Technological Forecasting & Social Change 115 (2017) 167–179

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

The characteristics and impacts of scientific publications in biotechnology research referenced in standards

Michael Raven [a,b], Knut Blind [a,c,*]

[a] Technische Universität Berlin, Chair of Innovation Economics, Marchstraße 23, 10587 Berlin, Germany
[b] European School of Management and Technology, Schloßplatz 1, 10178 Berlin, Germany
[c] Fraunhofer Institute of Open Communication Systems FOKUS, Kaiserin-Augusta-Allee 31, 10589 Berlin, Germany

ARTICLE INFO

Article history:
Received 8 March 2016
Received in revised form 25 August 2016
Accepted 2 October 2016
Available online 17 October 2016

Keywords:
Standardization
Standards
Research
Scientific publications
Biotechnology

ABSTRACT

The integration of research papers in standards has not yet been addressed using quantitative approaches. This paper investigates the characteristics of research articles on biotechnology related to standards. The analysis is based on a study of standards produced by the standardization consortia *BioSharing*. Research, i.e. scientific articles, included in standards is more likely to lead to follow-up research and diffusion over a longer period of time than comparable scientific publications measured by the number of citations relative to most-related articles. In addition, research relying on scientific publications referenced in standards is more valuable for the research progress.

1. Introduction

The fundamental purpose of standards is to enable interoperability and coordination. Standards can arguably limit creativity in the research and innovation process, but recent studies have established that the potential drawbacks of standards are outweighed by the benefits (Allen and Sriram, 2000; Baldwin and Clark, 2000; Blind, 2004; Tassey, 2000; Temple et al., 2005). Standards reduce the costs of research and innovation by narrowing the set of research and technology opportunities while promoting interdependent research and innovation tasks (Baldwin and Clark, 2000). With regard to the research and innovation process as a whole, standardization is regarded as a catalyst which facilitates technology transfers (Bozeman, 2000), i.e. standards promote the diffusion of technology, as part of the innovation system (Besen and Farrell, 1994; Tassey, 2000). This matter fosters and creates value for the research and development (R&D) process, as well as other investments in knowledge creation (Temple et al., 2005). Overall, standards are a source of relevant information to actors within an innovation system. This implies that the research, as well as the standards community, constantly monitors, alerts and matches standardization efforts. On the one hand, the research community pulls information for research and pushes information on standardization. On the other hand, the standards community pulls information for standardization processes and provides input for research. In order to understand these interdependencies, we need to define the properties of standards in research, as well as the relation between research and standardization.

To date, literature has differentiated between three categories of standards: formal standards, consortia standards and de-facto standards. Formal standards are established by standard-setting organizations (SSOs), such as the International Organization for Standardization (ISO) or the European Committee for Standardization (CEN) (e.g. Büthe and Mattli, 2011), and follow a strict procedure, which is transparent to stakeholders and guarantees a high level of consensus, but can also be tedious and costly. Consortia standards[1] are those that evolve from an exclusive group or arrangement (e.g. Blind and Gauch, 2008; Leiponen, 2008; Delcamp and Leiponen, 2014). Consequently, the interests of all stakeholders are not necessarily considered, resulting in lower overall levels of consensus within a given industry or society as a whole. However, consortia standards have faster development cycles and greater general flexibility. Finally, coordination can be achieved through competition, leading to de-facto standards (e.g. Gallagher, 2007; Schilling, 2002; Shapiro and Varian, 1999; Shurmer and Swann, 1995; Suarez, 2004).

Interoperability and the coordination of research activities are of particular importance to industries, such as biotechnology, which rely on varying disciplines, technologies and skills (Gillis, 2003). Especially due to the vast increases in data, the research community has

---

* Corresponding author at: Technische Universität Berlin, Chair of Innovation Economics, Marchstraße 23, 10587 Berlin, Germany.
E-mail address: knut.blind@tu-berlin.de (K. Blind).

[1] See Hawkins (1999) for a first definition of standardization consortia.

http://dx.doi.org/10.1016/j.techfore.2016.10.001

recognized the need for efficient standards for several years (Wang et al., 2005; Almeida et al., 2006; Quackenbush, 2006). In addition, research labs typically have document systems with SOPs (standard operating procedures), which can be understood as "best practices", ex. the use of the anatomy of the fruit fly as a semantic standard. However, there are currently no existing international standards published by SSOs, such as ISO, on biotechnology. At the European level, some standards have been published by CEN, but are limited to large-scale production, performance indicators and criteria for reaction vessels.

However, industry experts have indicated that more informal standards may be better suited to the needs of biotechnology, due to the dynamic and cooperative nature of the industry and that traditional patterns of standardization do not work (Rai, 2010). in addition, the development of more informal standards will be essential, as regulatory requirements evolve, for example in response to the imposition of increased requirements for the market entry of new products by authorities, such as the *US Food and Drug Administration* (FDA) and the *European Medicines Agency* (EMA). The success of less formal standards can already be observed in medical biotechnology, where several de-facto standards have evolved. The *World Health Organization* (WHO) affects standardization in medical biotechnology by publishing the *WHO Technical Report Series* (TRS), as well as by providing reference preparations, which serve as measurement standards. Furthermore, some consortia have evolved in medical biotechnology supporting the process of drug developments, e.g. the *CMC-Biotech Working Group* (CMC-BWG) and the *Predictive Safety Testing Consortium* (PSTC). CMC-BWG publishes practitioner guidelines, which support the standardization of quality requirements and PSTC assists the standardization of biomarkers. Noticeable across the whole biotechnology industry is the establishment of certain technological platforms, which can also be seen as de-facto standards, e.g. host organisms such as *Escherichia coli* and *Chinese Hamster Ovary Cells*. Concepts of the regulatory authorities, such as *Good Manufacturing Practices* (GMP) and *Quality by Design* (QbD), also diffuse into the whole industry, even outside of the regulatory framework.

As standardization at the beginning of the innovation process, particularly in basic research, has received little attention, this paper investigates the integration of research results into standards. The aim of the study is to gain a better understanding of the role of standardization along the research process. We will show that the scientific publications referenced in standards applied in biotechnology receive both significantly more follow-up citations and for a longer period of time, compared to similar publications grouped in a comparison sample. In addition, the next generation of articles referencing the scientific publications integrated into standards is of higher quality than a second comparison sample of articles. The results of our study can be transferred to other technologies and eventually reveal an enduring and effective instrument to foster innovation at early research stages via standardization activities.

In the past, research in standardization has often focused on compatibility of new products from a market perspective (Farrell and Saloner, 1985). Most attention has been paid to formal standards by SSO, as well as information and communications technology markets (Simcoe et al., 2009; Simcoe, 2012). However, few studies have investigated the interdependencies between standardization and research (Blind and Gauch, 2009; Zi and Blind, 2015). Therefore, we investigate the interplay of research and standards – as a specific and rather new form of science-technology relationship in biotechnology (see Subramanian and Soh, 2010 for more traditional links) – using the particular example of *BioSharing*, a standardization consortia active in biotechnology. Our paper contributes to this literature by investigating the implications of including research results into standards by referencing scientific publications for the first time. In contrast to standards in information and communication technologies, which reference so called standard-essential patents, this phenomenon is rather unusual – despite the high relevance of patents (e.g. Messeni Petruzzelli et al., 2015) – especially for biotechnology and many other technologies (ECSIP, 2014). On the one hand, we expand the empirical analyses of referencing patents into standards initiated by the seminal contribution by Rysman and Simcoe (2008), followed by a number of further studies referencing scientific publications in standards. On the other hand, we are not replicating their approach, rather we identify articles related to standards independent from a particular point in time. Moreover, we go one step further by looking at the impact of using scientific publications referenced in standards on follow-up research. The results of our analysis enhance our understanding of the role of standardization in the research phase. Furthermore, our study derives implications not only for SSOs and policy makers, but also and perhaps more importantly, the research community.

