Technology Standards and Standards Organizations: Introduction to the Searle Center Database*

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Abstract

This article describes the Searle Center Database on Technology Standards and Standard Setting Organizations (SSO). This is the first large scale database with information on technology standards, SSO membership and SSO characteristics that is designed for economic research. In particular, the database includes data on quantifiable characteristics of 629,438 standard documents issued by 598 SSOs, institutional membership in a sample of 195 SSOs, and the rules of 36 SSOs on standard-essential patents (SEPs), openness, participation and standard adoption procedures. Using the Internet Archives, the database tracks both institutional membership and the SSO rules and procedures over time since the inception of the Archives in 1996. We identify more than 62,368 firms and other organizations participating in at least one SSO. The paper describes how to combine this data with other new databases and sketches avenues for empirical research.

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1 Introduction

Technology standards are of considerable importance for invention, innovation, commercial transactions, and economic growth. Standard Setting Organizations (SSOs) establish many technology standards in addition to those set by market interactions and government actions. Because the development and implementation of technology standards interacts with economic decisions and market transactions, it is necessary to take standards into account in empirical economic analysis. However, there has been no comprehensive database that supports economic research on the critical effects of technology standards and SSOs.

To help address economic research questions in this area, we have developed the Searle Center Database on Technology Standards and Standard Setting Organizations. This is a comprehensive and systematic database of technology standards documents and information about SSOs. This paper introduces the Searle Center Database, provides an initial overview, and examines some potential applications of the database to economic research.

The Searle Center Database consists of quantifiable characteristics of 629,438 standard documents. In particular, this information includes a database of 3,564,975 references between standard documents. In addition, the Database identifies institutional membership for a sample of 195 SSOs, and the rules of 36 SSOs on standard-essential patents (SEPs), openness, participation, and standard adoption procedures. Using the Internet Archives, we track both institutional membership and the SSO rules and procedures over time since the inception of the Archives in 1996. We identify 62,368 enterprises participating in at least one SSO.

Technology standards are rules that have far-reaching economic consequences. Spulber (2013) emphasizes the central role of technology standards in the field of Innovation Economics because of the endogenous determination of standards, market structure, and innovative efficiency. Swann (2010b) identifies various purposes of technology standards, including reducing product variety, maintaining product quality and performance, measurement, codifying knowledge, assuring compatibility, articulating a vision of the industry, assuring health and safety, and controlling environmental quality. Swann (2010b) observes that technology standards affect economic conditions such as economies of scale, the division of labor, firm competencies, barriers to entry, network effects, transaction costs, manufacturing precision, trust, and risk.

Technology standards provide a foundation for economic transactions. Technology standards often operate in the background allowing product compatibility and interoperability. For example, the U.S. Department of Commerce's National Institute of Standards and Technology (NIST), although not a typical SSO, provides a time measurement standard using atomic clocks. NIST time "is used to time-stamp hundreds of billions of dollars in U.S. financial transactions each working day".[1] The time standard is essential to the operation of networks, "NIST time is also disseminated to industry and the public through the Internet Time Service, which as of early 2014 received about 8 billion automated

[1]http://www.nist.gov/pml/div688/nist-f2-atomic-clock-040314.cfm

requests per day to synchronize clocks in computers and network devices; and NIST radio broadcasts, which update an estimated 50 million watches and other clocks daily".[2]

To study technological standards it is also necessary to understand how they are developed. SSOs play a central role in establishing technology standards. SSOs are voluntary organizations consisting of industry members that develop and disseminate technology standards. There are about one thousand SSOs in operation, with many thousands of members.[3] SSOs develop tens of thousands of technology standards every year that interact with the innovative decisions of most manufacturers. Technology standards by SSOs interact with market-based de facto standards and government standards. For example, the European Telecommunications Standards Institute (ETSI) "produces globally-applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and internet technologies".[4]

Perhaps as a testament to the effectiveness of technology standards and SSOs, their operation primarily concerns technical and scientific personnel and goes largely unnoticed by the general public. Economists had studied various regulatory and market standards, but have devoted less attention to technology standards and the formal activities of SSOs. Economic research has been hampered by an absence of consistent information about technology standards and detailed characteristics of SSOs. Economists have benefited from the availability of databases related to other aspects of innovation, particularly patents. Studies of particular technology standards or particular actions by a few SSOs are not directly comparable because of a lack of consistent data spanning diverse technologies and SSOs. There is also a need for data on technology standards and SSOs that allows different research studies to use the same data, facilitates replication and comparisons of empirical results, and allows the development of complementary databases.

In addition to basic economic research, the Searle Center Database should also be useful for empirical research addressing public policy issues in the area of innovation. Public policy makers have expressed concerns about the effects of technology standards on competition and social welfare. An important policy question concerns interactions between technology standards and the market value of intellectual property (IP), particularly for standard-essential patents (SEPs). Antitrust policy and public policy towards IP requires much more extensive data about technology standards and SSOs and empirical analysis of that data.

This paper discusses the methodology of the data collection, presents preliminary empirical insights, and considers some empirical research topics that are made possible by the new database. Section 2 presents an introduction to technology standards and SSOs. Section 3 provides a review of the empirical economic literature on standardization and discusses how the Searle Center database compares with available data used in previous research. Section 4 presents the data collection methodology, discussing in turn the analysis of SSO rules and policies, the collection of membership data, and the aggregation of databases on standard documents. Section 5 provides summary statistics and discusses

[2]http://www.nist.gov/pml/div688/nist-f2-atomic-clock-040314.cfm

[3]The website consortiuminfo.org currently lists 957 SSOs, and the online standards store IHS distributes standards from over 400 different SSOs (both websites last consulted on February 19, 2015)

[4]http://www.etsi.org/about

some preliminary empirical insights. Section 6 examines some opportunities for new research using this data and section 7 concludes the discussion.

2 What are technology standards and SSOs?

2.1 Technology standards

Standards are rules that include language, customs, traditions, social norms, business practices, industry conventions, laws, and government regulations. Technology standards are subset of such rules, many of which govern the characteristics of goods and services. The Searle Center Database focuses on technology standards.

Technology standards are an essential component of economic activity. Standards promote interoperability of parts and components that are necessary for the design and production of complex products, particularly in ICT. Commodities and financial assets traded on organized financial markets must be standardized to facilitate exchange. Standards for products reduce the transaction costs of search and bargaining because buyers and sellers can readily identify the features of the products being exchanged. Standards for productive inputs and manufacturing equipment improve the efficiency of transactions between input suppliers and producers. Standards promote international trade by reducing the costs of obtaining and providing goods and services across international borders.

Technology standards are adopted by industries or governments whenever economic agents benefit from harmonizing their activities and products. For example, according to the NIST, "The need for standards was dramatized in 1904, when more than 1,500 buildings burned down in Baltimore, Maryland, due to incompatibility of fire-hose couplings. When firefighters from Washington and as far away as New York arrived to help douse the fire, few hoses fit the hydrants. More than 600 sizes and variations in fire-hose couplings had been collected in a previous investigation and, after the Baltimore fire, efforts immediately began for selecting a national standard."[5]

Technology standards are pervasive in the economy. Surowiecki (2002) points out that "We live in a standardized world. Whether made by the Gap or American Eagle, a pair of khakis with a 32-inch inseam and a 34-inch waist will fit you just about the same. A Panasonic phone will plug into the jacks in your home as easily as a phone from AT&T... And Diablo II will run just as well on a Dell as on a PC from IBM. We take this kind of standardization for granted, but without standardization, there would be no mass production or mass communication. Which is to say, without standardization there wouldn't be a modern economy."

Technology standards produced by SSOs are expressed as formal documents often with detailed scientific and technical language, formulas, and illustrations. According to the NIST, "A standard is a document that contains technical specifications or other precise criteria to be used consistently as a rule, guideline, or definition of characteristics, to ensure that materials, products, processes, personnel or services are competent and/or fit

[5] http://gsi.nist.gov/global/index.cfm/L1-2/A-158, Accessed March 25, 2015.

for their intended purpose(s)."[6] The International Organization for Standardization (ISO) states "A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose."[7]

Some standards are very precise and describe a specific technology in great detail. Other standards describe larger technological systems, and often refer to other standards to deal with particular technical details. A normative reference from one standard to another means that in order to comply with the referencing standard, a user also has to fully implement the referenced standard.

Technology standards refer both to individual documents and to technology platforms consisting of many documents. In some SSOs, the individual technical document is called a Technical Specification (TS) and the technology standard designates a technology platform consisting of a set of TS documents. In the Searle Center Database, each TS document is referred a standard, including both the documents dealing with detailed technical aspects, and the documents listing and aggregating other documents to create more complex technological systems. It is often useful to study sets of TS documents that together describe a technological system or platform. We call these groups of documents a "standard project."

Technology standards fall into two broad categories: quality and interoperability. *Quality standards* ensure that a product or service meets particular performance criteria. These criteria can include a large spectrum of requirements for products or services to serve a particular purpose, such as environmental, and health and safety standards. The well-known set of quality standards ISO 9000 governs quality management systems (QMSs) for products and services.[8] Quality standards facilitate contracting on technical aspects of a service or product, reduce asymmetric information between vendors and customers, create greater comparability between competing products, or facilitate public regulation. Government agencies often adopt industry standards in formulating regulatory policy and in the development of mandated standards (Spulber, 1989).

Interoperability standards ensure the compatibility of products and product components in complex technological systems. In network technologies, compatibility standards are necessary so that different products can be used together (e.g. two compatible phones can be used for communication). In complex technologies, technology standards are necessary so that various components can be combined to create a functioning product (e.g. the various components of a car, computer, or mobile phone).

The standards created by SSOs are usually not proprietary standards. A *proprietary standard* is used to ensure quality and interoperability of products manufactured by a single

[6] http://gsi.nist.gov/global/index.cfm/L1-5/L2-44

[7] http://www.iso.org/iso/home/standards.htm

[8] According to ISO "The requirements cover a wide range of topics, including your supplier's top management commitment to quality, its customer focus, adequacy of its resources, employee competence, process management (for production, service delivery and relevant administrative and support processes), quality planning, product design, review of incoming orders, purchasing, monitoring and measurement of its processes and products, calibration of measuring equipment, processes to resolve customer complaints, corrective/ preventive actions and a requirement to drive continual improvement of the QMS. Last but not least, there is a requirement for your supplier to monitor customer perceptions about the quality of the goods and services it provides." http://www.iso.org/iso/pub100304.pdf, Accessed March 26, 2015.

firm, or by a single firm and its licensees. The owner of a proprietary standard may choose to use IP rights to exclude others from creating products that conform to the standard. For example, the toy manufacturer LEGO has used patents, copyrights and trademarks on the shape and position of the stubs to prevent competitors from manufacturing toy bricks that can be interlocked with LEGO bricks.[9]

We refer to the standards created by SSOs as *open standards*. This is because these standards are commonly available and are not owned by a single firm or a group of firms. The question of what is an open standard is the subject of some controversy and there is no generally accepted definition of this term.[10] For example, Lemley (2002) argues that standards set by SSOs that do not restrict IP rights of patents included in the standard are "closed" rather than open. In contrast, we classify SSO standards as open without reference to the rules of the SSO regarding patents covered by the standard. The policies of SSOs regarding IP vary considerably, as will be seen below. SSO standards can include patented technologies and material that are protected by IP rights. The text of the standard document itself is generally protected by copyright and offered for sale. Conforming to the standard may require the use of patented technologies and paying licensing fees to patent owners. SSOs may require that patents included in the standard be made available by their owners with licensing royalties that are fair, reasonable, and non-discriminatory, referred to as either FRAND or RAND. There is considerable disagreement about the meaning of (F)RAND, see Sidak (2013, 2015) for an overview.

Standards can be general rules or normative recommendations. For example, the International Telecommunications Union (ITU-T) states "The main products of ITU-T are normative Recommendations. Recommendations are standards that define how telecommunication networks operate and interwork. ITU-T Recommendations are non-binding, however they are generally complied with due to their high quality and because they guarantee the interconnectivity of networks and enable telecommunication services to be provided on a worldwide scale."[11] The International Electrotechnical Commission (IEC) recognizes common usage of their standard "A standard is a document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context."[12]

2.2 Standard Setting Organizations (SSOs)

SSOs are industry organizations whose members choose to participate voluntarily. Technology standards involve cooperative decision making by members with varying rules for the formation of a consensus. For example, the ISO "responds to a request from industry or other stakeholders such as consumer groups. Typically, an industry sector or group communicates the need for a standard to its national member who then contacts ISO." Then, "ISO standards are developed by groups of experts from all over the world, that are

[9]http://www.nytimes.com/2005/02/02/business/worldbusiness/02iht-lego.html?pagewanted=all&_r=0, last consulted on April 1, 2015

[10]see Ballard (2012)

[11]http://www.itu.int/en/ITU-T/publications/Pages/default.aspx

[12]http://www.iec.ch/standardsdev/publications/is.htm

part of larger groups called technical committees. These experts negotiate all aspects of the standard, including its scope, key definitions and content."[13]

SSOs generally follow open standard-setting procedures. The SSO provides information to interested parties about the standard-setting project. Members attend standard setting meetings, vote on standardization decisions, and make technological contributions. An open standard setting process need not include every interested party. Participation in standard setting can be subject to a substantial fee. Members incur costs of participation that include opportunity costs of the time spent by technical personnel. In addition, members incur participation costs in terms of preparing for meetings, making proposals, and conducting research and development (R&D) to develop technical contributions to the standard. Finally, some members incur R&D costs as they create new technologies that are related to the development of the technology standard.

Some private organizations contribute to the process of setting standards even though they are not SSOs. Organizations such as industry "upstream" consortia act as forums where companies exchange ideas and coordinate R&D regarding a particular standard that is developed and issued at an SSO (Leiponen, 2008; Baron and Pohlmann, 2013; Baron et al., 2014). Other organizations such as industry "downstream consortia" deal with the promotion or certification of existing standards that were developed at an SSO. Another group of organizations, including the American National Standards Institute (ANSI) and NIST, do not issue formal standards, but define standardization policies, coordinate the work of different SSOs, or act as an interface between government and private SSOs. The Searle Center Database initially covers SSOs, even though linkages to other types of standards organizations are an avenue for future extensions of the database.

All SSOs in our sample are contractual organizations and have rules (also called bylaws, constitutions etc.) regarding the procedures for setting standards, and regarding the policies applicable to SEPs. Most SSOs in the sample mandate some form of disclosure of SEPs. Many SSOs have rules regarding the licensing of SEPs. The most common rule is that SEP holders shall commit to making licenses available on a RAND basis. In most cases, the SSO bylaws do not themselves grant implementers of the standard a right to use the patented technology described in the standard. This right must be negotiated in private agreements that take place outside of the SSO. No SSO in our sample organizes or supervises licensing negotiations. In particular, SSOs must be distinguished from patent pools. Patent pools are organizations that may provide joint licensing contracts for bundles of SEPs held by different firms, but essential to the same standard. The Searle Center Database provides comprehensive data on patent pools; but patent pools are not covered by the present paper.[14]

Formal standard setting by SSOs differs from standards set in the market place. Market standards can result from explicit coordination in the form of contracts between buyers and sellers, technical specifications issued by large buyers or large sellers, industry alliances, and market making activities of intermediaries. Market standards can emerge through competition among technology platforms, with customer choices determining

[13] http://www.iso.org/iso/home/standards_development.htm

[14] Data on patent pools is available under the following link: http://www.law.northwestern.edu/research-faculty/searlecenter/innovationeconomics/data/technologystandards/index.html

whether a dominant standard emerges. Market standards also can emerge from de facto standardization through implicit coordination. For example, the gradual convergence of adoption choices by users of a network good can generate tacit coordination around a particular technology. Markets can greatly facilitate the emergence of de facto standards. The owner of a technology can use pricing, advertising and contracting to have its technology adopted as a standard (Katz and Shapiro, 1986; Spulber, 2008a).

In addition to private standards set by SSOs and by markets, governments can establish standards. Government standards can be set through legislation or by administrative agencies that issue rules. SSOs accredited by governments issue regulatory standards. Government bodies also participate in standard setting both within countries and internationally. Government standard setting involves the participation of individuals, firms, industry groups, consumer groups, unions, and many other interest groups.

Many technology standards result from a combination of activities by SSOs, markets, and governments. SSOs can adopt and endorse market standards already in use. Standards issued by SSOs compete in the market with other standards (de facto standards or other SSO standards). Regulatory agencies often mandate standards that already existed as voluntary standards. Many regulatory standards are set by organizations that also issue voluntary standards. Even though the Searle Center Database only covers standards issued by SSOs, these standards can include regulatory standards and standards resulting from market standardization.

3 Literature

Empirical economic research on technology standards has been limited by the scarcity of available data. There have been relatively few studies of the formation of technology standards by SSOs or of interactions between technology standards and innovation. This situation contrasts with the extensive empirical economic literature on patents. Widely available and standardized databases with quantitative characteristics of patents (such as the NBER patent database and Patstat) have facilitated empirical research on the patent system and the role of patents in innovation. More data on technology standards and SSOs should facilitate more extensive empirical economic studies of the connections between standards and innovation.

