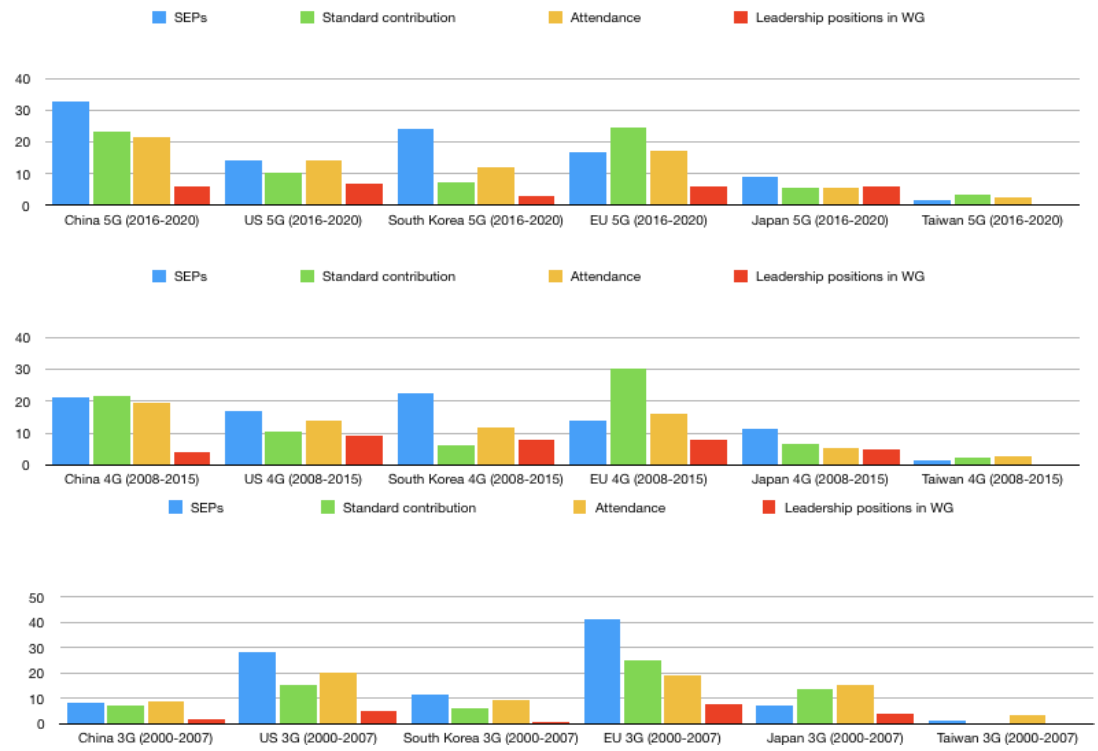

Figure 20

Truth Table

OUT: output value

n: number of cases in configuration

incl: sufficiency inclusion score

PRI: proportional reduction in inconsistency

	INN	ECO	DOM	POL	OUT	n	incl	PRI
16	1	1	1	1	1	4	0.972	0.962
15	1	1	1	0	1	1	0.946	0.898

13	1	1	0	0	1	4	0.919	0.872
5	0	1	0	0	0	2	0.794	0.649
12	1	0	1	1	0	1	0.714	0.569
10	1	0	0	1	0	1	0.624	0.380
11	1	0	1	0	0	2	0.616	0.425
1	0	0	0	0	0	2	0.580	0.207
9	1	0	0	0	0	1	0.573	0.328

Cases

16 China 5G (2016-2020),EU 5G (2016-2020),EU 4G (2008-2015),EU 3G (2000-2007)

15 Japan 3G (2000-2007)

13 US 5G (2016-2020),US 4G (2008-2015),Japan 4G (2008-2015),US 3G (2000-2007)

5 China 4G (2008-2015),China 3G (2000-2007)

12 South Korea 5G (2016-2020)

10 South Korea 3G (2000-2007)

11 Taiwan 5G (2016-2020),South Korea 4G (2008-2015)

1 Japan 5G (2016-2020),Taiwan 3G (2000-2007)

9 Taiwan 4G (2008-2015)

Figure 21

Sufficiency Plot on All Solutions Formula

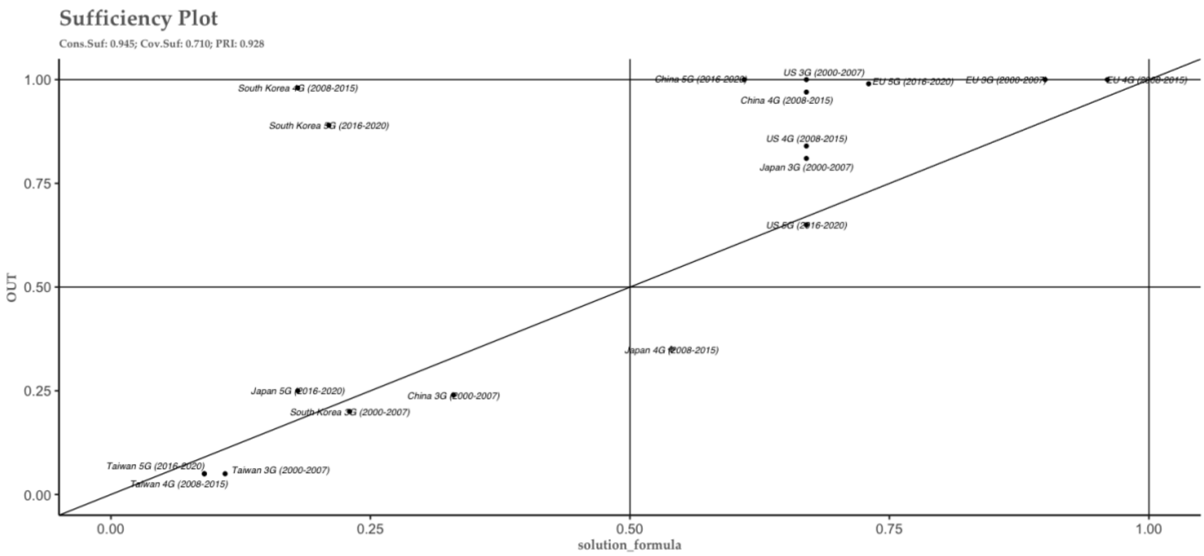

Figure 22

Radar Plot on Solution Formula