The remainder of the paper is organized as follows: Section 2 derives our hypotheses on the characteristics of scientific publications integrated in standards. In Section 3, we present our data, i.e. standards in biotechnology research and our methodology. The results of our empirical investigation, including the derivation of the implications of our results, the limitations of our research and proposals for future research, are then presented and discussed in Section 4. Section 5 summarizes and concludes this piece and provides suggestions for future activities.

2. Hypotheses

As previously noted, standardization increases interoperability and decreases coordination costs. However, standardization potentially limits variety and requires costly efforts to set up an efficient standardization process. The question arises as to how the tradeoff between the benefits and the costs of standards shift depending on the differentiation between basic research and more applied activities. For the purpose of our research, basic research is defined as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts" and applied research as work that is "undertaken in order to acquire new knowledge directed primarily towards a specific practical aim or objective" (OECD, 2002).

Existing research on standards suggests that formal standards play an increasing role as a source of information when R&D activities are market-oriented (Blind and Gauch, 2009). In line with these findings, Zi and Blind (2015) have shown that researchers involved in formal standardization publish less or in lower ranked journals, whereas scientists focusing on applied research, i.e. publishing less due to confidential collaborations with industry or in more applied journals, are not impacted by this tradeoff.

In spite of the aforementioned arguments, there is also a line of argument in favor of standardization in early research phases. In a related research field, it is established that patenting researchers are more successful in publishing (Agrawal and Henderson, 2002; Van Looy et al., 2006; Czarnitzki et al., 2007, 2009; Stephan et al., 2007). Analogous to the field of patents, standardization activities arguably circulate relevant knowledge and are beneficial for those who seek knowledge relevant to current research challenges. However, in contrast to the positive relationship between publishing and patenting, the incentives for an involvement in standardization might be reduced by the threat of free-riders (Cabral and Salant, 2014).

Therefore, the role of standardization in research is an open empirical question, which we try to answer on the basis of the data available via *BioSharing*. To our knowledge, the only existing qualitative empirical evidence for the important role of different types of standards both for applied and basic researchers in nanotechnology is provided by Blind and Gauch (2009).

The general positive impacts of standards are valid for the production of knowledge, i.e. research, not only in process innovation in the sense of productivity (Acemoglu et al., 2012; Blind and Jungmittag, 2008), but also on product innovation (e.g. Lim and Prakash, 2014). From the general definition of terms, i.e. semantic standards, we can derive that standards mitigate misconceptions in the communication between researchers, especially in joint research projects. Through the unification of methods, e.g. for measurement and testing, scientists can be more productive in subsequent research efforts. Standardized research methods also allow for a more transparent and reliable knowledge generation process. Moreover, researchers save time and effort when relying on common standards. Consequently, the online-platform *BioSharing* has pointed out the need to stop wasteful reinventions in its mission statement. Finally, even interface standards experience more relevance than in the past as research becomes more complex and enters interdisciplinary fields (Gauch and Blind, 2015). In addition to the line of argument about the economic benefits of standards being applied to research productivity, our reasoning relies on the empirical insights provided by Rysman and Simcoe (2008) regarding the selection of SSOs of promising technologies as measured by patent citations, which increase substantially following standardization.

Our first hypothesis draws on two lines of reasoning. On the one hand, we rely on the positive economic impacts – especially of compatibility standards – on network externalities, as theoretically backed by Farrell and Saloner (1985, 1986) and empirically proven by Mahler and Rogers (1999) or Goldenberg et al. (2010), for example. These theoretical and empirical studies show that after the successful enforcement of a standard or a dominant design (Suarez, 2004), the diffusion of the related technologies and products is both accelerated and pushed to a larger number of implementations, customers and consumers. Consequently, we argue that these impacts from standards can be transferred to the diffusion of knowledge within research. On the other hand, previous studies have used patent citations to illustrate the diffusion of knowledge over time (Hall et al., 2005; Metha et al., 2010). In a similar manner, the citation-age profile of scientific articles integrated in standards can be examined, in order to investigate their effect on the production of knowledge over time as with patents as presented by Rysman and Simcoe (2008), which show that the age distribution of SSO patent citations is shifted toward later years (relative to comparable patents). Related to scientific publications, we argue that research integrated in standards diffuses knowledge over a longer period of time compared with similar publications. Combining these lines, we derive our first hypothesis.

Hypothesis 1. *Scientific publications referenced in standards receive more forward citations over a longer period of time than comparable scientific publications.*

Testing the previous hypothesis cannot answer the question of whether the knowledge integrated in standards is beneficial for the progress of research in the long run. The issue of being locked into inferior standards has been addressed in numerous studies e.g. by Arthur (1989), Farrell and Saloner (1985) and in the review article by Farrell and Klemperer (2007). Each of these studies focus on the lock-in of technologies or products, but only a few provide case studies, e.g. about the mobile telephony standard GSM (Cabral and Kretschmer, 2006). However, there are – to our knowledge – no quantitative empirical studies that have measured the difference between inferior and superior technologies. We transfer the differentiation between these two types of technologies to the quality of knowledge integrated into standards and develop a quantitative approach to evaluate the impact of the standards for follow-up research.

Therefore, in our second hypothesis, we examine whether follow-up inventions, which reference knowledge integrated in standards, are more successful than comparable follow-up inventions, which do not consider such knowledge. Here, we reference Sorenson and Fleming (2004), who find that patents referencing scientific publications receive a higher number of forward citations, which is also confirmed for patents in biotechnology (Subramanian and Soh, 2010). They base their argument that publications are an important mechanism for accelerating the rate of technological innovation, i.e. patents that reference published material receive more citations primarily, because their influence diffuses faster in time and space. Within this scope, we argue that scientific publications that are referenced in a standard receive more citations, because the existence of the standard pushes the knowledge diffusion over time. Consequently, we hypothesize that standards facilitate research advancement in a sustainable manner.

Hypothesis 2. *Scientific publications referenced in standards generate more forward citations for their citing articles than those which are not.*

3. Data and descriptive statistics

3.1. Data sources

In our analysis, we focus on an online-platform of biotech standards named *BioSharing*,[2] which originated in the United Kingdom in 2009. In total, 35 members, mainly research institutes, but also the formal German SSO DIN contributes to the platform. *Bio-Sharing* is free of charge. Everybody can register and contribute to the platform, whose mission is to “serve those seeking information on existing standards, but also to […] promote harmonization to stop wasteful reinvention.” Thereby, the platform provides standards, which are as transparent and easily accessible as formal standards, require only short development times similar to company and consortia standards and are flexible in nature.

As of May 2013, *BioSharing* consisted of 518 standards, which are categorized according to standard type. Ninety-five standards are linked to 98 scientific publications, which allows for an in-depth analysis of the relationship between research and standardization. The publications relate to 56 different biotechnology journals in the time period between 1996 and 2013.

Within the *BioSharing* platform, standards are classified according to “terminology artifact”, “reporting guidelines” and “exchange format”. In combination with keywords, such as “ontology” for semantic standards, “minimum information” for measurement and testing standards and “File XXX” for interface standards, an accurate matching with regard to the content of the standards can be ensured. Overall, 64.5% of the standards in *BioSharing* refer to semantic standards, 11.6% of the standards deal with measurement and testing standards and 24.9% of the standards define interface standards. With biotechnology being a rather new scientific discipline, it is unsurprising that the majority of standards address terminology issues. Furthermore, the development of *high-throughput-screening* and *next-generation-sequencing* have increased the need for interface standards dealing with large and complex databases.

3.2. Methodology

To measure the general characteristics of knowledge integrated in standards, we compare the arithmetic mean of the impact factors of journals which publish articles referenced in standards to the arithmetic mean of journals in biotechnology. For the latter, ‘Journal Citation Reports’ by *Thomson Reuters* provides a peer group of biotechnology journals. Thereby, we assume that journals focusing on basic research have higher impact factors than journals which relate to more applied focused research (Garfield, 1972, 2006). This reasoning stems from the definition of the impact factor that it resembles the ‘significance’ of a journal for future research efforts. For the purpose of our analysis, we use the most prevalent two-year journal impact factor. The additional information of the scientific impact of journals, which publish articles referenced in standards, is an explicit difference and advantage of our approach in relation to the methodology applied by Rysman and Simcoe (2008).