The economic literature on technology standards has focused on market standardization. [15] This literature explores the question whether standard adoption can be characterized by "technology lock-in". For an overview and discussion of this literature, see Spulber (2008b). A number of quantitative case studies also consider market standardization (Dranove and Gandal, 2003; Augereau et al., 2006). The anecdotal evidence for "technology lock-in" has been contested by Liebowitz and Margolis (1990). Forman and Goldfarb (2006) review empirical evidence for network effects and suggest that it is difficult to distinguish such effects from the effects of technology adoption costs. Spulber (2008b) observes that theoretical "technology lock-in" studies tend to assume that there is no

[15] See Brander and Eaton (1984); Farrell and Saloner (1985, 1986); Katz and Shapiro (1986, 1985); Matutes and Regibeau (1988, 1992); Economides (1992); Kristiansen (1998); Clements (2005)

explicit coordination on standards either among consumers or among firms, or between consumers and firms. In practice, however, SSOs and other industry organizations provide mechanisms for coordination in technology adoption.

Economists have recognized the role of SSOs in establishing standards (Anton and Yao, 1995; Goerke and Holler, 1995; Greenstein and Stango, 2007; Spulber, 2008b, 2013). A number of theoretical studies consider models of cooperative standardization. For example, Farrell and Saloner (1988) examine a consensus based decision making process that can complement coordination through market mechanisms. Besen and Farrell (1994) analyze different competitive strategies with respect to technology standards, including the choice between consensus standardization and rivalry between different standards in the market. Goerke and Holler (1995) find that the welfare implications of SSO standardization are highly sensitive to the SSO's procedures, and in particular majority rules.

A number of studies examine SSOs as economic institutions for building a consensus on standardization. Farrell and Simcoe (2012) explore the implications of different SSO rules on standard adoption for the speed and efficiency of standardization. Lerner and Tirole (2006); Chiao et al. (2007); Lerner and Tirole (2015) describe SSO rules as the result of the competition between SSOs to attract holders of valuable technology. They argue that competition between SSOs will fail to result in efficient rules for the licensing of SEPs, and needs to be supplemented with government regulation.

Many empirical analyses of SSO take the form of case studies. Early qualitative contributions, such as Bekkers (2001) and DeLacey et al. (2006) shed light on the strategic behavior of companies within SSO standardization processes. More recent quantitative studies of individual SSOs use SSO procedural data to consider the incentives to participate in standard setting, the effect of participation in an SSO on firm success, or the factors explaining that a firm's contribution to a standard is accepted through SSO vote (Leiponen, 2008; Simcoe, 2012).[16]

There are various limitations to what can be observed from the case study approach. First, given that there are hundreds of SSOs, studies of particular organizations cannot capture effects of standardization on aggregate measures of innovation, competition, or industry growth. Second, case studies can only identify the incentives to participate in a specific organization. This setting does not allow studying the overall standardization strategy of firms, such as the choice of how many SSOs to participate in, and how to optimally combine membership in different organizations.[17]

Third, and more generally, case studies of single SSOs cannot unveil strategic interactions and interdependence between SSOs. SSOs compete for technological contributions (Lerner and Tirole, 2006; Chiao et al., 2007), for participating members willing to invest efforts in standard development, and SSO standards compete in the product market for implementers.

[16]See Baron and Gupta (2015) for a survey of available sources and existing research usinig data from single SSOs.

[17]Some studies use survey data (Blind and Thumm, 2004; Blind and Mangelsdorf, 2013) or measures computed from business communications (Aggarwal et al., 2011) to observe firm participation in standardization and complement SSO membership data, although these types of data also have limitations.

Not only do SSOs compete with each other, but they also cooperate within a dense network of agreements and frequently adopt standards previously developed by other organizations. These complex interactions make it necessary to gather comprehensive data on a large sample of SSOs in order to study the market for standardization.

One aspect of SSOs for which quantitative data across SSOs is more readily available and has been used extensively by empirical researchers is the disclosure of assumed SEPs. SSOs have policies encouraging or requiring members who believe that their patents may be or become standard-essential to disclose these patents to other SSO members. Many SSOs make these disclosure statements publicly available. Beginning with Rysman and Simcoe (2008), economists have used this data to study the interplay between patents and standards. For a survey of the literature on the interface between patents standards, a methodological discussion, and presentation of the currently most comprehensive database on declared SEPs and standard-related patents, see Baron and Pohlmann (2015).

In order to shed light on the complex issues at the interface between patents and standards, it is important that information on declared SEPs can be matched to standardized databases on both patents and standards. The existing literature tends to connect data on declared SEPs to patent data, and studies the implication of disclosure for patents and patent holders. For a more comprehensive understanding of these issues, including the importance of patented technologies for standards and the role of SSO policies, it is necessary that databases of similar quality provide information on the standardization processes and institutional environment that the SEP declarations originate from.

The Searle Center Database provides information on technology standards, membership and the rules and procedures of a large sample of SSOs. This database updates and complements existing surveys of SSO rules and procedures. The Searle Center Database also integrates, processes and extends different databases on SSO membership and technology standards presented in previous research. An important contribution of the Searle Center Database is to connect and integrate these different sources of information on standards and SSOs. Furthermore, this data can be combined with information on SEPs and standard-related patents (see Baron and Pohlmann (2015)) as well as data on detailed standardization procedures at 3GPP (see Baron and Gupta (2015)). All different databases are connected through a system of standardized identifiers.

There is a small empirical literature using large samples of standards from different SSOs in economic research.[18] First, counts of standard documents by country and sector have been used to study the effect of technology standards on economic growth (Blind and Jungmittag, 2008; Spencer and Temple, 2013) and international trade (Swann (2010a) for a review). All existing papers in this literature we are aware of use data from PERINORM.[19] PERINORM is a repository of standards documents and is one of the inputs to our database. Baron and Schmidt (2014) use PERINORM data to study the effect of the adoption of new information and communication technology standards on total factor productivity and the business cycle. They process PERINORM data in order to avoid

[18] An important contribution using a large sample of standards from a single SSO is Simcoe (2012).

[19] Papers on the role of standards in international trade also use data on ISO 9000 adoption, agreements on the mutual recognition of regulation and other sources of information which are relevant only in the context of international trade (see Swann (2010a) for a discussion).

double-counting of documents released by multiple SSOs, and distinguish new standards from upgraded versions of existing standards. Baron and Schmidt (2014) also show that standard documents can be usefully weighted by the number of received normative references from other standards as a measure of the importance of a standard. The database presented here extends the data used in Baron and Schmidt (2014) to other sectors and countries and to SSOs not included in PERINORM by making use of additional sources of information.

Second, PERINORM is used to study the evolution of technology standards over time, and match data of declared SEPs to standards data (Baron et al., 2013, 2014). Using data on standard documents to study technology standards makes it necessary to aggregate the different versions of a standard document over the standard lifetime, as well as the different technical specifications that together constitute a standard. The present database extends the efforts described in these earlier papers to a much larger sample of standards. For a more detailed description how to match SEP declarations data with the database of technology standards, see Baron and Pohlmann (2015).

Data on SSO membership has so far only been available and used for single SSOs (Gandal et al., 2004; Bar and Leiponen, 2014; Stoll, 2014) or small groups of related SSOs and consortia (Leiponen, 2008; Delcamp and Leiponen, 2014). There does not appear to be another database that tracks membership in a large number of different SSOs. The list of 200 SSOs included in the Searle Center Database draws on a combination of the CEN Survey of Standards Consortia and the list hosted by Andy Updegrove at consortiuminfo.org. Parts of the membership data have been used in Baron and Pohlmann (2013); Pohlmann (2014); Baron et al. (2014). With respect to the earlier data described in these papers, the present database has been massively expanded and updated. Furthermore, we include formal SSOs originally excluded from the data. Finally, we use name standardization techniques as well as the Orbis database to standardize the names of participating firms and other entities.

There are a number of surveys of the rules and procedures of SSOs. Lemley (2002) provides a tabular overview over the IP disclosure and licensing rules in a sample of 43 SSOs. The survey describes IP rules by five categories (type of IP covered, disclosure requirement yes or no, search requirement, can standard include IP, and licensing provisions such as RAND or royalty-free). Chiao et al. (2007) extend Lemley's survey to 59 organizations. They standardize and code the data, and also collect data on the type of membership (all corporate or also individuals), the type of decision making rule (majority or consensus), and the age and scope (single purpose or not) of the SSO. Bekkers and Updegrove (2012) offers a more detailed survey of the Intellectual Property (IP) rules of a more restricted sample of 12 important SSOs. They compare how very specific aspects of the IP disclosure process and licensing requirements are treated in different SSOs. In many cases, the comparison only applies to subsets of the organizations, because specific issues only arise in particular SSOs. Our study compares general rules for a larger sample of SSOs rather than identifying best practices for a particular procedural issue.[20]

[20]The Searle Center Database survey of IP rules provides more detail than Lemley (2002) and Chiao et al. (2007), and includes several aspects surveyed by Bekkers and Updegrove (2012) that are generally applicable to all SSOs. Similar to only Chiao et al. (2007), we also extend our survey to rules on the

In contrast to these studies, the Searle Center Database observes how the rules and procedures of the SSOs in our sample have evolved over time. The only existing survey of rule changes in SSOs is Tsai and Wright (2015), who survey changes in the IP rules of eleven SSOs. Their interest is however different from ours. Their survey characterizes IP rules by their degree of ambiguity. Furthermore, Tsai and Wright (2015) focus on the nature of the rule changes, whereas we focus on the characteristics of the rules at a particular time. We observe relatively general characteristics of the SSO rules, which are unaffected by most editorial changes and disambiguations. We include a larger sample of SSOs, and cover more aspects of SSO policies and observe more substantive heterogeneity of rules both between SSOs and over time.

4 Methodology

4.1 Sample selection

We collected data on technology standards, membership and rules for a large sample of SSOs. We identified SSOs that have been studied in earlier surveys of SSO rules and that were still active as of 2013. In most of the cases, we could access bylaws and other documents describing IP policies or standard development procedures on the SSO website. In two cases, we obtained these documents upon request from SSO representatives (PICMG and OIF). This resulted in a sample of 36 SSOs. Because the declarations of SEPs almost exclusively occur in Information and Communication Technologies (ICT), all SSOs in this sample are active in ICT (even though some SSOs also operate in other technologies). We interviewed several practitioners from the industry, who confirmed that this list includes the most important SSOs active in ICT.

Next, we identified sources providing centralized access to standard documents. In particular, we used the PERINORM standards library, and gathered data from websites offering standard documents for sale (IHS Standards Store and Document Center). We complemented our database with data from the websites of specific SSOs. Because the objective is to obtain comprehensive data on a sample of SSOs, we particularly focused our efforts on the SSOs included in the rules database. This resulted in an overall sample of 600 SSOs, including 26 SSOs from our sample of 36 organizations for which we reviewed the rules.

Third, we gathered data on SSO membership. We only collected data on corporate membership, excluding information on individual or national SSO membership. Several organizations do not have corporate members or do not make member lists publicly available. We were able to identify membership for 195 SSOs, including 29 out of the 36 SSOs in our sample with rules information.

standard adoption process. Our survey on these issues is however more detailed, and we also surveyed rules on openness and balance of interests.

4.2 Surveying SSO rules

We identified from the literature procedural and institutional dimensions of SSOs that are economically relevant and for which we expected interesting variation. We focused on three dimensions of SSO rules: policies on standard-essential IP, procedures for the adoption of standards, and provisions on openness and balance of interests. IP policies have been in the focus of interest of the recent academic discussions. Procedures for standard adoption (in particular, majority vs. consensus decision making and all the intermediate thresholds for standard approval) are central to the economic analysis of the efficiency of committee standardization vs. market adoption, and can shed light on an interesting economic trade-off between procedural efficiency and broad support for the chosen standard. Differences between SSOs in their degree of openness are relevant e.g. for governments mandating standards for public procurement. SSO provisions on the balance of interest inter alia capture the distinction between Special Interest Groups and other SSOs.

We then analyzed a sample of 10 important SSOs that have been widely studied in the existing literature to identify precise rules and provisions to be included in the dataset. On the one hand, selected rules should be sufficiently general in order to be applicable in all or almost all SSOs in our sample. Because the procedures of different SSOs can substantially differ, many detailed procedural aspects cannot be compared across organizations. On the other hand, rules should be sufficiently specific to allow for variation both between SSOs and over time. Many rule changes at SSOs are editorial changes, clarifications of existing provisions, or substantive changes to idiosyncratic aspects of SSO rules, which are not captured as rule changes by our method (the analysis of Tsai and Wright (2015) captures such rule changes as more or less significant reductions in the ambiguity of SSO rules). We do however wish to capture changes that have implications for economic incentives (such as the policy change discussed in Stoll (2014)). We also add information on relationships to other SSOs, and on the maintenance procedures for existing standards.

Once we created this roster, we analyzed the rules and procedures of the 36 SSOs in our sample. Many of the rules that we are interested in are described in the bylaws (also called policy, constitution, memorandum of understanding or articles) of the SSOs. Many SSOs have separate documents describing their IP policy, and some SSOs also describe their procedures for developing standards in separate documents. We therefore downloaded the bylaws, and if applicable the IP policies and standard adoption procedures, from the websites of the SSOs. In several cases we create document files by copying descriptions from SSO websites. We then searched in the Internet Archives (www.archive.org) for the previous version of the same document, by visiting the website of the SSO at the latest possible date prior to the date of adoption of the current version. We replicated this procedure as often as possible in order to identify the full set of past versions of SSO rules. The earliest copies of websites saved in the Internet Archives are from 1993. Several SSOs, including e.g. OASIS, provide the history of policy changes on their current SSO websites.

Using the files assembled this way, we created a table describing SSO policies at different points in time. As a first robustness check, we compared the results of this survey with existing surveys, using in each case the version of the rules that is contemporaneous to the publication of the respective papers. We then standardized the rule observations across organizations and over time. We thus created slightly more general categories to describe similar rules at different SSOs. We use the original files to support the classification of a particular rule in cases of doubt.

The information on SSO rules is presented in the table **SCDB sso policies.dta**.[21] Each row in the table designates a different policy. There are multiple rows per SSO if an organization has changed its policies over time. *year* designates the year in which the policy was issued. In order to describe SSO policies at a particular point in time, users of the data can extend each entry of the databases to all following years up to the next policy observation for the same SSO. The variable *SSO ID* is a standardized ID, and can be used to match the information on SSO policies to data on SSO membership and standard documents.

4.3 Collecting data on standard documents

We built a large database of standard documents, technology standards and their characteristics. Our first input was PERINORM, a large library of standard documents compiled by three European SSOs (DIN, BSI and AFNOR) and marketed by Beuth Verlag. PERINORM is the only comprehensive database on standard documents that has so far been used in economic research. We negotiated an agreement with Beuth Verlag to use PERINORM data to build a quantitative database that can be made available to other academic researchers. In particular, we use the release and withdrawal dates, number of pages, references among standards, version histories, international relationships and technological classification of standards. We do not include document numbers, titles, keywords, abstracts and other similar information on the technological content of the standard that would allow using our database as a substitute for PERINORM. Standard documents in our database are identified by a standardized *standard document id*. In the case of observations generated from PERINORM, the ID is equivalent to the *AC Code* in PERINORM and allows PERINORM users to retrieve additional information on the standards.

PERINORM however only covers a subset of the hundreds of active SSOs. While many of the most important SSOs are covered, other important bodies such as the Internet Engineering Task Force (IETF) are not. We therefore used data collected from the IHS standards store[22] to complement the PERINORM data. The IHS standards store offers standard documents issued by 615 SSOs for sale, and provides some of the same bibliographical information that can be found in PERINORM. While the bibliographical information in IHS is less detailed than in PERINORM, IHS covers a much larger number of SSOs. We identified 513 international or US-based SSOs in IHS that are not included in PERINORM. For specific, particularly relevant SSOs, we furthermore collected additional data from other sources. We collected data on ASTM and IEC standards from Document Center, and data on IETF standards (so-called Requests for Comment, or RFC) from data made publicly available by Tim Simcoe. We complemented our data on ETSI, 3GPP and IETF standards documents by scraping the information on standards directly from the SSO websites. We matched all the additional data with the PERINORM/IHS data

[21] Bold letters indicate tables, and italic letters indicate variables.
[22] https://global.ihs.com/

using standard numbers, publication year and month and version numbers. We kept the PERINORM or IHS data whenever the same document is included in multiple sources, and generated new entries for the remaining standard documents.

The table **SCDB standards.dta** lists the *standard document ID* of all standards included in the Searle Center database, as well as basic bibliographic information, such as the identitiy of the *issuingbody*,[23] *publicationdate*, *withdrawaldate* (if applicable), *origincode* (IX for international, and US for US based SSOs), *pagecount* and *datasource*. The standard documents can be matched to the table **SCDB icsclass.dta** to retrieve the *ics class* (International Classification for Standards) codes of the standard document. There can be multiple *ics class* per standard document.

