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A PRELIMINARY TEST OF GOOGLE SCHOLAR AS A SOURCE FOR CITATION DATA: A LONGITUDINAL STUDY OF NOBEL PRIZE WINNERS

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ABSTRACT

Most governmental research assessment exercises do not use citation data for the Social Sciences and Humanities as Web of Science or Scopus coverage in these disciplines is considered to be insufficient. We therefore assess to what extent Google Scholar can be used as an alternative source of citation data. In order to provide a credible alternative, Google Scholar needs to be stable over time, display comprehensive coverage, and provide non-biased comparisons across disciplines. This article assesses these conditions through a longitudinal study of 20 Nobel Prize winners in Chemistry, Economics, Medicine and Physics.

Our results indicate that Google Scholar displays considerable stability over time. However, coverage for disciplines that have traditionally been poorly represented in Google Scholar (Chemistry and Physics) is increasing rapidly. Google Scholar's coverage is also comprehensive; all of the 800 most cited publications by our Nobelists can be located in Google Scholar, although in four cases there are some problems with the results. Finally, we argue that Google Scholar might provide a less biased comparison across disciplines than the Web of Science. The use of Google Scholar might therefore redress the traditionally disadvantaged position of the Social Sciences in citation analysis.

INTRODUCTION

> *The "methodologically indefensible" peer-review element of the research excellence framework should be scrapped and replaced by citation data drawn from a free internet application. [...] "It is mythical to suppose that any group of people can assess 200,000 research outputs," [Dunleavy] said. "Everybody knows it, but universities go along with it because they think it is the best way of defending their (financial) position."*

LSE Professor Patrick Dunleavy about the British REF in an
article published in the Times Higher Education Supplement.
(Jump, 2011).

In the past decades there has been a growing demand for research assessment. The main reasons for this are accountability and value-for-money considerations on the part of governments as the provider of public funding for research (Murphy 1996). Although a range of studies have found strong correlations between peer review and bibliometric indicators (see Kousha, Thelwall & Rezaie, 2011 for an overview), most governmental research assessment exercises do not use citation data for the Social Sciences and Humanities. For these disciplines, the assessment of research quality usually depends solely on peer review. Although, when executed properly, peer review is often seen as superior to bibliometric indicators, it is very time-consuming and has an inherent element of subjectivity. Assessors are expected to base their assessment purely on the quality of the publications submitted. However, in practice both the perceived quality of the journal in which the article was published, and the perceived status of the university affiliation of the authors, are likely to create positive or negative halo effects.

The Australian research assessment exercise (Excellence in Research for Australia, ERA) illustrates another disadvantage of peer review. Peer review might well lead to a much harsher "verdict" than an assessment that is mainly based on bibliometric evidence. In ERA, citation data are used for Engineering, the Sciences and Medicine, whereas the Social Sciences, Information and Computing Sciences, and Humanities use peer review. After the outcomes of the 2010 ERA had been published, the common verdict was that although Australia had achieved excellence in much of the Sciences and Medicine, it performed very poorly in the Social Sciences and Humanities (see e.g. Hare, 2011). However, these results do not seem to accord with bibliometric data. The Web of Knowledge's Essential Science Indicators shows that – in comparative terms – Australia has a much larger output in the Social Sciences than in the Sciences and Medicine. In terms of papers published in ISI-listed journals, Australia ranks #4 in the ESI Social Sciences General category and #5 in the Economics & Business category[1], but only #10 in Clinical Medicine, #14 in Chemistry and #18 in Physics.

Of course there might be a discord between quantity (number of papers) and quality (often measured as citations per paper). Australian research in the Social Sciences and Economics & Business certainly ranks much lower on citations per paper than on papers published (see also Harzing, 2005). However, the same is true – admittedly to a lesser extent – for Medicine, Chemistry and Physics. In fact, the five aforementioned disciplines differ very little in their world rank in terms of citations per paper[2]: Chemistry #19, Clinical Medicine #14, Physics #22,

[1] Humanities are not included in the Essential Science Indicators. We acknowledge that the high ranking for Australia in the Social Sciences/Economics & Business is partly caused by its "English-language" advantage. ISI has a bias towards English-language journals and local language journals are more common in the Social Sciences than in the Sciences and Medicine. However, this does not invalidate the argument as ISI listed journals are generally perceived to be top journals in their fields; many Australian journals are not ISI listed either. Hence Australia still punches above its weight. Moreover, although one can quibble with the number of papers measure, the citations per paper measure shows that the Social Sciences perform on par with the Sciences and Medicine.

[2] As small sample sizes can easily distort the citations per paper metric, we ignored countries that had published less than 100 articles a year.

Economics & Business #19, Social Sciences General #15. Yet the average ERA score for Australian universities for these disciplines was: Chemical Sciences 3.5, Medical Sciences 3.2, Physical Sciences 3.7, Economics & Business 2.2, Social Sciences ranging from 2.1 to 2.2 (on a scale of 1=well below world standard to 5=well above world standard). We argue that the “peer review” effect might well have been a contributing factor for the much lower scores for the Social Sciences (incl. Economics & Business).