With regard to the test of our two hypotheses, we use scientific publications as defined units of knowledge. Thereby, we differentiate between articles linked to standards, i.e. included in the list of references

---

[2] See McQuilton et al. (2016) for further information about BioSharing.

Table 1
Characteristics of dependent variables.

Variable	Definition	Source
Journal	Name of the publishing journal	Science Citation Index (SCI)
Impact factor	Two-year impact factor of publishing journal	Journal Citation Reports
Forward citations_{jt}	Number of forward citations to article j in year t	SCI
Cumulative citations_{jt}	Number of forward citations from publication date to year t	SCI
Average forward citations_{j1}	Average forward citations_{j1} to articles in the same journal with t = 1	Journal Citation Reports

and most-related articles. Most-related articles are matched to the articles referenced in standards using the following protocol: first, each publication linked to a standard in *BioSharing* is matched to the 'most-related' article in the same volume of the same journal using a search algorithm developed[3] by the National Library of Medicine (NLM) in order to constitute a meaningful comparison sample; second, the NLM algorithm generates similarity rankings between documents in the *PubMed* database and is an established user interface on the *PubMed* website. The same methodology has also been used by Furman and Stern (2011) for a similar matching exercise. As a robustness check, an alternative comparison sample is constituted on the basis of the 'most-related' article without taking the volume and the journal into account.

For the second hypothesis, the amount of follow-up research is operationalized by the number of forward citations. To account for the different time horizons dependent on the publication year, we account for the number of annual forward citations.

In order to examine the second hypothesis, we choose the first forward citation to each article referenced in standards and constitute a comparison sample in the same manner as for articles referenced in standards. This means, the same matching procedure as described above is conducted for the first forward citation of each article referenced in a standard. Once again, the matched sample is compared on the basis of forward citations as an approximation of follow-up research. This analysis also uses an alternative comparison sample that disregards identical volumes and journals, as a robustness check.

Either forward citations in the first year after publication, forward citations in year t, or cumulative forward citations since publication serve as dependent variables for our analysis (Garfield, 1979). Table 1 provides an overview of the available information for the dependent variables.

With regard to the independent variables, we introduce a dummy variable 'article referenced in a standard', which differentiates between articles related to standards and the comparison group. In a more sophisticated model, we further differentiate between the three different types of standards. The publication title and author names are used as identifiers across the different databases. We extend the model stepwise by controlling for the age of the publication, the number of authors, whether the first author is from a top 50 university and whether the article is published in a top journal (see definition in Table 2). Random tests of author origin confirm the argument that most publications are based on research collaborations between different universities. Table 2 provides an overview of the available information for the independent variables.

3.3. Summary statistics

Our standards data consists of 95 standards linked to 98 articles on the *BioSharing* platform. For the first hypothesis, the data processing results in 196 articles, i.e. 50% of the articles relate to standards and 50% relate to the comparison group (Table 3). The mean average for publication year is 2008 and approximately 11 authors contribute to each article. The forward citations are collected for each year after the publication. Therefore, a sample of 1160 data points results, with a mean of 13.23 forward citations per article per year. On a cumulative basis, each article receives on average 78.33 forward citations. 35% of the articles are published in top journals and 30% of the authors originate from a top university.

One particular characteristic of the forward citations is the skewed distribution. Forward citations are count data, i.e. greater or equal to zero. Very few articles receive hundreds of citations annually with most being cited five times or less per year.

An investigation of the descriptive statistics differentiated by the comparison group provides a good overview of the empirical findings (Table 4). On average, articles referencing standards are cited three times more often than the most-related articles on a yearly basis, as well as on a cumulative basis. Noticeably, there are also three times more authors per publication involved with articles referenced in standards in comparison to the most-related articles. The difference in forward citations, depending on author number, might be due to the fact that more authors also lead to more self-citations. An alternative explanation might be that having more authors increases the quality of a paper and higher quality eventually leads to more forward citations. In our analysis, we cannot disentangle these two possible explanations, but with respect to our analysis, it is only important that we control for both possible explanations. Thirty-six percent of the articles referenced in standards, as opposed to 24% of the comparison articles, originate from a top 50 university.

As previously done for patents (Metha et al., 2010), the citation age profile for standards illustrates the diffusion of standards with respect to comparison articles over time (Fig. 1). In general, articles referenced in standards are cited more often than comparison articles. Noteworthy, these articles seem to pursue a different time trend than the comparison articles. In the first two years, forward citations to both groups rise, while articles referenced in standards receive more forward citations. However, in the second year after publication, the most-related articles reach a maximum and subsequently decline. In contrast, articles referenced in standards reach their maximum in the third year after publication and continue to stay at a relative high level, although we have to point out that after six years the confidence interval dramatically increases due to the lack of available data. Only 25% of the articles are older than six years. The intervals around the median show the 90% confidence intervals and are constructed according to Conover (1980). This observation supports our presumption of the second hypothesis. Within our regression model we will address this issue by introducing an interaction term constructed from a multiplication of the standard variable with the age variable.

An overview of the type of standards shows that the different content of the standards is not proportionally linked to articles within the online-platform (Fig. 2). As of July 2013, the online platform contains 329 semantic standards, 60 measurement and testing standards and 129 interface standards. While the majority of standards in *BioSharing* consist of semantic standards, only few semantic standards are linked to publications in journals, i.e. only 6.1% of the semantic standards. The opposite holds true for measurement and testing standards, i.e. 73.3% of the measurement and testing standards are linked to publications in journals. Therefore, even within the standards in *BioSharing*, different types of standards might diffuse differently or have diverse relevance in the field of biotechnology.

While the aforementioned descriptive statistics have focused on the data with regard to articles referenced in standards, in the following we will provide the descriptive statistics with regard to articles referencing the former articles. Our data of articles referencing scientific publications referenced in standards consists of 93 papers and 93 comparison articles (Table 5). The number of articles differs from the original sample of 98 articles referenced in standards, because five articles had not yet received a

---

[3] If the search algorithm does not provide a most-related article in the same volume of the same journal, the preceding article in the same volume of the same journal is used as an alternative most-related article.

Table 2
Characteristics of independent variables.

Variable	Definition	Source
Article referenced in a standard	Dummy variable equal to 1 if article is referenced in a standard and equal to 0 if article belongs to the comparison group	BioSharing/PubMed
Type of standard	Dummy variables equal to 1 for *semantic standards*, *measurement and testing standards*, as well as *interface standards* respectively and equal to 0 otherwise	BioSharing
Article title	Name of article used as identifier	BioSharing/PubMed/SCI
Names of authors	Names of publishing authors used as identifier	SCI
Number of authors	Number of publishing authors	SCI
Country of origin	Location of lead author of the publication	SCI
Top 50 university	Dummy variable equal to 1 if corresponding author is associated with a top 50 university according to the Times Higher Education ranking - Life Sciences 2013	Times Higher Education & Thomson Reuters
Top journal	Dummy variable equal to 1 if the publishing journal belongs to the top 10% in the field, i.e. has an impact factor >8	Journal Citation Reports
Publication year	Year in which article j is published	SCI
Age	Year t − article publication year	SCI

first forward citation. Overall, these articles result in a total of 1052 data points with forward citations. Given that the articles are the first forward citations of the articles referenced in standards, their average publication year is slightly more recent. On average, these articles are produced by fewer authors than the articles referenced in standards, i.e. 7 authors per publication compared to 11 authors, respectively. Furthermore, they are less frequently published in top journals, i.e. 24% compared to 35% and they less frequently originate from a top university, i.e. 20% compared to 31%. The same observation holds true with regard to the forward citations of the articles referencing articles linked to standards in relation to their comparison articles. On average they receive 7.86 forward citations per year opposed to 13.23 forward citations and they receive 44.47 cumulative forward citations opposed to 78.33 forward citations.