The same standardized *standard document ID* is also used in the data on SEPs (Baron and Pohlmann, 2015) and 3GPP procedures (Baron and Gupta, 2015). This code thus allows matching information on standards to SEPs and related patents as well as to standardization meetings, contributions, change requests and work items at 3GPP.

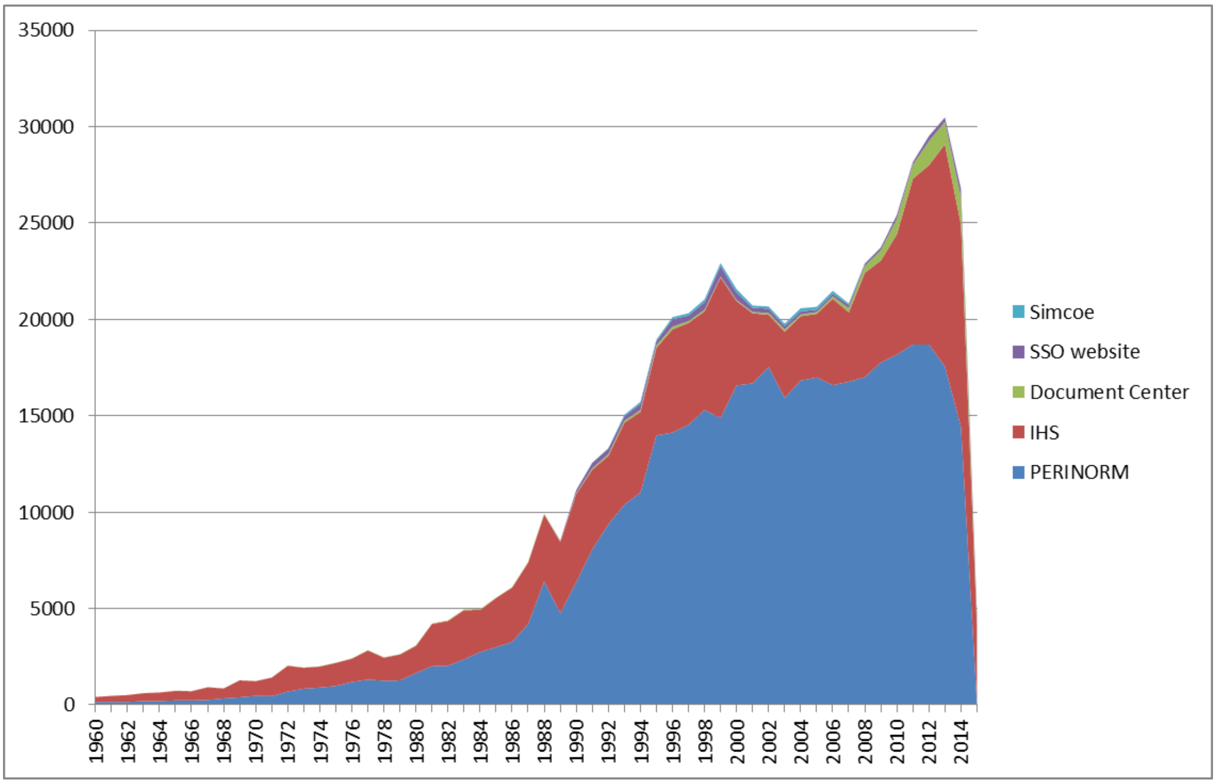

Figure 1: Standard documents by data source and year of release

It is important to understand the difference between standards and standard documents. First, each standard document is issued by a specific SSO. It is very common that multiple SSOs issue identical standard documents under different designations, e.g. because the SSOs collaborate in the development of a standard, or because an SSO has a policy to systematically endorse the standards issued by a specific partner SSO, or because some companies first agree on a standard in a smaller or less formal SSO before it is accepted at a

[23]The variable *issuingbody* can be matched with the name cleaning file **SCDB sso names.dta** to retrieve the standardized *SSO ID*. The data on standard documents can be matched with the data on SSO rules and membership using this standardized ID.

larger SSO with a broader membership basis or a higher requirement for consensus (Baron and Pohlmann, 2013; Baron et al., 2014). Many formal SSOs have specific procedures for processing fully developed standard proposals submitted by other SSOs or groups of member companies. PERINORM and other databases of standard documents therefore include the same standard documents multiple times under different designations. However, we can use information provided by PERINORM to identify duplicate observations. The table **SCDB international relationship.dta** lists the *standard document ID* of all equivalent standard documents.

Second, standards change over time. The process of maintaining a standard, i.e. constantly revising it in order to keep up with technological change, can take different forms according to the SSO. Many SSOs issue different versions for their standards, each version superseding the previous version at the date of its release (Baron et al., 2013). SSOs can also issue new standard documents amending existing standard documents, in which case the amended document remains active. Researchers interested e.g. in the success of a standard (survival, number of times it is referenced by other standards, number of SSOs endorsing it, number of citations from patents etc.) should take into account the full standard history from the release of the first version to the final withdrawal of the standard. The table **SCDB version history.dta** lists the *standard document ID* of all standard documents sharing a common version history (i.e. different versions of the same standard). The datafile **SCDB replacement.dta** lists the *standard document ID* of standard documents and the document that they directly replace.

Third, the word standard often designates complex technological systems described by large numbers of interdependent yet different standard documents. A standard document can describe the technical details of narrowly defined technologies, or they can define complex technological systems. In the latter case, standard documents typically *reference* other standard documents to deal with technical details. A normative reference in a standard document means that the reference is integral part of the standard.[24] In this case, implementing the referenced standard is also required in order to comply with the referencing standard. An example is the DVD standard, which stipulates to use MPEG2 as video coding technology. An informative reference indicates that the referenced standard provides useful guidance, but implementing the referenced standard is not strictly required to comply with the referencing standard. Our database of standard documents covers technical specifications, including both disaggregate standards describing technological details, and standard documents referencing other documents in order to define more complex technological systems.

PERINORM, IHS and Document Center provide information on references. We retrieved the references from all standard documents covered by these database, and kept all references for which either the referencing or the referenced standard are included in our database. None of these sources lists references from ETSI standards or IETF documents. We thus retrieved the references from ETSI standards and IETF RFCs by scraping and parsing the standards documents available on the SSO website.[25] All sources of information

[24]On all ETSI standard documents, references are introduced with the following sentence: "The following documents contain provisions which, through reference in this text, constitute provisions of the present document."

[25]We scraped more than 100,000 standard documents, resulting in more than 600,000 additional references

on references list the referenced documents such as designated in the referencing document. We cleaned the designations of the standard number and the version number (often, references indicate the publication year instead of a version number), and matched the designations of the referenced standard with our standards database. A reference can be unique, i.e. designate a specific standard document, or designate a standard description applicable to multiple documents.[26] In case of unique references, we only establish a match of the referencing document with the specific designated document. In case of non-unique references, we establish a match between the referencing document and all documents to which the reference is applicable (in most cases, these are different versions of a standard sharing the same standard number).

The table **SCDB references.dta** lists the *standard document ID* of referencing and referenced standard documents. These are the standardized document codes and can be matched with other tables such as **SCDB standards.dta**. The binary variables *unique* and *informative* designate unique and informative references, respectively. We can only identify informative references in the case of ETSI standards.

4.4 Creating the membership data

We collected membership information for a large sample of SSOs. We based our search on the 2010 edition of the CEN survey of ICT standards consortia and the list of standards consortia provided by Andy Updegrove on www.consortiuminfo.org, consulted in 2010. The union of these samples includes 670 organizations.[27] Among these organizations are many organizations dealing with standards that are not SSOs. We use paragraphs describing the work of these organizations, built upon the self-description of the organizations on their websites and kindly provided by Andy Updegrove, to identify organizations that develop standards or participate in developing standards. Finally, we searched the websites of the selected organizations for member lists.

The data was retrieved from the websites of the SSOs, and we only included SSOs that make this information publicly available. Many SSOs have institutional membership, but some SSOs have individual membership, or SSO members are countries represented by national SSOs or regulatory bodies. Many SSOs have mixed forms of membership. We only included SSOs with institutional membership. In the case of mixed membership, we only collected information on institutional membership. Institutional membership information includes e.g. public and private firms, universities, public research institutes, governmental agencies, not-for-profit organizations and other SSOs.

Many SSOs have different levels or tiers of membership. Higher tiers typically provide more rights (e.g. more voting rights), but involve higher membership fees. Sometimes, the level of the tier is related to the size of the company (measured e.g. by the volume of sales).

[26] A unique reference to a specific standard document is only applicable to the specific referenced version. If the referenced version is replaced, it is still the old referenced version that is part of the referencing standard. This is e.g. specified on all ETSI standards: "For a specific reference, subsequent revisions do not apply. For a non-specific reference, the latest version applies."

[27] Both surveys operate similar selection criteria. All included SSOs have standardization activities regarding more than one standard, operate at least partly in ICT, have open membership and operate on an international level.

There is a large variety of different tier structures, and the rights and duties associated with each tier can change over time. We did not attempt to standardize information on tier structure across SSOs, and therefore only collected lists of all firms designated as SSO members. We include all voting members, and only exclude observers.

We used Internet Archives to retrieve historical membership data. Since 2010, we collected updated membership data every year. For each year, we collected membership data close to the end of the year. For each year prior to 2010, we used the latest version of the membership that is available from the Internet Archives (the number of times a website is crawled per year varies between websites and over time), and each year since 2010 we collected updated membership data between November and early February of the following year directly from the SSO website.

Whenever possible, the lists were directly copy-pasted from the SSO websites. Sometimes, the member lists are saved as logos or links, in which case we either copied the page source code or manually entered the membership information. As is frequently the case with firm names, there is a large number of different designations for each member organization[28]. We kept the original member designations (including errors resulting from the data collection process), and created a separate file for partially standardizing member names. We standardized different designations for the same firm or institution (e.g. IBM Corporation and IBM, or Matsushita and Panasonic), and also replaced the names of 100% controlled divisions by the name of the general ultimate owner. In general, the standardization of member names is based on the names as provided in the files, i.e. IBM Germany will be recognized as a division of IBM. We also replaced department designations by the name of the university.

The membership data is provided in the table **SCDB members.dta**. Each entry is a combination of *SSO ID*, *company name* and *year*, and indicates that this company was listed as a member of this organization in this year. The variable *company name* can be matched with the name cleaning file **SCDB Firms.dta** to retrieve the standardized *company ID* which can be used e.g. to combine SSO membership information with data on companies declaring SEPs or contributing to 3GPP.

In order to reliably describe the full participation of relevant firms in SSOs, we then created a sample of "most relevant member organizations", consisting in all declared SEP holders, members contributing to 3GPP, and the 243 organizations that are member of at least 15 SSOs. For all these relevant organizations, we collected the names of all their affiliates from Orbis, and matched the names of these more than 20,000 affiliates with the SSO membership lists. We replaced the name of all 100% controlled affiliates with the parent name. We can thus more accurately describe the full SSO attendance profile of all major players in standardization. We used the remainder of the membership data for member counts by SSO and year. While even after standardization there are still 62,368 different member designations, the selected relevant organizations account for 18% of the SSO membership observations.

[28]There are 84,062 different member designations in the raw data.

5 Descriptive statistics and analysis

5.1 Data on SSO rules

5.1.1 IP policies

The IP policies of SSOs can deal with various IP aspects of standardization. We focused exclusively on policies regarding SEPs. We did not collect e.g. data on the policies regarding the copyright over the standard documents or the transferal of copyright over contributions made for incorporation into standards. The SSO policies regarding SEPs cover two important aspects: rules on the disclosure of (potential) SEPs, and requirements to make SEPs available for licensing.

Obligations to make licenses for SEPs available can arise from SSO rules through various processes. First, SSOs can condition the acceptance of a technical proposal on the fact that the owners of all patented inventions covered by the proposal make these patents available for licensing under specific conditions. If a company refuses to commit to these conditions, the patented invention cannot be included. There are currently 18 SSOs in our sample practicing such a policy. In six cases, the failure to obtain a commitment from every SEP holder must not automatically result in the patented invention being excluded, but there is a specified procedure for determining whether the inclusion of the invention is still justified. Second, nine SSOs require their members to make their patented technologies available for inclusion into the standards of the SSO and for licensing under specified conditions to standard implementers. Five SSOs only require members to make licenses available for patents covering the contributions they submitted themselves to the SSO, as opposed to all standards voted by the SSO. In three SSOs, the obligation for members to make their patented inventions available can be waived, e.g. if the patent holder demonstrates a substantial business interest in keeping the technology private.

The language specifying the conditions of licensing offers for SEPs differs from SSO to SSO. We can however distinguish four broad types of polices. First, only one SSO does currently not specify any licensing requirement[29]. Second, nine SSOs require licensing on fair, reasonable and non-discriminatory (FRAND) terms. This category also includes all organizations mandating reasonable and non-discriminatory (RAND) terms, or policies that stipulate that licensing offers must be "reasonable and free of any unfair discrimination".[30] Third, 23 SSOs offer patent holders a menu of licensing options they can choose from, including FRAND as the least restrictive option. Typically, the other options include royalty-free (or royalty-free on top of FRAND), and non-assertion. A policy of offering such a menu of options is very similar to a policy requiring FRAND licensing, but the choice to explicitly provide the option to commit on less restrictive terms can be seen as an endorsement of stronger commitments. Fourth, five SSOs either always require licensing on royalty-free basis or non-assertion of SEPs, or can require royalty-free licensing of SEPs

[29]This SSO is PCCA, which had a licensing policy but dropped it from its bylaws.

[30]It is possible in principle that these nuances bear a different legal meaning. The Court of Appeal ruling in the recent Ericsson vs. DLink case made it clear that RAND commitments do not entail generic obligations, but that the language of the specific commitment should be taken into account. We are however not aware of any case in which a licensing term has been found to be reasonable, but unfair; or discriminatory, but free of unfair discrimination.

Table 1: SSO licensing requirements

Name	Licensing terms	Licensing mandatory for members	Assurance necessary for inclusion?
3GPP	RAND	Encouraged	Not specified
Accelera	RAND, RF, NA (optional)	No	Yes
ANSI	RAND or RF (optional)	Not specified	Yes
ASTM	RAND or RF (optional)	Not specified	Yes
ATIS	RAND or RF (optional)	No	Yes
BioAPI	RF	Yes	Implied
CEA	RAND	No	Yes
CEN	RAND or RF (optional)	No	In principle yes
DMTF	RAND or RF (optional)	No	Yes
DVB	RAND	In principle yes (1)	Not specified
ECMA	RAND or RF (optional)	For contributors	Yes
ETSI	RAND	Requested (2)	In principle yes
Home Plug	RAND	Yes	Implied
Home PNA	RAND	Yes	Implied
IEEE	RAND, RF, NA (optional)	No	In principle yes
IETF	RAND, RF, NA (optional)	No	Yes
IMTC	RAND or RF (optional)	No	Yes
IrDA	RAND or RF (optional)	For contributors	Yes
ISO	RAND or RF (optional)	No	Yes
ITU	RAND or RF (optional)	No	Yes
JEDEC	RAND or RF (optional)	For participants (3)	Yes
MEF	RAND, RF, NA (optional)	No	Yes
OASIS	RAND, RF or NA (by WG)	For participants	No
OGC	RAND or RF (by WG) NA (optional)	Contributors, participants	No
OIF	RAND or RF (optional)	No	No
OMA	RAND	In principle yes (2)	Not specified
Open Group	RF, NA (optional)	For contributors	Not specified
OSGI	NA to other members	Yes	Not specified
PCCA	Not specified	Not specified	Not specified
PCI-SIG	RAND to other members	Yes	Not specified
PICMG	RAND, RF, NA (optional)	For contributors	Not specified
SDR Forum	RAND, RF, NA (optional)	For contributors	Yes
TIA	RAND or RF (optional)	No	Yes
VESA	RAND	No	Yes
VITA	RAND, NA (optional); disclosed maximum rate	Yes	Yes
WI-FI	RAND or RF (optional)	For participants	Not specified

for some of their standards or working groups (e.g. as a result of a vote of the working group).

Overall, licensing requirements have become more stringent over time, with four SSOs partly or fully adopting royalty-free or non-assertion policies after practicing a less restrictive rule, and two SSOs moved from no obligation for members to mandatory licensing assurance.

In addition to specifying the general nature of the required licensing offer for SEPs, many SSOs adopt additional rules on SEP licensing. We collected data on the most common

Table 2: SSO licensing requirements, continued

Name	Irrevocability	Reciprocity	Binding on Transfer	Defensive suspension
3GPP	Not specified	Not specified	Not specified	Not specified
Accelera	Yes	Not specified	Yes	Not specified
ANSI	Yes	Not specified	Not specified	Not specified
ASTM	Yes	Not specified	Not specified	Not specified
ATIS	Yes	Allowed	Yes	Not specified
BioAPI	Not specified	Not specified	Not specified	Not specified
CEA	Not specified	Not specified	Not specified	Not specified
CEN	Yes	Allowed	Yes(8)	Not specified
DMTF	Not specified	Not specified	Not specified	Not specified
DVB	Not specified	Not specified	Yes	Not specified
ECMA	Not specified	Allowed	Not specified	Not specified
ETSI	Yes	Allowed	Yes	Not specified
Home Plug	Yes	Not specified	Yes	Not specified
Home PNA	Not specified	Not specified	Yes	Not specified
IEEE	Yes	Allowed	Yes	Not specified
IETF	Not specified	Not specified	Not specified	Not specified
IMTC	Yes	Not specified	Yes(9)	Not specified
IrDA	Not specified	Allowed	Not specified	Not specified
ISO	Yes	Allowed	Yes	Not specified
ITU	Yes	Allowed	Yes	Not specified
JEDEC	Not specified	By default	Not specified	By default
MEF	Not specified	Not specified	Not specified	Not specified
OASIS	Yes if non-assertion	Allowed	Not specified	Allowed
OGC	Yes	Not specified	Not specified	Allowed
OIF	Not specified	Not specified	Not specified	Not specified
OMA	Not specified	Allowed	Not specified	Not specified
Open Group	Not specified	Not specified	Not specified	Not specified
OSGI	Yes	Not specified	Yes	Allowed
PCCA	Not specified	Not specified	Not specified	Not specified
PCI-SIG	Not specified	Allowed	Yes	Not specified
PICMG	Yes(6)	Not specified	Not specified	Not specified
SDR Forum	Yes	Not specified	Not specified	Not specified
TIA	Yes	Allowed	Not specified	Not specified
VESA	Yes	Allowed	Yes	Allowed
VITA	Yes	Allowed(7)	Yes	Allowed
WI-FI	Not specified	Allowed	Yes	Not specified

specifications. First, 16 SSOs offer the possibility to condition a FRAND commitment on reciprocity. The option to condition licensing commitments on reciprocity is more frequent for royalty-free policies, especially if the royalty-free commitment is a voluntary option. Second, SSOs may explicitly allow the defensive suspension of a FRAND or royalty-free licensing contract on SEPs in case the patent holder is sued by the licensee. Third, an increasing number of SSOs explicitly specifies that licensing commitments are irrevocable (19) and binding on transfer (16). We recorded 12 rule changes adding one

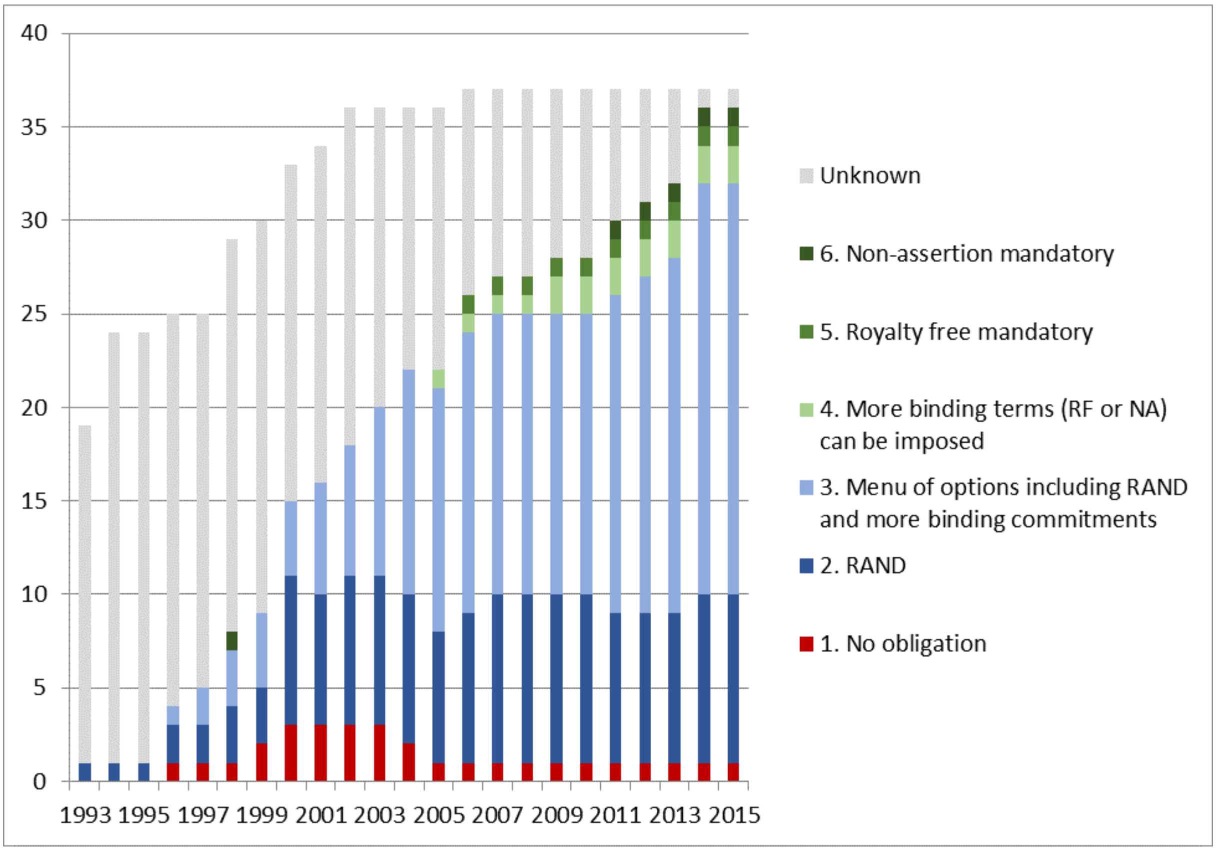

Figure 2: Licensing requirements at the SSOs in the sample

of these specifications (this is in line with Tsai and Wright (2015) finding an increasing disambiguation of SSO rules).

Besides conditioning inclusion of patented technologies on the availability of licensing offers, five SSOs have a language in their IP policy formalizing a general preference for unpatented technology. In these SSOs, the inclusion of patented technology into a standard has to be ”technically justified”, or it has to be shown that no unpatented alternative exists[31]. The prevalence of such requirements is decreasing (CEN and IEEE have dropped similar requirements from their policies).

Almost all SSOs require their members to disclose patents that may be or become essential to a standard or proposed standard. Four SSOs do not require, but encourage the disclosure of SEPs, or more generally have a policy of voluntary disclosure of SEPs. Five SSOs do not specify any disclosure policy. In these SSO, members are however often generally required by membership to make licenses on SEPs available.

While almost all SSOs generally require the disclosure of SEPs, this disclosure if often explicitly limited to the personal knowledge of the meeting attendee. The majority of SSOs explicitly state that a detailed patent search is not required in order to comply with the disclosure obligation, and the other SSOs do not specify any policy on the obligation of a patent search (no SSO in our sample explicitly requires a patent search). Some of the SSOs that explicitly do not require a formal patent search however ask for ”good faith”, ”reasonable efforts” or ”best efforts” of their members to disclose their (potential) SEPs.

[31]Only at ASTM, and only in the case of American National Standards

While there is limited variation between SSOs regarding the general disclosure obligation and the absence of an obligation to carry out a patent search, SSOs differ on their stance with respect to *blanket* declarations. These are generic statements by a company declaring that it holds one or multiple SEPs for a specific standard or standard project, as opposed to the disclosure of a specific and clearly identified patent or patent claim. Nine SSOs explicitly and generally require the disclosure of specific patents, whereas five SSOs more or less explicitly generally tolerate blanket declarations. Some of these SSOs accept, but discourage blanket declarations. Blanket declarations are generally not allowed if the patent holder chooses not to make its patents available for licensing. Two additional SSOs generally require the disclosure of specific patents, but accept blanket declarations if the patent holder commits to non-assertion or royalty-free licensing of SEPs.

The timing of the required disclosure varies substantially between SSOs. While many SSOs generally ask for "timely" disclosure, or disclosing SEPs "as early as possible", many SSOs adopted more specific policies. The required timing can be a specified number of days either after the publication of a specification, standard or draft standard, or before the (final) vote on a standard[32], or after the SSO issues a disclosure request. In addition, SSOs may require that a disclosure statement must be made simultaneously with a technical contribution to the standard. The most generous disclosure policy allows patents to be disclosed within 90 days from issuance of a final specification. The majority of SSOs that do specify a disclosure timing with respect to standard adoption (7 out of 10) require disclosure prior to approval/vote on a standard.

While the language of many SSO policies on the disclosure of SEPs has changed over time, most of the changes seem to have been clarifications and minor changes. We highlighted little substantive variation of disclosure obligations within SSOs over the observation period.

5.1.2 Voting rules and standard adoption

SSO rules on standard adoption determine the functioning of SSOs as economic institutions (Goerke and Holler, 1995). Many SSOs have multistage procedures for the adoption of standards. We tried to identify consistently the voting rules governing the decisive, final vote on a standard specification. Also, several SSOs have menus of different standard adoption procedures with different voting right allocations etc. In these cases, we tried to identify which procedure is typically used at the SSO.

SSOs use different bases to allocate voting rights. 30 SSOs have tiered membership, in which case not all members have voting rights. Whether a SSO member has voting right in a working group or plenary meeting depends upon its membership tier (higher tiers are associated with higher fees), and may also be conditioned on attendance or participation in past votes. Usually, each voting member has one vote.[33] At ETSI, votes are weighted either by the volume of sales of a firm, or (for different standardization processes) on a

[32]Similarly, before the holding of a general assembly etc.

[33]Note however that many SSOs have tiered membership. Whether a SSO member has voting right in a working group or plenary meeting often depends upon its membership tier.

Table 3: SSO rules on the disclosure of SEP

Name	Disclosure required?	Patent search required?	Blanket statement? level of details	Disclosure timing
3GPP	Yes	Not specified	Any IPR	asap
Accelera	Yes	No	Any patent	Not specified
ANSI	Not specified	Not specified	Not specified	Not specified
ASTM	Not specified	Not specified	ANSI/NA	Not specified
ATIS	Encouraged	Not specified	Discouraged	asap
BioAPI	Yes (implied)	Not specified	Not specified	Not specified
CEA	Yes	Personal knowledge	Any patent	asap, prior to vote
CEN	Yes	Good faith, best effort	Any patent	asap
DMTF	Yes	Personal knowledge	Any patent	asap
DVB	Yes	Not specified	No	90 days from approval
ECMA	Yes	No	Only if willing to license (discouraged)	2 weeks before plenary 2 weeks before plenary
ETSI	Yes	Reasonable efforts	No	3 months from call
Home Plug	Yes	No	All patents	Multiple criteria (FN)
Home PNA	Yes	No	Not specified	Multiple criteria (FN)
IEEE	Yes	Reasonable and good faith inquiry	Any patent	asap, prior to standard approval
IETF	Yes	Personal knowledge	No	asap
IMTC	Yes	Reasonable efforts	Only if license	asap
IrDA	Yes	No	Yes	Upon call
ISO	Yes	Good faith, best efforts	Any patent	asap
ITU	Yes	Good faith, best efforts	Any patent	asap
JEDEC	Yes	Personal knowledge	No	asap; within 30 days of draft completion
MEF	Yes	Not specified	Yes	prior to approval
OASIS	Yes	Personal knowledge	All patents	Not specified
OGC	Yes	No	Yes if RF, no if RAND	Before vote; at contribution
OIF	Yes	Personal knowledge	Not specified	2 days before vote
OMA	Yes	Reasonable efforts	No	asap
Open Group	Yes	Personal knowledge	No	asap
OSGI	Not specified	Not specified	Yes (non-assertion)	Not applicable
PCCA	Not specified	Not specified	Not specified	Not specified
PCI-SIG	Not specified	Not specified	Not specified	asap
PICMG	Yes if RAND, encouraged if RF	Personal knowledge	Only if willing to license (discouraged)	multiple criteria (FN)
SDR Forum	Yes	No	Yes (only if agree to grant license)	asap
TIA	Encouraged	No	Yes	asap
VESA	Yes	No	List (submitters) any patents (others)	28 days from call
VITA	Yes	Good faith and reasonable inquiry	No	Multiple criteria (FN)
WI-FI	Encouraged	No	No	asap

national basis reflecting the allocation of votes to countries practiced in the European Council.

Table 4: Standard adoption processes

Name	Quorum	Approval requirement	Appeals allowed
3GPP	30% in meeting, 0 by correspondence	71%	Yes
Accelera	50%	Majority members present	Not specified
ANSI	as established by SSO	as establised by SSO	Yes
ASTM	Unknown	Unknown	Yes
ATIS	33.3% attend.; 50% votes	75%, objections addressed	Yes
BioAPI	Not specified	66%	Not specified
CEA	50%	66%	Yes
CEN	No	71%	Yes
DMTF	No	Majority	Not specified
DVB	Not specified	Consensus	Not specified
ECMA	50% of all members	Majority members present	Not specified
ETSI	0	71%	Yes
Home Plug	Majority of Sponsors	2/3 of members present	Not specified
Home PNA	2/3 of voting members	2/3 of members present	Not specified
IEEE	50%	75%	Yes
IETF	Not specified	Rough consensus	Yes
IMTC	Majority voting members	Majority members present	Not specified
IrDA	Unknown	Unknown	Unknown
ISO	Not specified	>= 66% yes; <= 25% no	Not specified
ITU	50%	100% (Consensus)	Not specified
JEDEC	50% or 20 companies	66%; 75% (board approval)	Yes
MEF	1/3 of voting power	Majority members present	Not specified
OASIS	Not applicable	15% ”yes” and no ”no”	Yes
OGC	33% voting members (TC stage)	66% excl. abst. (TC stage) Simple majority (PC stage)	Yes
OIF	Majority of members FN	Majority (1st step), 3/4 (2nd step) Abstention not counted	Not specified
OMA	33.3%; 51%(if less than 30 voting members)FN	Majority	Not specified
Open Group	no quorum	Consensus (draft in forum); 75% excl. abst.(company review)	Not specified
OSGI	1/3 of voting members	Majority members present	Not specified
PCCA	1/3 of voting members	Majority members present	Not specified
PCI-SIG	2/3 of voting members	Majority,excl. abstentions	Not specified
PICMG	50% of eligible voters	Majority,excl. abstentions	Not specified
SDR Forum	1/3 of voting power	Majority (initial appr.); majority excl. abst. (final appr.)	Yes
TIA	50%	Consensus	Yes
VESA	40%	66%	Not specified
VITA	75%	75%	Yes
WI-FI	50% (member meetings); 66% (sponsor-member meetings)	66%	Not specified

A vote on a standard document is typically conditioned on the existence of a sufficient quorum. If specified, the quorum ranges from 30 to 51 % of eligible voting members that must be present. The requirement for the approval of a standard ranges from simple majority (50,1 %) to full consensus (100%) of expressed votes. SSOs are relatively evenly distributed over this spectrum (figure 3). Approximately half of the SSOs (15) allow appeals by members to votes and decisions on standards.

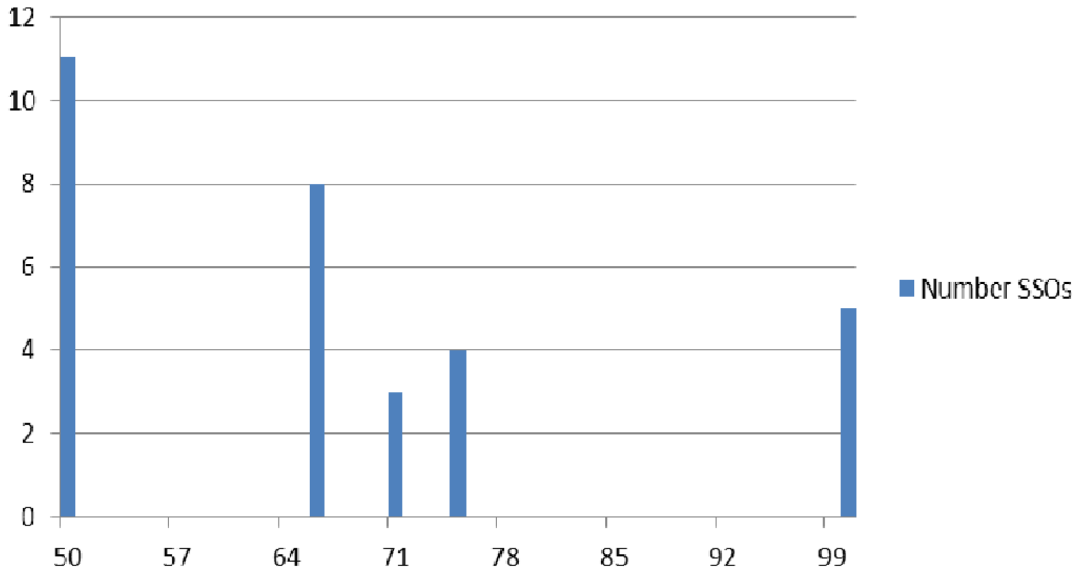

Figure 3: Number of SSOs: Required percentage of approvals among votes (approval stage)

5.1.3 Policies on openness and balance of interest

Although all SSOs in our sample have policies on Intellectual Property Rights and standard adoption, not all SSOs have explicit policies on openness and balance of interests. We collected information from those SSOs that have policies on openness and balance of interests.