When we differentiate between the means of the articles referencing publications included in standards and their comparison group, the difference is much less prevalent than for the latter, but a small increase in favor of articles referencing scientific publications integrated in standards can still be observed (Table 5). Again, more authors have produced the articles referencing papers referenced in standards, which we have to control for within the regression analysis. Twenty-two percent of the articles referencing scientific publications mentioned in standards originate from top universities, while only 18% of the comparison articles originate from a top university.

The citation age profile supports the presumption that articles referencing the scientific publications integrated in standards are cited more often than the respective comparison articles (Fig. 3). However, in contrast to articles referenced in standards, both groups reveal a similar pattern over time: an increase in the first two years, a maximum between the second and the fourth year and a subsequent decline. Therefore, in view of the second hypothesis, we argue that both groups are similar articles, but articles referencing articles integrated in standards are more successful in terms of forward citations.

Table 3
Means and standard deviations for articles referenced in standards and their most-related articles.

Variable	Mean	SD	Min	Max
Article characteristics (number of articles = 196)				
Article$_j$ referenced in a standard	0.50	0.50	0	1
Publication year	2008.01	3.17	1996	2013
Authors	10.76	13.92	1	98
Top journal	0.35	0.48	0	1
Top university	0.30	0.46	0	1
Citation characteristics (number of citations = 1160)				
Forward citations$_{jt}$	13.23	41.28	0	682
Cumulative citations$_j$	78.33	224.60	0	1962
Age	4.99	3.17	0	17

4. Empirical analysis

4.1. Standardization in research-oriented environments

For the purpose of the first hypothesis, we examine the environments in which standards of *BioSharing* are used. We look into the type of journals that relate to *BioSharing* standards, because the type of journal serves as a reference to the audience.

We find that standards in our database are linked to journals with an aggregated two-year impact factor of 10.07 (median impact factor: 5.32). In comparison, a control group of biotech journals reported by the 'Journal Citation Reports' (JCR) shows an aggregated two-year impact factor of 3.78 (median impact factor: 2.47). Given the 95% confidence intervals, we can conclude that scientific publications referenced in standards are more likely to be published in biotechnology journals with higher impact factors (Table 5). Assuming that higher impact factors relate to basic research (Garfield, 1972, 2006), we retain that the standards of *BioSharing* are mostly used in early-stage research activities.

4.2. Research results integrated in standards

4.2.1. Paired t-test

In order to investigate the role of knowledge referenced in standards within research, we examine publications linked to articles referenced in standards in comparison to their peer group in the same journal and volume. In the first step, we compare forward citations in the first year after publication of articles mentioned in standards with the average forward citations to articles in the same journal. A paired *t*-test shows at the 1% significance level that articles referenced in a *BioSharing* standard receive, on average, 1.5 times more forward citations in the first year than articles in the same journal. Since the articles referenced in standards are also included in the average forward citations to the journal and we only consider the first year after publication, this test can be regarded as a conservative test. In the second step, we expand the paired *t*-test by comparing cumulative forward citations of articles referenced in standards with most-related articles published in the same journal in the

Table 4
Means and standard deviations of characteristics of papers referenced in standards and most-related articles.

	Articles referenced in standards: articles associated with BioSharing	Comparison articles: most-related articles
Number of papers	98	98
Forward citations	19.45 (53.69)	6.99 (21.13)
Cumulative citations	115.33 (292.12)	41.33 (115.36)
Authors	16.09 (17.56)	5.43 (4.72)
Publication year	2008.01 (3.17)	2008.01 (3.17)
Top university	0.36 (0.48)	0.24 (0.43)

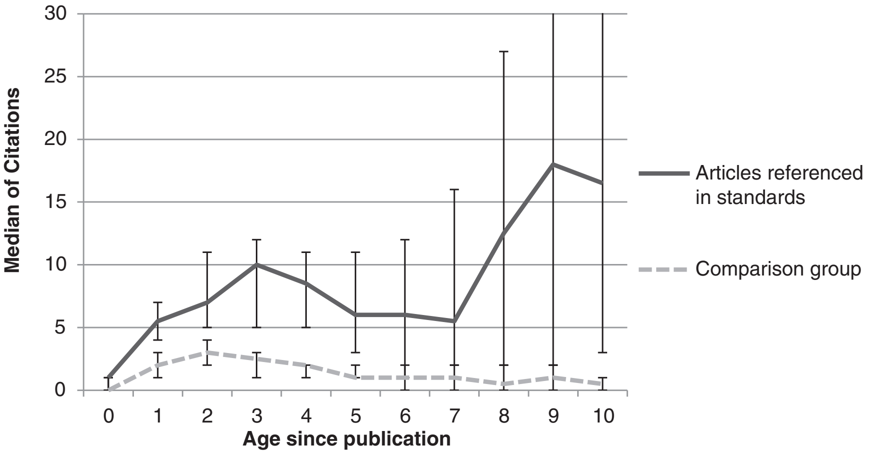

Fig. 1. Citation age profile for articles referenced in standards.

same volume. At the 1% significance level, the paired *t*-test reveals that these articles receive, on average, 2.8 times more forward citations than the comparison group over the entire lifetime of a publication. As the paired *t*-test relies on a normal distribution, we have to review the robustness of our results. Therefore, we use a Wilcoxon signed rank sum test as a non-parametric robustness check (Hollander and Wolfe, 1973). The Wilcoxon test for the difference in means without any assumption about the distribution remains significant at the 5% significance level supporting our second hypothesis.

4.2.2. Model of multivariate analysis

A paired *t*-test is limited to a comparison of two variables. A multivariate linear regression would consider different variables, but also relies on the assumption of normal distribution. Although one can argue that normal distribution is a reasonable assumption for cumulative forward citations, Fig. 3 in the previous section clearly demonstrates that the assumption does not hold true for forward citations on a yearly basis. Therefore, we cannot use an ordinary least square regression model, but have to account for the characteristics of count data by applying a Poisson model or a negative binomial model for further analyses. Since we are confronted with over-dispersed count data, i.e. the conditional variance is larger than the conditional mean, we have chosen a negative binomial model over a Poisson model analogous to Furman and Stern (2011). However, all reported results also hold true in a Poisson model at the same level of significance or even higher.

Our baseline model identifies the effect of an article related to a standard on yearly forward citations. Furthermore, we have already reported in Fig. 1 that, at least in the first years after publication, citations rise over time. Therefore, we also include the age of the publication in the model. In addition, the summary statistics have shown that, on average, more authors are involved in articles referenced in standards than in most-related articles. This is unsurprising, as standards require a level of consensus, which is more likely to be achieved if many authors are involved in the development process. However, researchers are also more likely to cite their own publications in future research than random articles and publications with more authors might be of higher quality. Therefore, we have to separate the effect of standardization from the number of authors. We cannot control whether more authors are more likely to self-cite their articles or whether more authors produce articles with higher quality, but this does not change the results of our analysis. Furthermore, we include the origin from a top university through a binary control variable. In conclusion, the baseline model estimates the number of forward citations article j receives in year t after publication controlling for the age, the number of authors and the origin from a top university:

$$\text{Forward citations}_{jt} = f\,(\Phi\text{article referenced in standard}_j + \beta\text{age}_t + \psi\text{authors}_j + \delta\text{top university}_j) \quad (1)$$

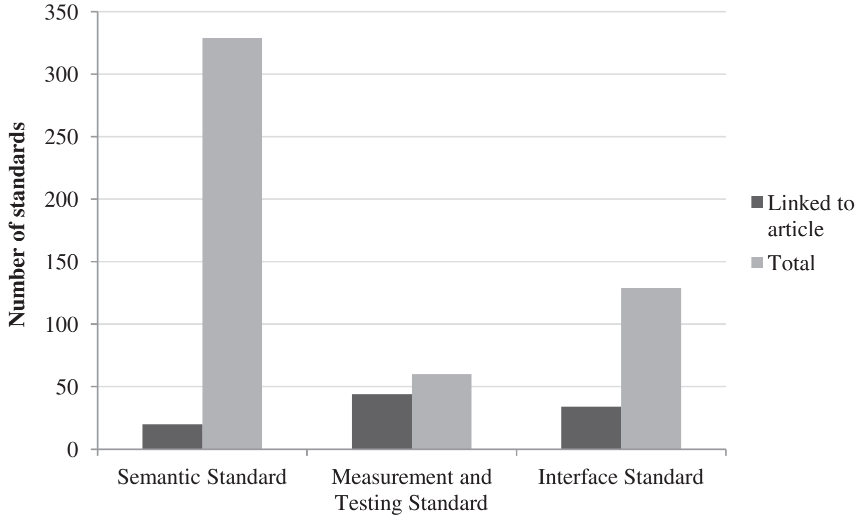

Fig. 2. Type of standards.