With respect to SSO policies on openness, we collected data on two specific rules that are specifically addressed at a larger number of organizations: first, almost all SSOs in our sample have open membership. Open membership means that there is a specific procedure for joining the SSO that is available to all interested parties. In Homeplug and Home PNA, lower tiers of membership are open for all interested parties to join, but the highest tier consists in a group of founding members and is not open to other parties. Membership is usually conditioned on a membership fee, which can be substantial and in practice limits the ability of smaller actors to join. We are collecting and processing data on membership fees and the fee structure in order to determine how accessible membership is to all interested parties.

Second, 14 SSOs have policies allowing non-members to participate in their meetings. 7 SSOs have a specific status of observers that allows companies to attend meetings, but not take part in the decision making process. We are extending the data on openness by collecting data on SSOs that make their standards, draft standards and meeting minutes publicly available.

Table 5: SSO policies on openness and balance of interests

Name	Balance	Dominance	Affiliation disclosure required?	Open meetings?
3GPP	Not specified	Not specified	Not specified	open to qualified organizations; upon invitation
Accelera	Yes	Not specified	Not specified	No
ANSI	Yes	Yes	Yes	Yes
ASTM	Yes	Yes	Yes	Yes
ATIS	Yes	No test unless claimed	Not specified	Not specified
BioAPI	Not specified	Not specified	Not specified	Not specified
CEA	Yes	Not specified	Not specified	Yes, except press
CEN	Not specified	Not specified	Not specified	Yes (case by case)
DMTF	Not specified	Not specified	Not specified	Not specified
DVB	Yes	Not specified	Not specified	With approval of chair
ECMA	Not specified	Not specified	Not specified	only upon invitation
ETSI	Not specified	Yes	Not specified	Not specified
Home Plug	Not specified	Not specified	Not specified	Not specified
Home PNA	Not specified	Not specified	Not specified	Not specified
IEEE	Yes	Not specified	Yes	Yes
IETF	Yes	Not specified	Not Specified	Yes (Inferred)
IMTC	Not specified	Not specified	Not specified	Not specified
IrDA	Unknown	Unknown	Unknown	Unknown
ISO	Not specified	Not specified	Not specified	Yes (Media Particip.)
ITU	Not specified	Not specified	Not Specified	Yes (Inferred)
JEDEC	Yes	Yes	Not specified	Yes (Inferred)
MEF	Not specified	Not specified	Not specified	Not specified
OASIS	Not specified	Not specified	Not specified	Yes
OGC	Not specified	Not specified	Yes	Upon Invitation
OIF	Not specified	Not specified	Yes. FN	Not specified
OMA	Not specified	Not specified	Not specified	Not specified
Open Group	Not specified	Not specified	Not specified	Invitation-based
OSGI	Not specified	Not specified	Not specified	Not specified
PCCA	Not specified	Not specified	Not specified	Not specified
PCI-SIG	Not specified	Not specified	Not specified	Not specified
PICMG	Not specified	Not specified	Not specified	Not specified
SDR Forum	Not specified	Not specified	Not specified	Not specified
TIA	Not specified	Not specified	Not specified	No
VESA	Not specified	Not specified	Not specified	No
VITA	Partial	Not specified	Not specified	No
WI-FI	Not specified	Not specified	Not specified	No

SSO policies on balance of interest include policies assuring balanced representation of categories of interest (e.g. large firms, small firms and consumers, or different industries etc.), and rules preventing a single member to dominate a standard development process. Only few SSOs explicitly specify such policies (10 SSOs have policies balancing the interests of categories of stakeholders[34], and 4 SSOs have rules against single-member dominance).

[34] E.g. the DVB project specifies maximum numbers of representatives from broadcasters, operators, manufacturers and administrations represented in a meeting.

5.2 Membership data

5.2.1 Membership counts per SSO

As a first cut at the membership data, we provide statistics on membership counts per SSO and year. We collected data on membership in 195 SSOs over time. Membership in individual SSOs can substantially fluctuate over time, and several SSOs in our sample have already disappeared since we initiated the data collection in 2010. The following chart provides an overview over the highest number of SSO members per organization over the observation period (excluding Bluetooth). Only four SSOs (five including Bluetooth) in our sample ever reached a membership record of more than 1,000 members (excluding individual membership). The average over the highest observations per SSO is 207.79 members, and the median SSO had 114 members at its point of largest membership.

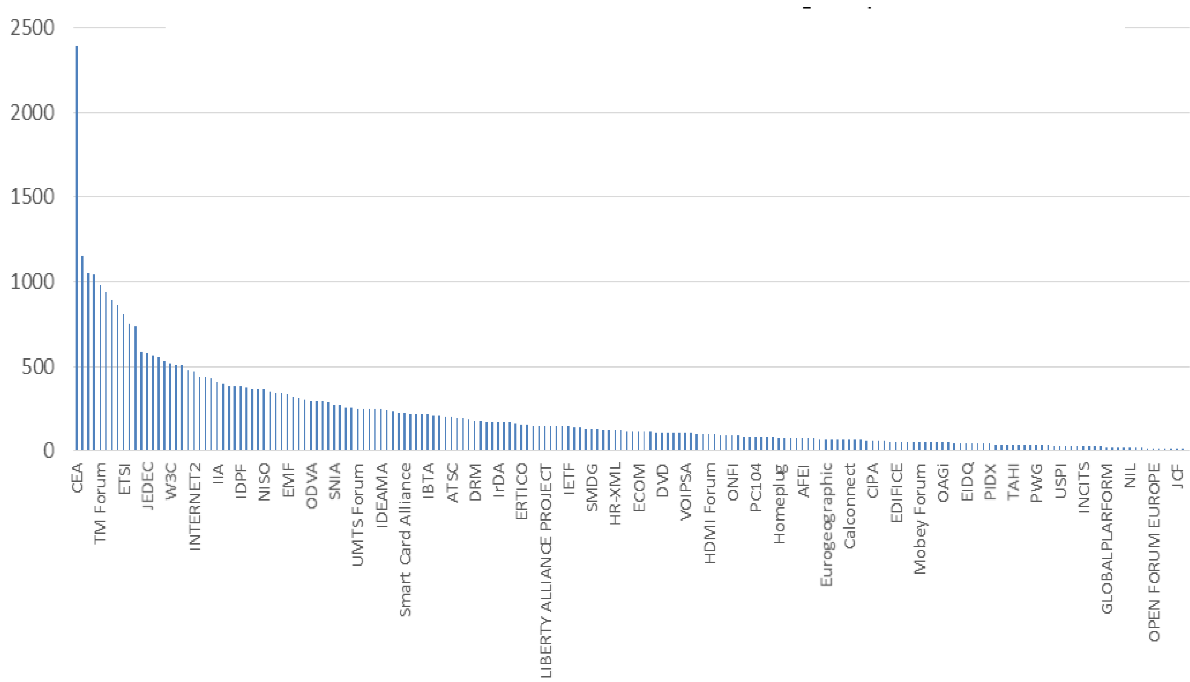

Figure 4: 195 SSOs by number of members at their largest membership observation (names of selected SSOs in legend)

Our membership records reach back to the beginnings of the Internet Archives in 1996. Figure 5 displays the number of membership entries in our sample by year of observation. The graph indicates both a substantial increase and a substantial amount of fluctuation in the total number of membership counts over time. Both phenomena are in large parts attributable to attrition in the data. SSOs enter the sample not only at creation, but also when they first make member lists available, when their website was first crawled by the Internet Archives, or when they changed their website to the earliest location that we were able to locate. Some SSOs-year observations are also missing in the middle of the sample period, including in particular the Bluetooth organization with its very large membership count. In order to study the evolution of aggregate membership counts over time, we thus created a sample of 40 SSOs for which we can observe membership in every single year from 2002 to 2013. Considering only this subsample, aggregate SSO membership appears to have been remarkably stable over the last 12 years.

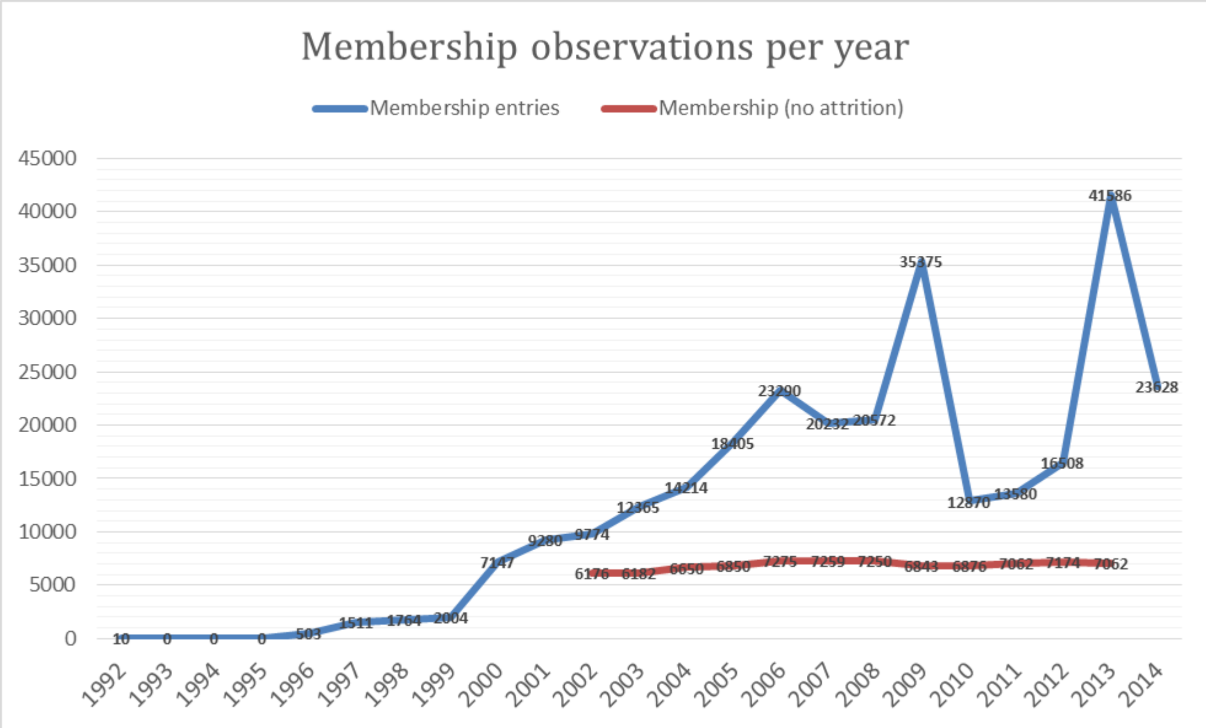

Figure 5: Total number of membership observations in the sample by year; and evolution of membership in a sample of 40 SSOs without missing membership lists

Despite the stability of the aggregate membership count, there are very substantial fluctuations in membership over time at the level of single SSOs. Figures 14 to 18 in the appendix show the evolution of membership counts at 36 SSOs. Out of the SSOs with more than 10 member lists in our sample, these are the organizations with the highest number of members. We grouped SSOs with similar maximum numbers of members together to facilitate the display of the membership counts. The six graphs display many different patterns of evolution of membership counts, including drastic increases or decreases over short periods of time.

Figure 6 illustrates the evolution of membership at seven well-known SSOs. Membership at these relatively established organizations is more stable than in many other SSOs, but there still is a substantial amount of fluctuation. We can see e.g. a decrease in membership at OASIS after 2005. (Stoll, 2014) discusses this decrease in membership and argues that it is a consequence of a change in the IP policy of this SSO. This is an interesting example of how fluctuation in SSO membership data can be used to provide evidence on important policy questions.

5.2.2 Identity of SSO members

Thanks to substantial efforts in the cleaning of member names, we can not only count membership entries by SSO, but also count SSOs that specific organizations are members of. In particular, we identify and count all SSOs where a company was ever listed as a member. The following table lists the 50 firms or other organizations (several public research institutions are listed among the top SSO members) with the highest number of SSOs they were ever involved with. The first company in this list is IBM, which has

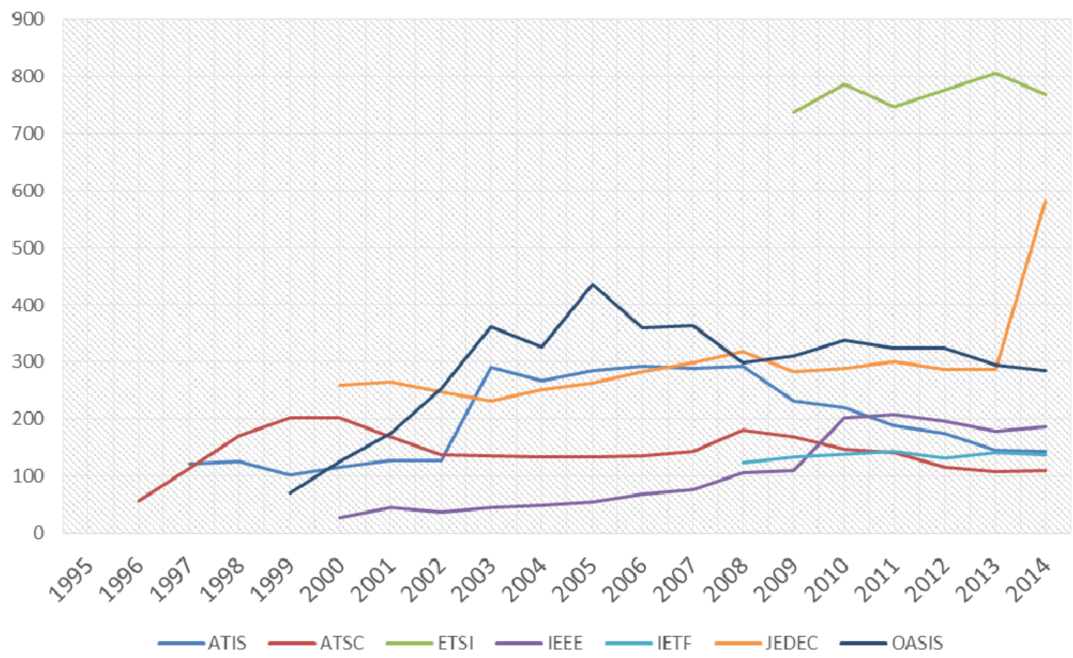

Figure 6: Number of membership observations per year, selected SSOs

been listed as member of 109 different SSOs in our sample. We also show how the number of SSOs has changed per company. There is a very substantial variation. The number of SSOs IBM, Philips or France Telecom are involved with is declining, whereas several large Asian companies, Qualcomm or the German public research institute Fraunhofer Gesellschaft are listed as members of an increasing number of SSOs.

We can also analyze different categories of SSO members. Given the large number of different member organizations in the data, it is difficult to assign firms to different industries, or distinguish between small and large firms etc. One category of members that is relatively easy to identify are universities. We created a list of words designating universities or other institutions dispensing higher education in different languages, and searched for these terms in the membership data. We identified 1,556 different academic institutions in the SSO membership data, accounting for 7,675 membership observations. The single most represented academic institution is the University of New Hampshire, which has been affiliated with 19 different SSOs in our sample over the observation period.

Academic institutions represent between 2 and 3.5 % of the membership observations per year, with no clear trend over the last 20 years. This number may slightly understate the real involvement of academic institutions, because some academic institutions may not be immediately recognizable as such from their name. We can however use this data to compare the extent of academic involvement between SSOs. University membership is negligible in most SSOs, including the largest SSOs like IEEE, 3GPP or IETF (note however that many academics are represented in IEEE and IETF as individual members). Some smaller SSOs in different technological fields (Table 7) are however dominated by university membership.