Table 5
Means and standard deviations of characteristics of papers referencing articles integrated in standards and most-related articles.

Characteristics of articles referenced in standards and their comparison group (n = 186)	Mean	SD	Min	Max
Article referenced in a standard$_j$	0.50	0.50	0	1
Publication year	2008.32	2.98	1998	2013
Authors	7.12	7.36	1	40
Top journal	0.24	0.43	0	1
Top university	0.20	0.40	0	1
Citation characteristics (n = 1052)				
Forward citations$_{jt}$	7.86	22.92	0	417
Cumulative citations$_j$	44.47	111.10	0	1043
Age	4.68	2.98	0	15

Means and standard deviations	First forward citation of an article referenced in a standard (n = 93)	Comparison articles: most-related articled (n = 93)
Forward citations	8.54 (17.48)	7.18 (27.31)
Cumulative citations	48.39 (100.56)	40.55 (121.14)
Authors	8.45 (8.49)	5.78 (5.73)
Publication year	2008.32 (2.98)	2008.32 (2.98)
Top university	0.23 (0.42)	0.18 (0.39)

Mean and median of the impact factor by biotechnology journals	Journals publishing articles referenced in BioSharing standards	Peer group of biotech journals according To JCR
Arithmetic mean	10.07	3.78
Confidence interval to the mean (95% significance level)	7.95–12.20	–
Median	5.32	2.47
Confidence interval to the median (95% significance level)	4.20–6.53	–

As an extension of the baseline model, we account for conditional fixed effects over time. Namely, dummy variables are included for each article pair. This provision accounts for the fact that the sample is a paired sample, rather than an independent sample (Hausman et al., 1984; Allison and Waterman, 2002). Furthermore, we include an interaction effect constructed from the age and the reference to an article integrated in a standard in order to address the second hypothesis, which has already been supported by the descriptive statistics.

The extended model is further refined by investigating the type of standards important to research activities. Instead of relying on a dummy variable for the article referenced in standards, we introduce three new dummy variables for each type of standard, i.e. semantic standards, measurement and testing standards and interface standards.

The same procedure as elaborated above is used to test the second hypothesis. In contrast to the previous model, we do not use the articles referenced in standards as unit of analysis, but rather the first article citing a scientific publication referenced in a standard.

4.2.3. Results of multivariate analysis

The first column of Table 6 reports the results for the baseline model. A significant positive coefficient implies a positive relation between the independent variables and forward citations. A positive coefficient translates into an incidence-rate ratio >1, while a negative coefficient translates into an incidence-rate ratio <1. The interpretation of the incidence-rate ratio is as follows: articles referenced in standards receive on average 2.1 times more forward citations than most-related articles. Thereby, we confirm our first hypothesis that articles referenced in standards lead to more follow-up research in terms of forward citations compared to scientific publications not referenced in standards.

As expected, the age of the publication is also positively linked to forward citations. On average, one additional year post-publication accounts for approximately 11% more forward citations. Furthermore, the number of authors has a statistically significant influence on the number of forward citations, at the 1% significance level. One additional author leads to an increase in forward citations of approximately 2%. However, the disproportionately high numbers of authors of articles referenced in standards are not accountable for the overall standardization effect. Publications from the top universities are cited 54% more frequently than from all other universities. The pseudo R^2 value shows that the baseline model overall has only limited explanatory power.

Most interestingly, the second column of Table 6 reports for the second model that the effect of age vanishes and the effect of the standard per se mostly disappears. Instead, the interaction effect between standard and age is highly significant. The incidence-rate ratio for the interaction effect is 1.176. This means that under the condition of being referenced in a standard, an article receives on average 18% more

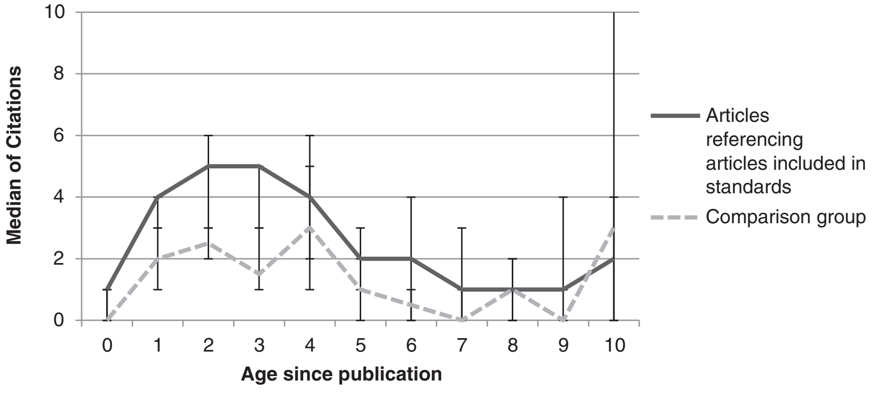

Fig. 3. Citation age profile for articles referencing articles included in standards.

Table 6
Negative binomial model based on articles referenced in BioSharing standards.

	Negative binomial model [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (1) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (2) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)
Article referenced in a standard	[2.100]	[1.271]	
	0.742^{***}	0.240^{*}	
	(0.106)	(0.127)	
Interaction (standard $*$ age)		[1.176]	[1.163]
		0.162^{***}	0.151^{***}
		(0.029)	(0.029)
Semantic standard			[0.797]
			−0.226
			(0.191)
Measurement and testing standard			[1.125]
			0.118
			(0.152)
Interface standard			[2.320]
			0.841^{***}
			(0.169)
Age	[1.110]	[0.968]	[0.974]
	0.105^{***}	−0.032	−0.026
	(0.023)	(0.023)	(0.028)
Authors	[1.017]	[1.027]	[1.024]
	0.017^{***}	0.026^{***}	0.023^{***}
	(0.005)	(0.004)	(0.004)
Top university	[1.542]	[1.727]	[1.655]
	0.433^{***}	0.546^{***}	0.504^{***}
	(0.109)	(0.136)	(0.136)
Number of article pairs		98	98
Constant	1.369^{***}	0.343	0.544^{**}
	(0.108)	(0.334)	(0.331)
Observations	1160	1160	1160
Pseudo R²	0.020	0.174	0.178
Log likelihood	−3629.23	−3057.62	−3042.87
Test of alpha = 0	2.870^{***}	0.871^{***}	0.839^{***}
	(0.123)	(0.050)	(0.049)

*** Significance at the 1% level.
** Significance at the 5% level.
* Significance at the 10% level.

forward citations per year. The control variables 'number of authors' and 'origin from a top university' remain significant. The effect sizes of the control variables further increase in the second model. In contrast to the first model, the intersection with the y-axis is no longer significant, but the explanatory power of the extended model has increased up to 17.4%. Therefore, the second model supports the second hypothesis, i.e. the knowledge of articles referenced in standards diffuse over a longer time period compared to regular research articles.

The most sophisticated model reported in the third column of Table 6 illustrates the diverse relevance of different types of standards. Only interface standards are significantly correlated at the 1% level and receive 2.3 times more forward citations than the most-related articles. Therefore, interface standards are most valuable to future research in terms of forward citations. Measurement and testing standards, as well as semantic standards, are not significantly correlated to forward citations.

Overall, the alpha test for all three model specifications is significant at the 1% level. Thus, the over-dispersion of the data is confirmed and the application of a negative binomial model is reinforced. The likelihood ratio test (F test) tells us that all three models fit significantly better than an empty model.

The first column of Table 7 shows that the difference between articles referencing scientific publications integrated in standards and their closest peer group is too small to observe significant results, when we pretend to deal with an independent sample. When accounting for the conditional fixed effects, articles referencing the papers linked to standards are cited, on average, 1.3 times more often than comparable articles. The effect size of the variable indicating a reference to an article integrated in a standard is higher and more significant than the interaction term. Therefore, articles referencing papers in standards have a similar citation pattern over time compared to their most-related articles, while being more successful in terms of forward citations. This result supports the impression from the descriptive statistics (Fig. 3) and allows us to confirm the second hypothesis, i.e. references to scientific publications in standards increase the productivity of research efforts.

In line with the third model of the articles referenced in standards, the third column of Table 7 shows that articles referencing interface standards profit the most from the positive effect of referencing articles included in standards. Furthermore, it is confirmed that, in contrast to the articles referenced in standards, the interaction term is not significant, i.e. articles referencing standards as well as the comparison group have a similar citation age profile.

Analogous to Table 6, the alpha test confirms the over-dispersion of the data and a likelihood ratio test confirms that all three models fit significantly better than an empty model. As a robustness check, we conducted the same analysis with a different matching process for the comparison group. Instead of limiting the most-related article to the same journal issue, we used the most-related article provided by the NLM search algorithm independent of the publishing journal. In order to control for the variance due to different journals, we included whether the article was published in a top journal as an additional control variable. Overall, the results hold true and are provided in the Tables A.1 and A.2 for articles referenced in standards and publications referencing the former articles, respectively. One exception is the effect of interface standards on referencing articles which is not significant in the robustness check (Table A.2).

In an additional robustness test, we controlled for a potential cohort effect due to the publication year of the articles (Table A.3). Therefore, the sample is divided into quartiles which relate to publication years before

Table 7
Negative binomial model based on articles referencing scientific publications linked to standards.

	Negative binomial model [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (1) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (2) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)
Article referenced in a standard	[0.883] −0.124 (0.107)	[1.295] 0.259** (0.125)	
Interaction (standard * age)		[1.055] 0.053* (0.031)	[1.050] 0.049 (0.030)
Semantic standard			[1.277] 0.245 (0.205)
Measurement and testing standard			[0.906] −0.099 (0.146)
Interface standard			[2.277] 0.823*** (0.167)
Age	[1.036] 0.036 (0.025)	[0.959] −0.042* (0.024)	[0.959] −0.042* (0.024)*
Authors	[1.036] 0.073*** (0.009)	[1.047] 0.046*** (0.010)	[1.035] 0.034*** (0.010)
Top university	[0.700] −0.357*** (0.129)	[1.664] 0.509*** (0.153)	[1.750] 0.559*** (0.149)
Number of article pairs		93	93
Constant	1.458*** (0.113)	1.595*** (0.303)	1.860*** (0.302)
Observations	1052	1052	1052
Pseudo R^2	0.016	0.165	0.169
Log likelihood	−2918.62	−2478.00	−2464.30
Test of alpha = 0	2.699*** (0.130)	0.852*** (0.056)	0.839*** (0.049)

*** Significance at the 1% level.
** Significance at the 5% level.
* Significance at the 10% level.

2007, between 2007–2009, 2009–2011 and 2011–2013. However, the results of our analysis are not influenced by a potential cohort effect.

5. Discussion

5.1. Conclusions

Our empirical results confirm the argument of our first hypothesis, i.e. articles referenced in standards are cited more often than their peer group. Furthermore, the development of follow-up research over time has revealed that articles referenced in standards follow a different diffusion path than comparable articles. While the lifecycle of scientific articles is approximately five years with the mode being two years old, articles referenced in standards experience a longer lasting increase of follow-up research and do not show a definite decline after their peak citation year. Consequently, the lifecycle of scientific publications referenced in standards is longer than for comparable papers.

Consequently, we are able to confirm the results by Rysman and Simcoe (2008) on standard-essential patents in information and communication technologies and the impact of a biological resource center on future research proved by Furman and Stern (2011) for scientific publications referenced in standards in the area of biotechnology. In addition, the positive impact of scientific references in patents on their diffusion in general (Sorenson and Fleming, 2004) and biotechnology patents in particular (Subramanian and Soh, 2010) can be confirmed for the link between scientific publications references in standards and their diffusion. With regard to standards content, we are able to demonstrate that interface standards are most important for the research process in biotechnology. This finding underlines the necessity of standardization, especially in dispersed and interdisciplinary research fields, such as biotechnology. However, these findings are most likely transferable to similar fields, such as nanotechnology, medical engineering or neurosciences, where different disciplines have to be integrated.

Overall, these findings enhance the understanding of the interplay between standardization and research. The empirical results emphasize the importance of integrating scientific publications in standards for research advancement.

5.2. Limitations and further research

The main rationale for this quantitative study is an empirical characterization of the complex relation between research and standardization. While our study investigates the issue on the basis of research articles as a unit of analysis, the investigation can still be expanded to the individual level of researchers, where authors serve as a unit of analysis and network analysis might be applied. Although some of the findings already enhance the understanding of the conceptual mechanisms, detailed qualitative studies are still needed to investigate incentives, personal characteristics and systemic drivers for standardization in research. Our studies have not yet investigated the concrete implications of referencing scientific publications mentioned in standards for the transfer of R&D results. While we differentiate between different types of standards, the quantitative effects on technology transfer still need to be investigated.

The focus of our study on the biotechnology industry allows us an in-depth analysis of the research questions without any confusion from different industry backgrounds. As a shortcoming of such a specific data sample, generalizability of the results might be questionable. However, standardization in fields related to biological sciences requires flexible, easily accessible and quickly-developed standards, due to a rapidly changing technology basis and multidisciplinary challenges. We assume that many other high-technology industries have to comply with these requirements and our results can be transferred to other industries.

Further potential limitations of our study arise with regard to our data sample. First of all, approximately 20% of the standards in the *BioSharing* database are linked to research articles while - potentially due to a bias - 80% of the standards are not linked to a particular publication. The data sample does not contain an announcement date of the standards within the *BioSharing* database. Therefore, we cannot ascertain whether the inclusion in the online-platform has a significant effect on the citation profile as Rysman and Simcoe (2008) could show for patents.

5.3. Implications

Our research findings have various implications for future research, SSOs and policy makers. With regard to future research, we have to expand the bilateral analyses of the relationships between patenting and publishing and patenting and standardization to conduct a comprehensive investigation of the triangle of publishing, patenting and standardization that accounts for the particularities of scientific disciplines, technologies and institutional contexts. Furthermore, our findings provide new insights where standardization can facilitate progress in research. We establish the knowledge sourcing benefits of standardization, which enhance our understanding of knowledge bases included in standards and contribute to the literature of knowledge management.

Based on our findings, research organizations and companies should consider a more integrated and coordinated approach of their publication, patenting and standardization strategies, as already partly realized by patenting companies active in standardization in the field of mobile communication, in order to foster both the private and social impact of their research. Policy makers can optimize their sponsorships for research in order to overcome market failures, especially with regard to the performance of basic research and the diffusion of its results. Thus, given the benefits of integrating scientific publications in standards, policy makers should also emphasize standardization aspects in research funding and dissemination, like meanwhile initiated within the European Research Program Horizon 2020 (European Commission, 2011). Last but not least, SSOs have to adjust the focus of their standardization efforts to address more explicitly the research community in order to engage in early research and innovation stages of science and technology lifecycles.

Acknowledgements

Michael Raven received a PhD grant from the Berlin Doctoral Program in Economics and Management Science (BDPEMS).