Table 6: Top member companies

Member (cleaned)	ever	1998	2003	2008	2013
IBM	109	10	39	57	55
NEC CORPORATION	100	9	30	57	67
Intel Corporation	97	7	31	51	53
HEWLETT-PACKARD	94	9	38	53	47
HITACHI LTD	92	10	30	42	63
FUJITSU LIMITED	89	8	31	50	76
MOTOROLA SOLUTIONS	89	11	30	39	40
Samsung Electronics	88	9	27	43	50
MICROSOFT CORP	85	8	30	45	46
Nokia	84	7	26	49	39
SONY CORPORATION	82	9	25	40	53
SIEMENS AG	80	7	32	39	26
Toshiba	80	9	25	38	53
PANASONIC	78	7	32	38	46
CISCO SYSTEMS	76	2	26	33	48
ERICSSON AB	76	4	18	39	41
TEXAS INSTRUMENTS	73	6	21	37	31
Sun Microsystems	68	8	27	36	6
MITSUBISHI CORP.	67	7	28	32	47
NTT	62	6	17	30	43
Oracle	61	4	18	30	37
BROADCOM CORP	60	0	14	30	35
ALCATEL-LUCENT	60	.	.	34	31
Huawei Technologies	60	0	8	26	45
STMicroelectronics	59	1	14	32	34
LG Corp	58	3	16	25	41
Marvell Technology	56	0	4	23	33
QUALCOMM INC	54	2	12	27	50
Nortel Networks Ltd.	53	4	18	29	4
SHARP CORPORATION	51	6	19	19	31
NXP SEMICONDUCTORS	51	0	0	28	26
AGILENT TECHNOLOGIES	49	0	16	20	15
Fraunhofer	49	1	11	23	40
AT&T INC.	49	4	12	23	26
Infineon Technologies	48	0	12	23	18
Dell Computer	47	3	15	27	29
Lucent Technologies	47	9	15	2	2
Philips	47	1	16	12	2
ETRI	47	1	13	23	22
Renesas Electronics	46	0	5	25	28
France Telecom	46	4	16	23	9
Oki Electric	45	3	12	19	18
Freescale Semiconductor.	45	0	1	23	28
ADVANCED MICRO DEVICES	42	2	8	31	24
Thomson	42	3	10	16	1
Industrial Technology Research Institute	42	4	7	11	13
APPLE INC.	41	5	18	20	28
Verizon	41	0	10	21	22
ADI - Analog Devices Inc.	41	2	10	24	20

Table 7: Academic membership

SSO	Percentage	Number
INTERNET2	53.74%	237
NISO	48.02%	85
DMTF	39.78%	74
FIPA	38.46%	10
TEI C	35.21%	25
TM Forum	14.43%	141
W3C	8.63%	34

This analysis is just a first cut at the membership data. Carrying the member name standardization further, and matching firm names with outside data sources, will also make it possible to study SSO membership by type of organization, size, nationality etc.

5.3 Data on technology standards

Our sample includes 762,146 standard documents issued by 90 different SSOs. The database includes information on various document characteristics, such as the publication date, the issuing SSO, the technological classification, the number of pages, references between documents, equivalence between documents issued by different SSOs, and withdrawal dates (if the document is inactive).

5.3.1 Standard counts

Counts of standard documents can provide useful information, e.g. on the relative importance of SSOs, trends in standardization, and the technological focus of different SSOs. Figure 7 displays the number of standard documents issued each year since 1985 by selected SSOs. Our data includes standards set by SSOs, government and single companies. Large formal SSOs account for the majority of standard documents in our sample. Our sample includes 73,198 standard documents issued by ISO, and 64,808 documents issued by CEN. These are large international SSOs active in many different technological fields. IETF (4,873 documents) and IEEE (2,726 documents) have issued relatively smaller numbers of standard documents, but many of their standards are of particular commercial and technological importance.

We can also describe the evolution of standardization by technological field. We therefore use the technological classification *icsclass*. Among the sources we reviewed, only PERINORM and Document Center provide the ICS classification. Standard counts by technological class are thus restricted to observations generated from these datasources.

Figure 8 shows the distribution of the standards of selected SSOs over highly aggregated technological categories. It is apparent that many of the large SSOs are active in very diverse technological fields. The largest SSO active in a specific technological area is ETSI, which is active in the field of telecommunications, and has issued 46,303 documents

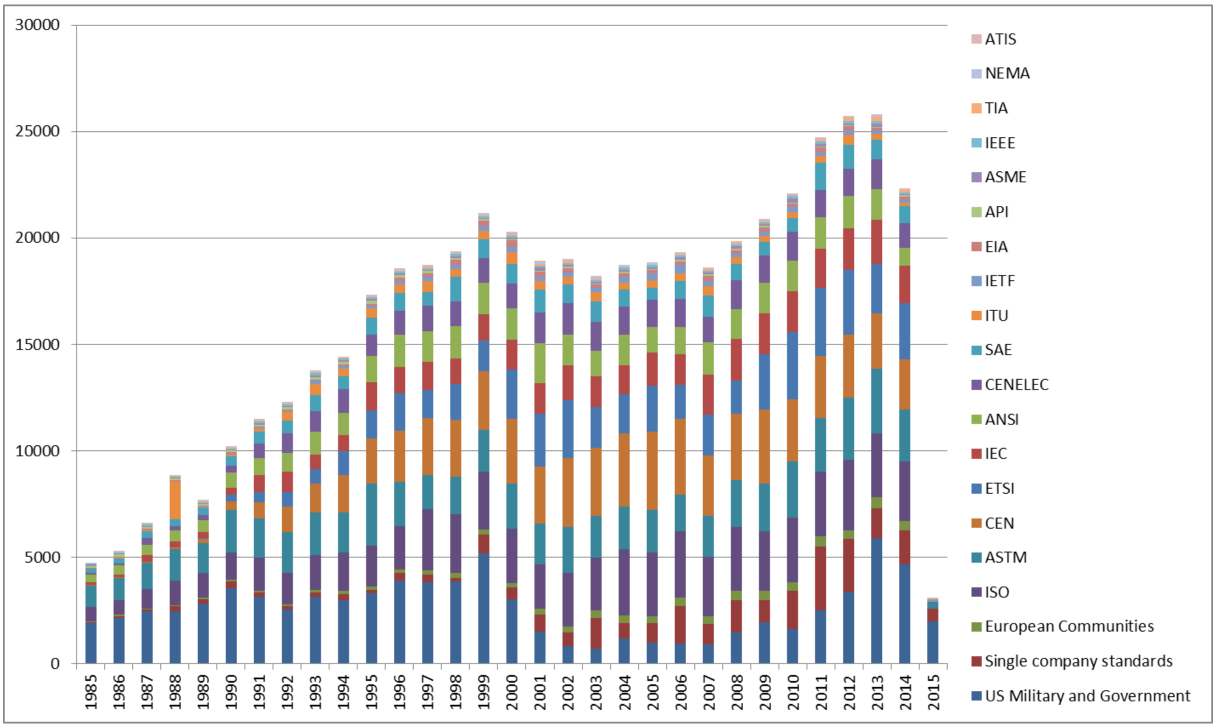

Figure 7: Number of standards issued each year by SSOs in our sample, by technological field

in our sample.[35] Other specialized SSOs with large numbers of documents include ITU (telecommunications), SAE (automotives) and ISO/IEC (the so-called Joint Technical Committee 1, specializing in Information Technology). It also visible from Figure 9 that the relative importance of government standardization and of the international SSOs where voting members represent countries (e.g. CEN and ISO) is slowly decreasing.

Figure 9 displays time trends of standardization by technological field. The most salient trend is the increasing importance of telecommunications and Information Technology (and to a lesser extent electronics), which is also visible from the increasing number of standards issued by ETSI and IETF as compared to other SSOs (cf. Figure 8).

5.3.2 Standard characteristics

Data on standard characteristics can complement and substantially enrich the empirical analysis. In particular, our data include variables describing the evolution of technology standards after their release. Standards are dynamic technological objects, as they constantly evolve and change through amendments, release of new versions, and standard replacements. Furthermore, standards diffuse gradually, as they are implemented in new products and technologies, and are endorsed by different organizations.

Three variables are of particular interest for describing these rich dynamics. First, references between standard documents indicate the use of a standardized technology for the implementation of another standard. A standard references another standard if

[35]Note that 3GPP standards are not separately listed in our sample. 3GPP standards are however also published by each of the six SSOs participating in 3GPP, including ETSI. The sample of ETSI standards therefore also includes the standards developed at 3GPP.

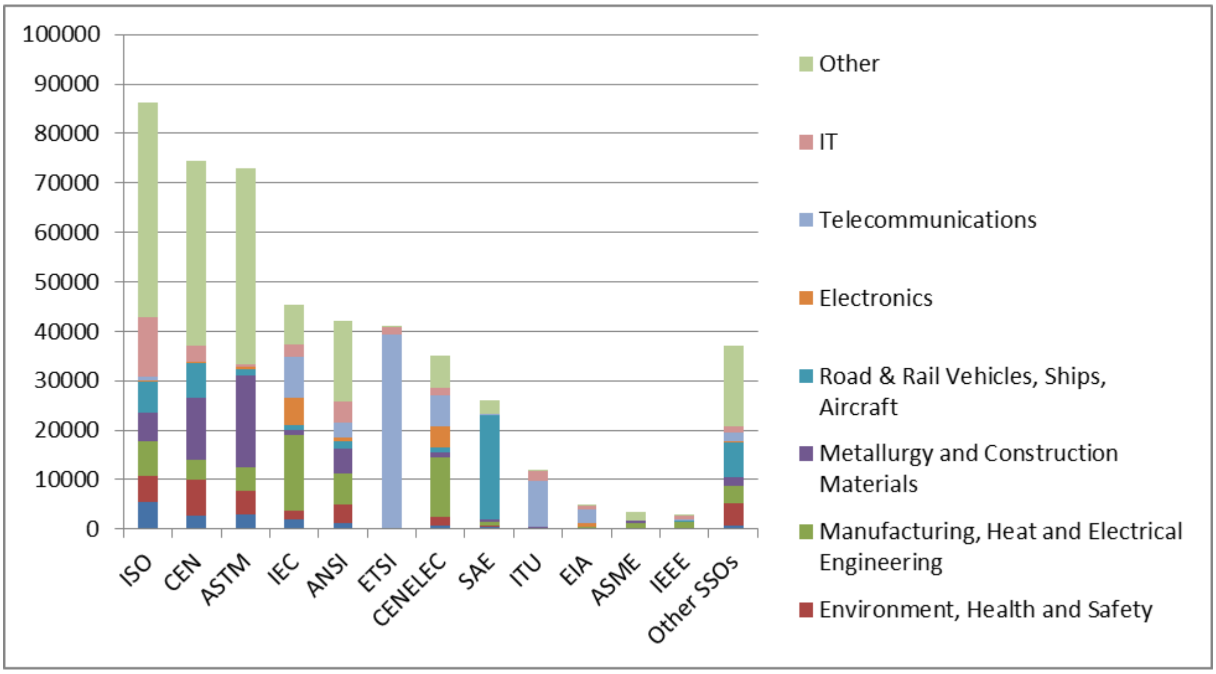

Figure 8: Standards by issuing SSO and technological field

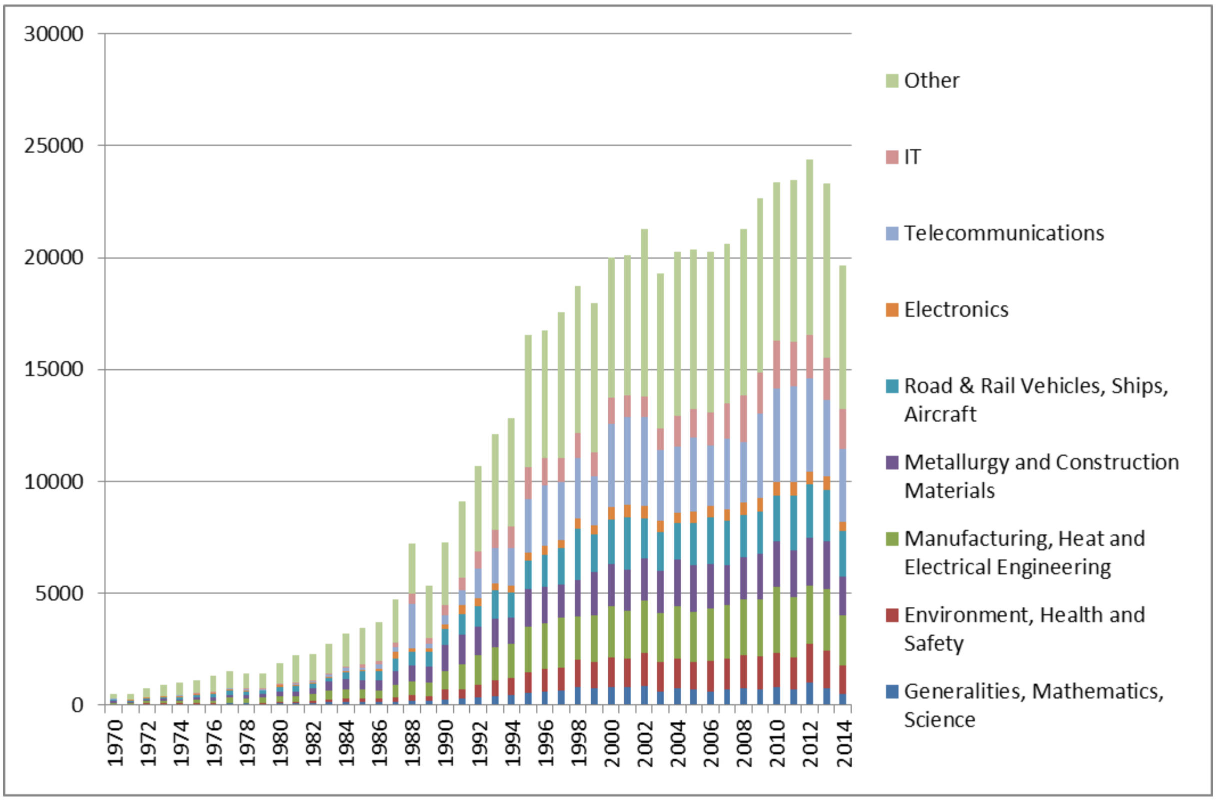

Figure 9: Number of standards issued each year by technological field

compliance with the referenced standard is required in order to correctly implement the referencing standard. The number of references thus indicates the number of different technological applications in which a technology standard is used. Baron et al. (2013) find that references to a standard reduce the likelihood that the referenced standard is replaced. On average, a standard document is referenced by 5.81 other standard documents. The distribution of references is however highly skewed (Figure 10). 71.8 % of standard documents do not receive a single reference, while 230 standard documents are referenced by more than 1,000 and six documents are referenced by more than 5,000 other standard documents. This skewed distribution is reminiscent of the distribution of the number of patent citations.

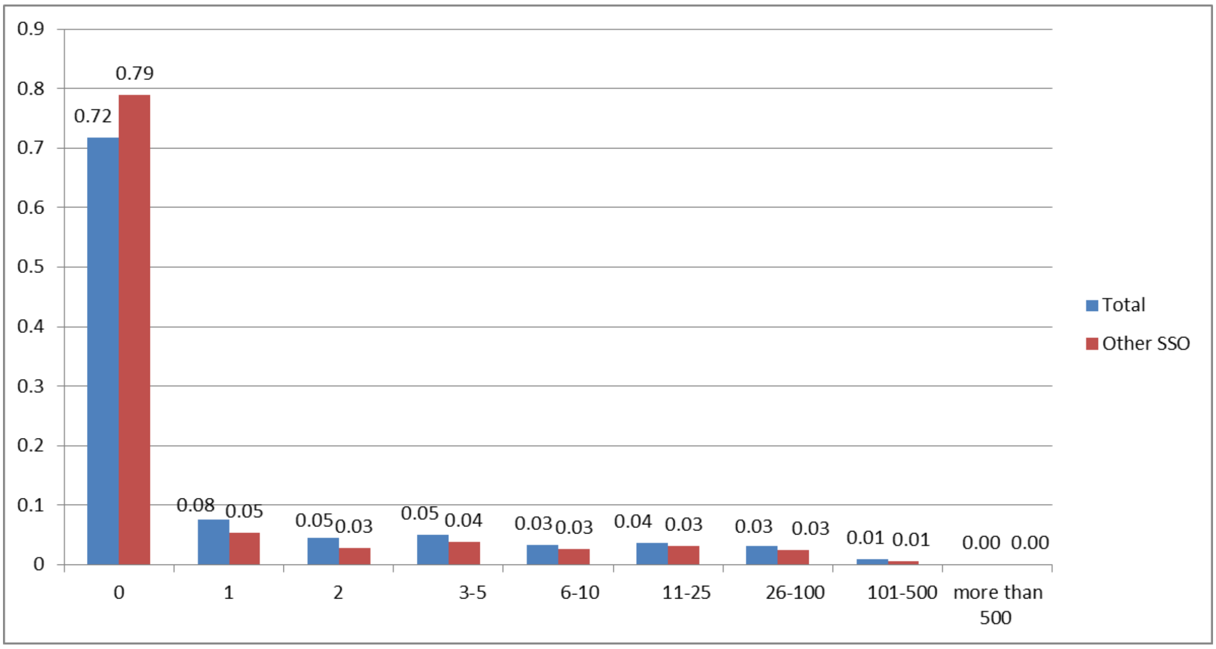

Figure 10: Standard references and references received from other SSOs

69 % of the references (2,528,846 out of 3,564,975 references) take place across SSOs. Most of these references across SSOs are directed at the international, formal bodies ISO, CEN, IEC, CENELEC and ITU (Figure 11). Related to the number of standards, IETF standards are particularly frequently referenced by the standards of other SSOs (14.65 references per document), followed by ISO, CEN and IEC (all from 10.3 to 10.5 references per document). ETSI standards are on average referenced by only 1.02 standards issued by other SSOs, but each ETSI standard document receives on average 10.48 references from other ETSI documents. While 70 % of ETSI standard documents are referenced by other documents, only 12 % are referenced by standard documents issued by a different SSO (Figure 12).

Another variable of interest is the number of standard accreditations. The same standards can be issued by multiple SSOs. This can for instance result from a cooperative standard setting process involving multiple SSOs. 3GPP standards for example are issued by the seven different SSOs cooperating within 3GPP. Another typical scenario is that a standard is first issued by one SSO and eventually adopted by other organizations. ISO and other international organizations frequently adopt standards developed by national SSOs; and national SSOs frequently adopt international standards. It is also common that standards are first developed and adopted at smaller and less formal SSOs, before they become formal standards backed by large and formal consensus bodies. On average, each standard document has 1.14 equivalent documents at other SSOs (so that each standard is adopted on average by more than two SSOs). The number of SSO accreditations per standard document is also highly skewed, even though less so than the number of references. 72 % of the standard documents have only one single SSO accreditation, but 13 % of the documents are accredited by more than ten SSOs.

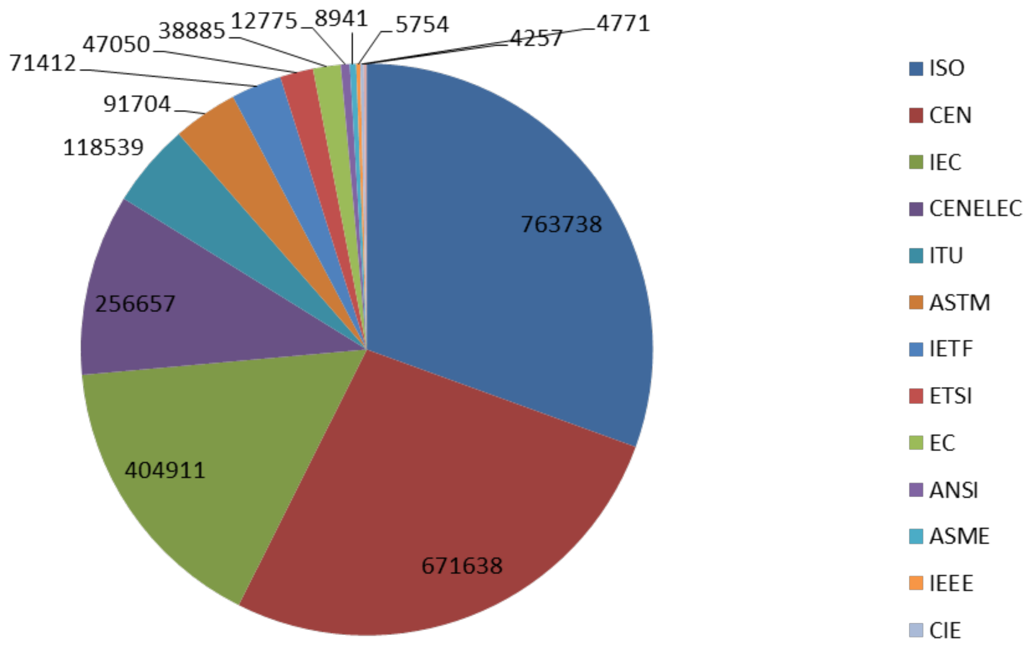

Figure 11: Standard references received from other SSOs, by SSO issuing the referenced standard

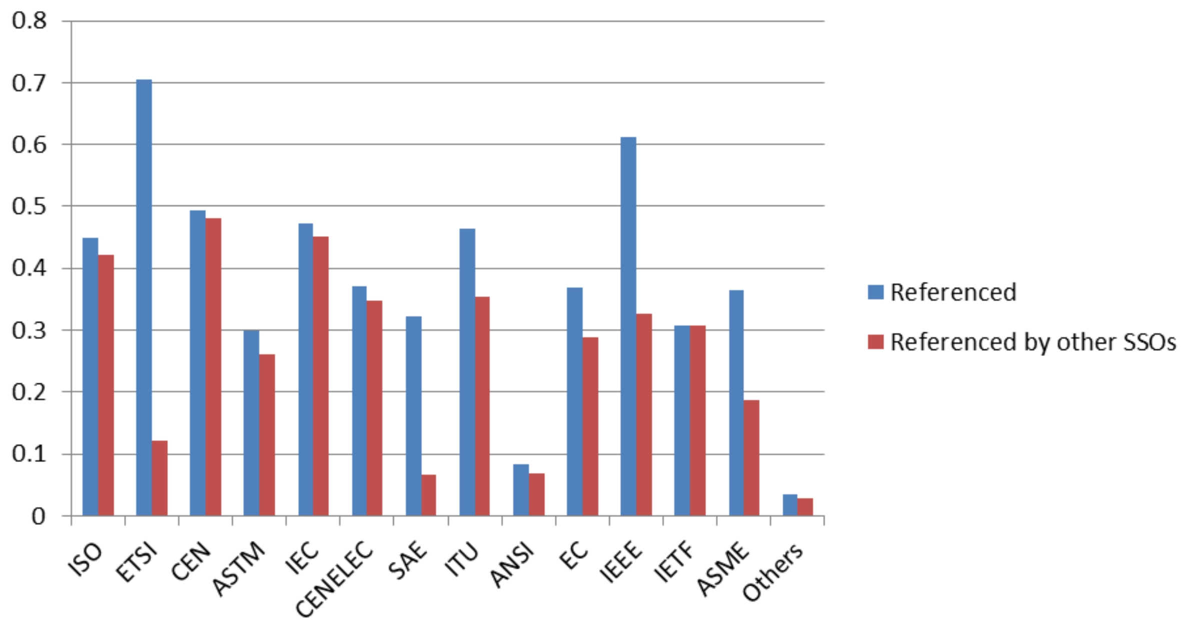

Figure 12: Share of standard documents receiving references, by SSO

Finally, we can also study the survival of standard documents, i.e. the time elapsed between release and official withdrawal of a standard document. Even though active standard documents may be over-represented in the data, 62.5% of the standard documents in our sample are inactive. Standard documents are frequently replaced by updated versions of the same standard, or by entirely different standards. SSOs can also simply withdraw standards that have become obsolete due to technological development. The half-life of a standard document in our sample is 67 months.

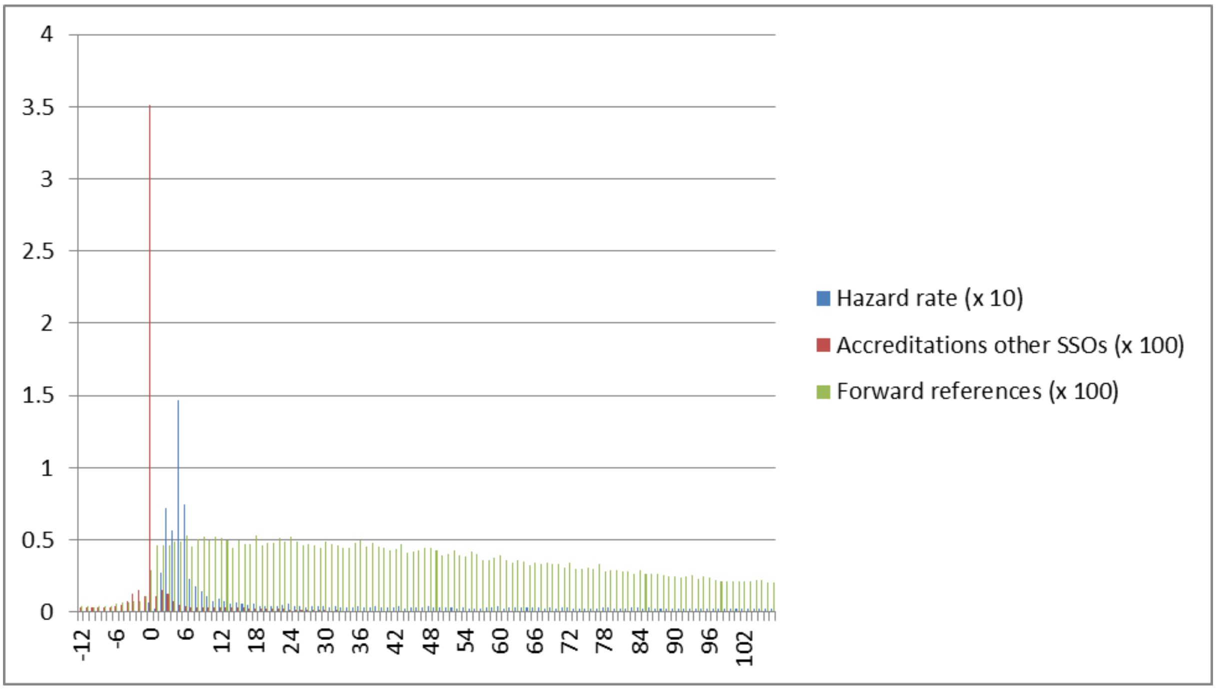

Figure 13: Standard references and accreditations and hazard rate of standard withdrawal over the standard lifetime

Figure 13 presents a graphical overview over the different events occurring over the standard lifetime. The hazard rate of standard withdrawal is highest over the 12 first months, and converges almost to zero after ten years. A standard document that has been in place for more than ten years faces a very low likelihood of being withdrawn. 9% of the standard accreditations at other SSOs are contemporaneous releases, i.e. made in the month of standard release. The other accreditations are prior or ulterior accreditations. The accreditations being symmetric in the overall standard population, the graph only shows the ulterior accreditations (except the prior accreditations from the 12 months preceding standard release). Most of the ulterior accreditations are made in the first 18 months after release, but standards continue to receive non-negligible numbers of new accreditations even 10 years after release. References arrive at a relatively constant rate over standard lifetime. This contrasts with the age profile of patent citations, which have been found to peak three to six years after patent application year (Mehta et al., 2010). The high number of references received by standards many years after standard release is remarkable, given that unlike patent citations, references cannot be made to inactive standard documents.

6 Outlook: Opportunities for research using the Searle Center Database

There is a large number of research questions that can be addressed using the Searle Center Database. The aim of this section is not to provide an exhaustive list of research opportunities, but to show that standards data have a great potential to be useful in many economic research projects.

6.1 Studies of technology standards

6.1.1 Analysis of standard counts

The simplest use of the standards data is to count standard documents in order to analyze how standardization evolves: is there an increase or decrease in the intensity of standardization activity over time? Using the data on issuing SSOs and the ICS classification, it is furthermore possible to analyze richer trends: which technological fields are generating relatively more technology standards, and which types of SSOs are gaining importance?

The analysis of such trends should be related to economic variables, such as measures of total factor productivity (TFP), economic activity (GDP), innovation, competition, product prices and trade. Baron and Schmidt (2014) use time series econometrics and counts of standard documents in ICT to analyze the effect of technology adoption on the business cycle. This study also shows that it is useful to weight standard counts by measures of standard importance (in particular the number of references from other standards), and to distinguish between new standards and new standard versions of existing standards. Standards data can also be used to study the relationship between technology adoption and new inventions, or the complex interactions between standardization, innovation and competition.

6.1.2 References and citations

This database furthermore provides rich bibliographical data describing standard documents, including references among standards. A normative reference from one standard document to another means that the referenced standard is necessary for implementing the referencing standard, whereas an informative reference means that the referenced standard is useful for implementing the referencing standard. References thus are a direct indicator of use: a standard referenced by many other standards is useful or necessary in many different technological applications.

References differ from citations between patents or academic articles, which indicate a knowledge transfer.[36] Standard references indicate that one standard prescribes the use of another standard. Economists are familiar with using patent citations as indicators of the *quality* of patents. While the theoretical arguments supporting this use of patent citations are disputable, the role of standard references makes them appear as a more direct measure of the use of a standard in different applications.

Besides their relevance as indicators of the extent to which a standard is used, references among standard documents can be used to study how firms use various organizations in establishing industry consensus on complex technologies. If a standard references another standard to address a specific technical problem, it delegates the consensus-finding role regarding this problem to another organization, and accepts that access to the standardized technology is conditioned by the IP policy of the other organization.

[36] The use of technology standards as knowledge input in further technological development is better studied using the available data on patents citing technology standards as part of the non-patent literature (NPL).

Normative references between standard documents furthermore define complex technological systems with many essential components. By the definition of normative references, a patent that is essential to the referenced standard also is essential to the implementation of all referencing standards. The possibility to implement a standard thus is conditioned not only on access to the SEPs of the standard itself, but also access to all SEPs for all referenced standards, and all SEPs to standards referenced by the referenced standards and so on. Normative references thus are useful for studying the stack of possibly patented technological components used by a standardized technology, and the set of different IP policies that regulate access to the different components.

6.1.3 Accreditations

The existing literature on the political economy of standard setting focuses on competition among SSOs (Lerner and Tirole, 2006; Chiao et al., 2007). There is however also a very significant degree of complementarity among SSOs. SSOs can collaborate on specific standard projects, one SSO can be a member organization of another SSO, and SSOs can approve standards already adopted by other SSOs. In many of these cases, different SSOs will publish identical standard documents under different standard numbers. We group these identical documents into single observations, and call *accreditation* the process by which an SSO publishes a standard document that is equivalent to an already existing document. The number of accreditations is a useful indicator, because each accreditation reflects endorsement of the standard by an additional organization.

There can be different reasons for the publication of standards by multiple SSOs. Many SSOs are national in scope, and collaborate with national SSOs from other countries through international SSOs like ISO. The accreditation of standards therefore often reflects an increasing geographical diffusion. Very frequently, standards of national SSOs are accredited by ISO, and ISO standards are accredited by national SSOs. More generally, each SSO has its own membership, and establishes an agreement between a particular set of members. As discussed, SSOs also have different requirements for the adoption of standards, ranging from simple majority to full consensus. Standards are thus frequently developed in small, informal organizations with a relatively restricted membership and less demanding approval requirements, and are eventually adopted by broad, formal and consensus-based organizations once a wider industry acceptance has been achieved.

This interaction of multiple SSOs in a dense web of mutual references and accreditations creates a complex system of gradual consensus building through a combination of competition and cooperation between firms and between SSOs. Using data on references and accreditations, it becomes possible to study how standards progress through multiple layers of consensus building, how consensus is reached on increasingly complex technological systems, how the multiple SSOs organize technological change at the component and the system level, and how the position of an SSO in its vertical relationship with other SSOs determines its rules and membership composition.

6.1.4 Standard survival

A third useful measure of standard success is the survival of standards. The analysis in Baron et al. (2013) differentiates between the survival of entire standards (i.e. the period from the release of the first version to the withdrawal of the last version) and the survival of standard versions. Short standard version lifetimes may indicate rapid technological progress on a standard, which experiences frequent improvements. Long standard lifetimes can be an indicator of the success of a standard in the marketplace, but can also indicate resilience to technological change or a failure of the SSO to keep up with technological progress.

Using the different indicators of standard success (references, accreditations, survival), the success of standards can be related to the rules and procedures of the issuing SSO and the composition of its membership. Furthermore, it can be studied whether the endorsement by multiple SSOs increases the likelihood of standard success, and which combinations of SSOs are particularly helpful. Simcoe (2012) finds that stronger implication of companies with commercial stakes in standardization at IETF has reduced the speed at which standards are adopted. One may however also expect that the participation of commercially relevant companies in standard setting helps building support for a standard in the marketplace and secures wide standard adoption and survival after a standard's release.

6.2 Studies of SSO membership

The membership data as well can be used in a large number of different research projects. The Searle Center Database provides the first large scale database of membership in a large sample of SSOs. This makes it possible to study the determinants of SSO membership not only at the level of a single organization, but the full SSO membership profile of a company. Thus, researchers can investigate how many SSOs a company joins, how membership in one SSO substitutes or complements membership in another organization, and how SSO membership decisions of a firm depend upon SSO policies, membership composition and standards output. Stoll (2014) analyzes how a particular rule change at one SSO induced a decline in the SSO's membership. Future studies will be able to extend this analysis to large samples of SSOs, and include a large range of explanatory factors. Such a setting will also allow addressing SSO rules and rule changes as endogenous economic decisions by SSOs and their members.

The membership data also allows study of the effect of firm membership in SSOs on measures of firm success, such as revenues, market value or the likelihood of a successful IPO. Existing studies using data on single organizations found evidence for a positive effect of SSO membership on firm success. Our large scale database of membership in a large sample of SSOs allows further investigation of the following questions. How does the effect of SSO membership on the value of a firm depend on SSO rules, membership composition and standards output? What is the incremental effect on the value of a firm of joining an additional SSO?