Appendix A

Table A.1
Negative binomial model based on articles referenced in standards (comparison group not limited to same journal).

	Negative binomial model [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (1) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (2) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)
Article referenced in a standard	[1.228] 0.206^{*} (0.112)	[0.945] −0.057 (0.121)	
Interaction (standard ∗ age)		[1.156] 0.145^{***} (0.028)	[1.159] 0.148^{***} (0.027)
Semantic standard			[0.622] -0.474^{**} (0.202)
Measurement and testing standard			[0.859] −0.153 (0.152)
Interface standard			[1.404] 0.339^{**} (0.161)
Age	[1.075] 0.072^{***} (0.025)	[0.981] −0.019 (0.021)	[0.976] −0.024 (0.021)
Authors	[1.003] 0.003 (0.004)	[1.031] 0.031^{***} (0.005)	[1.029] 0.028^{***} (0.005)
Top university	[1.563] 0.446^{***} (0.112)	[0.989] −0.011 (0.133)	[0.979] −0.022 (0.133)
Top journal	[2.834] 1.042^{***} (0.129)	[3.410] 1.227^{***} (0.153)	[3.483] 1.248^{***} (0.151)
Number of article pairs		98	98
Constant	1.805^{***} (0.112)	0.871^{**} (0.401)	1.057^{***} (0.403)
Observations	1183	1183	1183
Pseudo R²	0.016	0.184	0.186
Log likelihood	−3810.09	−3159.85	−3152.43
Test of alpha = 0	3.018^{***} (0.125)	0.810^{***} (0.047)	0.796^{***} (0.046)

*** Significance at the 1% level.
** Significance at the 5% level.
* Significance at the 10% level.

Table A.2
Negative binomial model based on articles referencing scientific publications referenced in standards (comparison group not limited to same journal).

	Negative binomial model [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (1) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (2) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)
Article referenced in a standard	[0.766]	[1.284]	
	−0.266**	0.250**	
	(0.106)	(0.120)	
Interaction (standard * age)		[0.973]	[0.967]
		−0.028	−0.033
		(0.029)	(0.029)
Semantic standard			[0.869]
			−0.141
			(0.195)
Measurement and testing standard			[1.713]
			0.538***
			(0.156)
Interface standard			[1.201]
			0.183
			(0.155)
Age	[1.090]	[1.032]	[1.037]
	0.086***	0.031	0.036*
	(0.023)	(0.021)	(0.021)
Authors	[1.047]	[1.077]	[1.075]
	0.046***	0.074***	0.072***
	(0.008)	(0.010)	(0.010)
Top university	[1.989]	[0.876]	[0.806]
	0.688***	−0.132	−0.216
	(0.123)	(0.164)	(0.172)
Top journal	[1.765]	[2.110]	[1.959]
	0.568***	0.747***	0.673***
	(0.137)	(0.163)	(0.162)
Number of article pairs		93	93
Constant	1.236***	1.576***	1.339***
	(0.120)	(0.357)	(0.365)
Observations	1098	1098	1098
Pseudo R^2	0.023	0.171	0.173
Log likelihood	−3135.70	−2659.07	−2653.95
Test of alpha = 0	2.603***	0.815***	0.839***
	(0.122)	(0.052)	(0.049)

*** Significance at the 1% level.
** Significance at the 5% level.
* Significance at the 10% level.

Table A.3
Negative binomial model based articles referenced in standards (controlling for cohort effects).

	Negative binomial model [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (1) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (2) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)
Article referenced in a standard	[1.728]	[1.271]	
	0.547***	0.240*	
	(0.110)	(0.127)	
Interaction (standard * age)		[1.176]	[1.163]
		0.162***	0.151***
		(0.029)	(0.029)
Semantic standard			[0.797]
			−0.226
			(0.191)
Measurement and testing standard			[1.125]
			0.118
			(0.152)
Interface standard			[2.320]
			0.841***
			(0.169)
Age	[1.151]	[0.968]	[0.974]
	0.141***	−0.032	−0.026
	(0.024)	(0.023)	(0.028)
Authors	[1.027]	[1.027]	[1.024]
	0.026***	0.026***	0.023
	(0.005)	(0.004)	(0.004)***

(continued on next page)

Table A.3 (*continued*)

	Negative binomial model [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (1) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)	Negative binomial model with conditional fixed effects (2) [Incidence-rate ratios in brackets in top line] Estimated coefficients in 2nd line (SE in parentheses in bottom line)
Top university	[1.404]	[1.727]	[1.655]
	0.339^{***}	0.546^{***}	0.504^{***}
	(0.110)	(0.136)	(0.136)
2007–2009	[1.19]	[0.373]	[0.454]
	0.433	-0.986^{**}	-0.790^{*}
	(0.109)	(0.410)	(0.403)
2009–2011	[2.753]	[0.600]	[0.474]
	0.433^{***}	-0.510	-0.746
	(0.109)	(0.463)	(0.465)
2011–2013	[0.635]	[0.169]	[0.110]
	0.433^{**}	-1.780^{*}	-2.203^{**}
	(0.109)	(1.005)	(1.017)
Number of article pairs		98	98
Constant	0.991^{***}	1.329^{***}	1.334
	(0.141)	(0.261)	$(0.258)^{***}$
Observations	1160	1160	1160
Pseudo R^2	0.029	0.174	0.178
Log likelihood	-3594.06	-3057.62	-3042.87
Test of alpha = 0	2.693^{***}	0.871^{***}	0.839^{***}
	(0.117)	(0.050)	(0.049)

*** Significance at the 1% level.

** Significance at the 5% level.

* Significance at the 10% level.

References

Acemoglu, D., Gancia, G., Zilibotti, F., 2012. Competing engines of growth: innovation and standardization. J. Econ. Theory 147, 570–601.

Agrawal, A., Henderson, R., 2002. Putting patents in context: exploring knowledge transfer from MIT. Manag. Sci. 48, 44–60.

Allen, R.H., Sriram, R.D., 2000. The role of standards in innovation. Technol. Forecast. Soc. Chang. 64, 171–181.

Allison, P.D., Waterman, R.P., 2002. Fixed–effects negative binomial regression models. Sociol. Methodol. 32, 247–265.

Almeida, J.S., Chen, C., Gorlitsky, R., Stanislaus, R., Aires-de-Sousa, M., Eleuterio, P., Carrico, J., Maretzek, A., Bohn, A., Chang, A., Zhang, F., Mitra, R., Mills, G.B., Wang, X., Deus, H.F., 2006. Data integration gets "sloppy.". Nat. Biotechnol. 24, 1070–1071.

Arthur, W.B., 1989. Competing technologies, increasing returns and lock-in by historical events. Econ. J. 99, 116–131.

Baldwin, C.Y., Clark, K.B., 2000. Design Rules: The Power of Modularity. MIT Press.

Besen, S., Farrell, J., 1994. Choosing how to compete - strategies and tactics in standardization. J. Econ. Perspect. 8, 117–131.

Blind, K., 2004. The Economics of Standards: Theory, Evidence, Policy. Edward Elgar, Cheltenham.

Blind, K., Gauch, S., 2008. Trends in ICT standards: the relationship between European standardisation bodies and standards consortia. Telecommun. Policy 32, 503–513.

Blind, K., Gauch, S., 2009. Research and standardisation in nanotechnology: evidence from Germany. J. Technol. Transf. 34, 320–342.

Blind, K., Jungmittag, A., 2008. The impact of standards and patents on macroeconomic growth: a panel approach covering four countries and twelve sectors. J. Prod. Anal. 51–60.

Bozeman, B., 2000. Technology transfer and public policy: a review of research and theory. Res. Policy 29, 627–655.

Büthe, T., Mattli, W., 2011. New Global Rulers: The Privatization of Regulation in the World Economy. Princeton University Press, Princeton.