Another possible analysis investigates networks of firms that are members of the same SSOs. The composition of SSO membership is also a coalition building problem, where firms decide to join the same SSO as some firms, but avoid SSOs in which other firms are member. The joint membership of firms in our large sample of 195 SSOs can be studied using the rich analytical tools of network analysis. It is also interesting to relate firm networks established through SSO membership to alliances outside standard setting. What is the effect of collaborating on standards on the likelihood to jointly engage in research joint ventures, commercialization alliances or illicit product market cartels? Leiponen (2008) and Ranganathan and Rosenkopf (2014) analyze how firm alliances outside SSOs determine the capacity of a firm to influence standard setting. Our data allows the study of how alliances established through joint membership in multiple SSOs affect standardization outcomes and firm influence.

6.3 Studies of SSO rules

The Searle Center Database furthermore provides opportunities for research on the political economy of SSOs. There is considerable variety of SSO rules on IP, voting, and openness. The rules and procedures adopted by an SSO can be related to the characteristics of the technological field, the presence of other SSOs, and the SSO's position in the network of collaborations with other organizations. Goerke and Holler (1995) find that the optimal rules of an SSO depend upon the characteristics of the standardized technology. Furthermore, changes in SSO rules over time can be analyzed and related to legal changes in important countries, or instances of technological change.

Chiao et al. (2007) characterize SSO rules as an endogenous response of SSOs to the ability of firms to choose between different organizations. It would be interesting to study how SSOs adjust their rules to market forces. Economists can study the interplacy between endogenous entry of SSOs and endogenous rule changes at existing organizations.

The Searle Center Database can furthermore be combined with three complementary datasets. These databases include data on declared SEPs and patents related to standards, detailed procedural data on standard development at 3GPP, and licensing of SEPs through patent pools. Combining these different data sources opens up a wide field of new research questions. The databases are set up in a way that facilitates their joint use.

7 Conclusion

The Searle Center Database on Technology Standards and SSOs is the first systematic source of empirical data on technological standardization that is designed for academic research. We have gathered data on SSO policies, membership and standards. Future efforts will further expand the sample and extend the data to further aspects of standardization.

This database can be used to study SSOs, firm strategies with respect to standardization, and the economic effects of technology standards. Despite the undeniable economic importance of technology standards, and the increasing role of standardization in the development of complex technologies, there has been so far very little empirical economic research on these questions. Important policy debates regarding e.g. the licensing of SEPs, the implications of technology standards for international trade, the role of government in standardization and the role of standards for public procurement are still insufficiently informed by empirical evidence. It is the aim of this database to provide a comprehensive and standardized source of empirical information that will facilitate a stream of new empirical research.

We invite researchers interested in the economics of standardization to use the Searle Center data in their research and to contribute to the further growth and improvement of the database. This database presents many opportunities to be used jointly with other new or established sources of information. The Searle Center is also involved in the creation of two other databases on technological standardization: one database on detailed standardization processes at 3GPP, and a comprehensive database of declared SEPs and patents technologically related to technology standards.

Appendix

Appendix 1

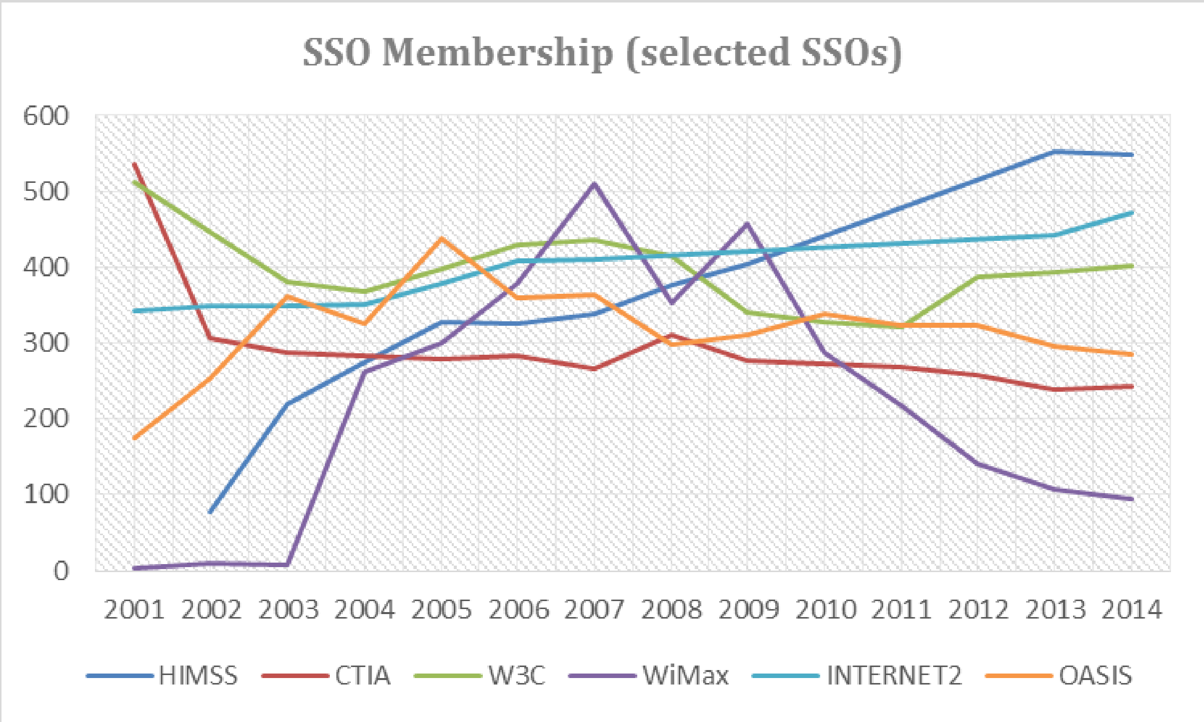

Figure 14: SSO membership, selected organizations

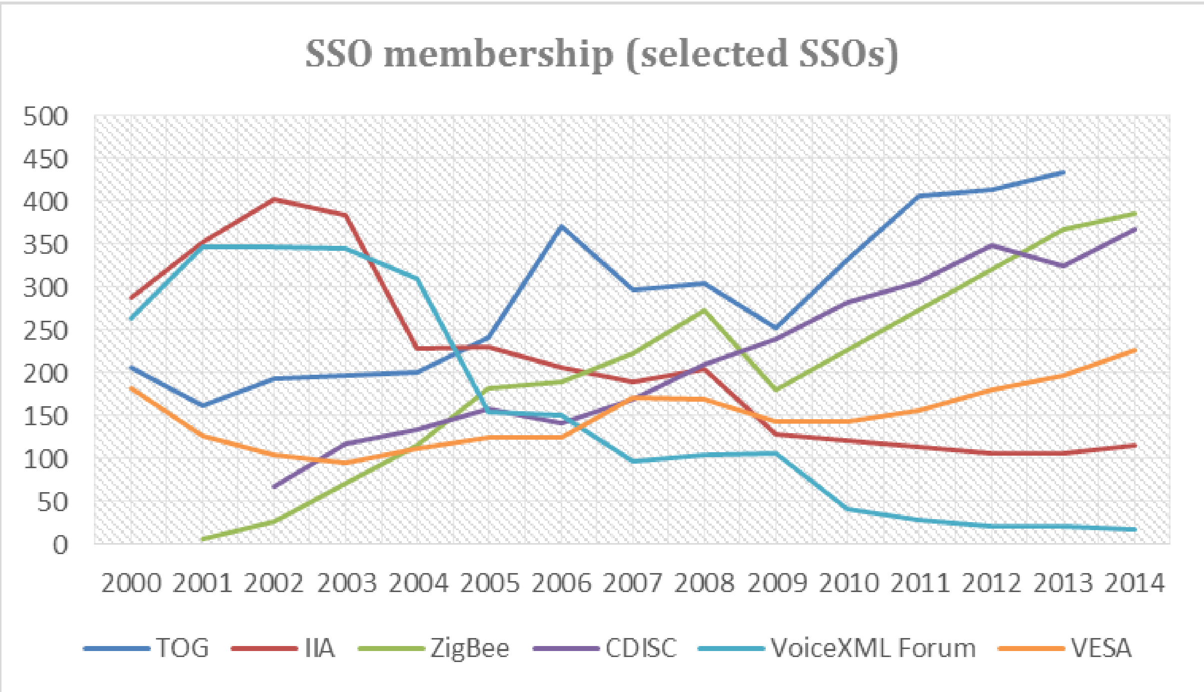

Figure 15: SSO membership, selected organizations

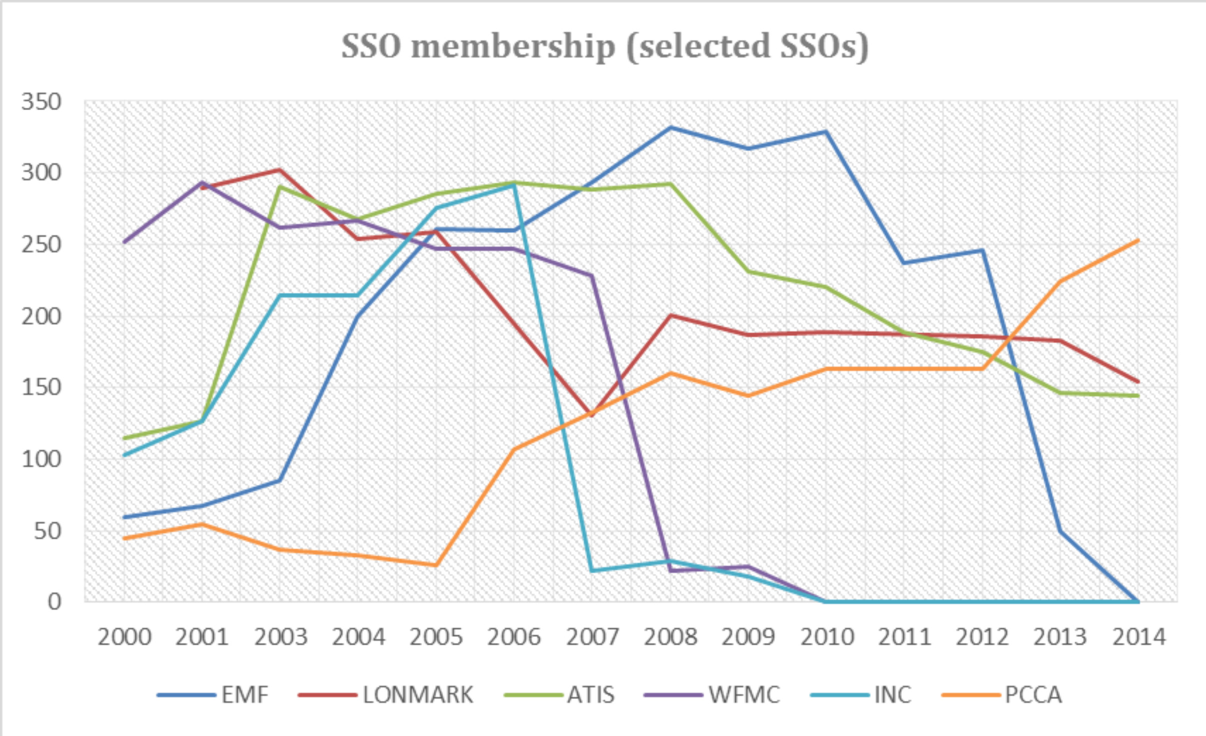

Figure 16: SSO membership, selected organizations

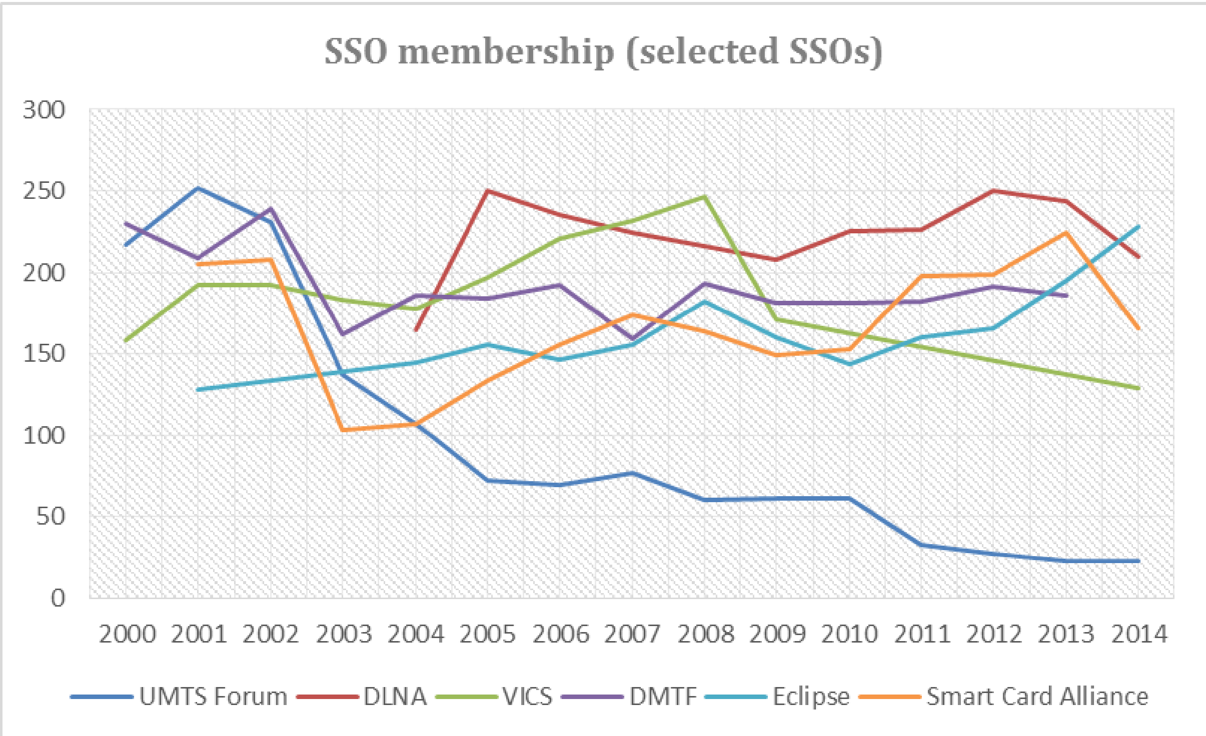

Figure 17: SSO membership, selected organizations

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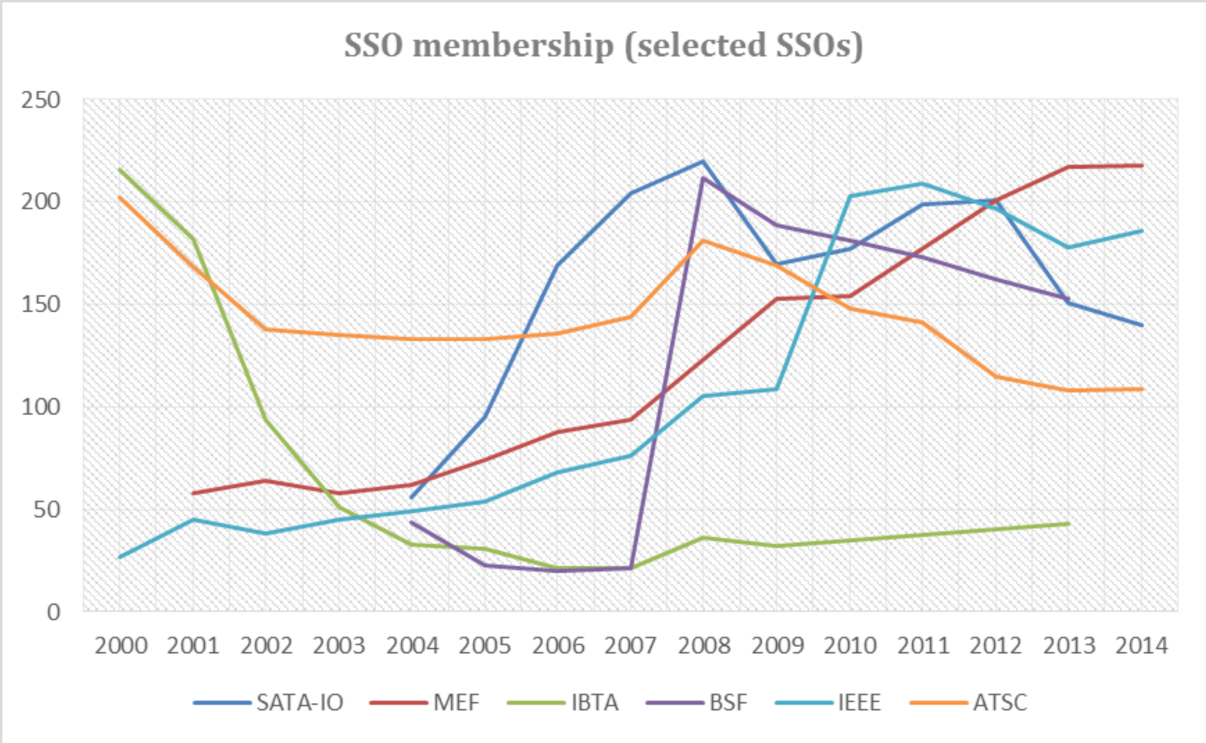

Figure 18: SSO membership, selected organizations

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