Cabral, L., Kretschmer, T., 2006. Standards battles and public policy. In: Greenstein, S., Stango, V. (Eds.), Standards and Public Policy. Cambridge University Press, pp. 329–344.

Cabral, L., Salant, D., 2014. Evolving technologies and standards regulation. Int. J. Ind. Organ. 36, 48–56.

Conover, W.J., 1980. Practical Nonparametric Statistics. 2nd ed. John Wiley and Sons, New York.

Czarnitzki, D., Glänzel, W., Hussinger, K., 2007. Patent and publication activities of German professors: an empirical assessment of their co-activity. Res. Eval. 16, 311–319.

Czarnitzki, D., Glänzel, W., Hussinger, K., 2009. Heterogeneity of patenting activity and its implications for scientific research. Res. Policy 38, 26–34.

Delcamp, H., Leiponen, A., 2014. Innovating standards through informal consortia: the case of wireless telecommunications. Int. J. Ind. Organ. 36, 36–47.

ECSIP, 2014. Patents and Standards: A Modern Framework for IPR-based Standardization: A Study Prepared for the European Commission Directorate-General for Enterprise and Industry.

European Commission, 2011. Horizon 2020 - The Framework Programme for Research and Innovation COM (2011) 808 Final, Brussels.

Farrell, J., Klemperer, P., 2007. Coordination and lock-in: competition with switching costs and network effects. In: Armstrong, M., Porter, R. (Eds.), Handbook of Industrial Organization vol. 3. Elsevier B.V., pp. 1967–2072.

Farrell, J., Saloner, G., 1985. Standardization, compatibility and innovation. RAND J. Econ. 16, 70–83.

Farrell, J., Saloner, G., 1986. Installed base and compatibility: innovation, product preannouncement and predation. Am. Econ. Rev. 76 (5), 940–955.

Furman, J.L., Stern, S., 2011. Climbing atop the shoulders of giants: the impact of institutions on cumulative research. Am. Econ. Rev. 101, 1933–1963.

Gallagher, S., 2007. The complementary role of dominant designs and industry standards. IEEE Trans. Eng. Manag. 54, 371–379.

Garfield, E., 1972. Citation analysis as a tool in journal evaluation - journals can be ranked by frequency and impact of citations for science policy studies. Science 178 (471–+).

Garfield, E., 1979. Is citation analysis a legitimate evaluation tool. Scientometrics 1, 359–375.

Garfield, E., 2006. The history and meaning of the journal impact factor. JAMA 295, 90–93.

Gauch, S., Blind, K., 2015. Technological convergence and the absorptive capacity of standardisation. Tech. Forcasting Soc. Chang. 91, 236–249.

Gillis, M., 2003. Harnessing new technologies for the 21st century. Proceedings, pp. 63–75.

Goldenberg, J., Libai, B., Muller, E., 2010. The chilling effects of network externalities. Int. J. Res. Mark. 27, 4–15.

Hall, B.H., Jaffe, A., Trajtenberg, M., 2005. Market value and patent citations. RAND J. Econ. 36, 16–38.

Hausman, J., Hall, B., Griliches, Z., 1984. Econometric-models for count data with an application to the patents R and D relationship. Econometrica 52, 909–938.

Hawkins, R., 1999. The rise of consortia in the information and communication industries: emerging implications for policy. Telecommun. Policy 23, 159–173.

Hollander, M., Wolfe, D.A., 1973. Nonparametric Statistical Methods. 2nd ed. Wiley, New York.

Leiponen, A.E., 2008. Competing through cooperation: the organization of standard setting in wireless telecommunications. Manag. Sci. 54, 1904–1919.

Lim, S., Prakash, A., 2014. Voluntary regulations and innovation: the case of ISO 14001. Public Adm. Rev. 74 (2), 233–244.

Mahler, A., Rogers, E.M., 1999. The diffusion of interactive communication innovations and the critical mass: the adoption of telecommunications services by German banks. Telecommun. Policy 23 (10), 719–740.

McQuilton, P., Gonzalez-Beltran, A., Rocca-Serra, P., Thurston, M., Lister, A., Maguire, E., Sansone, S.-A., 2016. BioSharing: curated and crowd-sourced metadata standards, databases and data policies in the life sciences. Database (Oxford), baw075 http://dx.doi.org/10.1093/database/baw075.

Messeni Petruzzelli, A., Rotolo, D., Albino, V., 2015. Determinants of patent citations in biotechnology: an analysis of patent influence across the industrial and organizational boundaries. Technol. Forecast. Soc. Chang. 91, 208–221.

Metha, A., Rysman, M., Simcoe, T., 2010. Identifying the age profile of patent citations: new estimates of knowledge diffusion. J. Appl. Econ. 25 (7), 1179–1204.

OECD, 2002. Frascati Manual. Sixth edition, Paris.

Quackenbush, J., 2006. Standardizing the standards. Mol. Syst. Biol. 2.

Rai, A., 2010. Law and technology: Unstandard standardization: the case of biology. Commun. ACM 53, 37–39.

Rysman, M., Simcoe, T.S., 2008. Patents and the performance of voluntary standard-setting organizations. Manag. Sci. 54 (11), 1920–1934.

Schilling, M.A., 2002. Technology success and failure in winner-take-all-markets: the impact of learning orientation, timing and network externalities. Acad. Manag. J. 45, 387–398.

Shapiro, C., Varian, H.R., 1999. The art of standards wars. Calif. Manag. Rev. 41, 8–32.

Shurmer, M., Swann, P., 1995. An analysis of the process generating de facto standards in the PC spreadsheet software market. J. Evol. Econ. 5, 119–132.

Simcoe, T., 2012. Standard setting committees: consensus governance for shared technology platforms. Am. Econ. Rev. 102 (1), 305–336.

Simcoe, T.S., Graham, S.J.H., Feldman, M.P., 2009. Competing on standards? Entrepreneurship, intellectual property and platform technologies. J. Econ. Manag. Strateg. 18, 775–816.

Sorenson, O., Fleming, L., 2004. Science and the diffusion of knowledge. Res. Policy 33, 1615–1634.

Stephan, P.E., Gurmu, S., Sumell, A.J., Black, G., 2007. Who's patenting in the university? Evidence from the survey of doctorate recipients. Econ. Innov. New Technol. 16, 71–99.

Suarez, F.F., 2004. Battles for technological dominance: an integrative framework. Res. Policy 33, 271–286.

Subramanian, A.M., Soh, P.-H., 2010. An empirical examination of the science-technology relationship in the biotechnology industry. J. Eng. Technol. Manag. 27, 160–171.

Tassey, G., 2000. Standardization in technology-based markets. Res. Policy 29, 587–602.

Temple, P., Blind, K., Jungmittag, A., Spencer, C., Witt, R., 2005. The empirical economics of standards. DTI Economics Paper, No. 12, June 2005.

Van Looy, B., Callaert, J., Debackere, K., 2006. Publication and patent behavior of academic researchers: conflicting, reinforcing or merely co-existing? Res. Policy 35, 596–608.

Wang, X., Gorlitsky, R., Almeida, J.S., 2005. From XML to RDF: how semantic web technologies will change the design of “omic” standards. Nat. Biotechnol. 23, 1099–1103.

Zi, A., Blind, K., 2015. Researchers' participation in standardisation: a case study from a public research organisation in Germany. J. Technol. Transfer. 40 (2), 346–360.

Michael Raven received his diploma in biotechnology from TU Berlin. His PhD was supervised by the European School of Management and Technology ESMT and eventually awarded by TU Berlin in 2014. After founding a biotechnology company Michael Raven joined McKinsey as Associate.

Knut Blind earned his doctoral degree at Freiburg University and currently is Professor of Innovation Economics at the Technische Universität Berlin. From 2008 till 2016 he also held the Endowed Chair of Standardization at the Rotterdam School of Management of the Erasmus University. Further, he is the initiator of the Berlin Innovation Panel and the German Standardization Panel. Besides numerous articles on intellectual property rights, especially patents, he published further contributions on standardization and other innovation aspects in refereed journals.