The main reason provided for not using bibliometrics for the Social Sciences is usually that Web of Science and Scopus coverage is judged to be insufficient for these disciplines as it does not generally cover citations in books, book chapters, conference papers or journals not listed in the Web of Science. Journal coverage differs dramatically between the Sciences and the Social Sciences. For instance Kousha & Thelwall (2007) found that about 77% (49 of 64) of their selected journals in science disciplines and only 13% (6 of 44) of social science journals were indexed in the Web of Science. In this article we will therefore assess to what extent Google Scholar can be used as an alternative source of citation data. Although Google Scholar might not offer the transparency of coverage or authority structure that librarians and bibliometricians would expect from a scientific information resource, it might well be of considerable use for individual academics interested in citation analysis, as well as higher level bibliometric analyses such as government research assessments. Google Scholar certainly has attracted significant criticism, most notably by Peter Jacsó (see e.g. Jacsó, 2010). Whereas no doubt some of his critique is justified, we were unable to reproduce most of the Google Scholar failures detailed in his papers (see Harzing, 2010), suggesting that Google Scholar has since rectified these failures. In fact, in his most recent paper Jacsó (2012) indicates that, with regard to “lost authors”, the current volume of errors is negligible. Most importantly, the bulk of Jacsó's critique was directed at inconsistent results for keyword searches, which are not relevant for the bibliometric analyses conducted in this paper. Furthermore, as we will show in the literature review, large scale bibliometric comparisons of Google Scholar and the Web of Science generally put Google Scholar in a positive light.

In order to provide a credible alternative to the Web of Science, Google Scholar needs to show stability over time, display comprehensive coverage, and provide non-biased comparisons across disciplines. Therefore, the three major research questions for this article are:

1. How *stable* is Google Scholar coverage over time? Does the stability over time differ by discipline?

2. How *comprehensive* is Google Scholar coverage in terms of finding significant publications?
3. How do citations metrics across disciplines *compare* between Google Scholar and the Web of Science?

In order to provide a broad comparison whilst keeping the scope of data collection manageable, we used a sample of Nobel Prize winners in Chemistry, Economics, Medicine and Physics. This sample ensures that we are studying a fairly comparable group of high-performing researchers, who are likely to see their citation levels increase over time. It also ensures that we capture researchers who have published over an extended period, hence enabling us to assess Google Scholar coverage for both older and more recent publications.

LITERATURE REVIEW

To the best of our knowledge, there have been no prior studies that investigated the stability of Google Scholar coverage on a longitudinal basis. However, there are a fairly large number of prior studies that have studied Google Scholar coverage at one point in time, often in comparison with the Web of Science. Several of these studies also provided explicit comparisons between disciplines. Here we provide a brief chronological review of the most important studies.

One of the first studies to review Google Scholar coverage was conducted about 8 months after its launch. Neuhaus, Neuhaus, Asher & Wrede (2006) compared the content of 47 databases with that of Google Scholar, using samples of 50 randomly drawn titles from each database. Coverage varied from 6% to 100%, with a mean value of 60%. In a systematic comparison of citations to 64 articles in different disciplines, Bosman et al. (2006) found overall coverage of Google Scholar to be comparable with both the Web of Science and Scopus. However, huge variations were apparent between disciplines, with Chemistry and Physics in particular showing very low Google Scholar coverage, Science and Medicine also displaying lower coverage than in the Web of Science, and Mathematics/Computer Science and the Social Sciences (incl. Economics) displaying a much higher level of citations.

Bar-Ilan, Levene & Lin (2007) compared the publication and citation records of 22 highly cited Israeli academics in the Web of Science, Scopus and Google Scholar. Google Scholar provided (much) higher counts for academics in Engineering, Computer Science & Mathematics, whereas counts in Molecular biology & genetics were 10-30% lower in Google Scholar than in the

Web of Science. The only Chemist in the sample had nearly three times as many citations in the Web of Science than in Google Scholar. Based on a sample of 1650 articles Kousha & Thelwall (2007) found that for the Social Sciences and Computing, Google Scholar citations were two to nearly eight times (for Economics) as high as Web of Science citations. Physics citations were similar, whereas for Biology Google Scholar had 85% of the Web of Science citations. Google Scholar coverage was lowest in Chemistry with only 43% of Web of Science citations. Mayr & Walter (2007) tested Google Scholar coverage for a list of nearly 7,000 journals taken from Web of Science. The coverage of journals varied between 81% for Arts & Humanities journals and 88% for Social Science journals. Norris & Oppenheim (2007) examined coverage of journal titles in the Social Sciences submitted to the 2001 British RAE. Although they were very critical about Google Scholar's bibliometric capabilities, they found its coverage of journal titles and a sample of articles to be comparable to the Web of Science. Walters (2007) compared Google Scholar to other discipline-specific or multidisciplinary databases, including the Web of Science. Based on 155 core articles on later-life migration published between 1990 and 2000, he found that Google Scholar covered 93% of this literature, whereas Web of Science only covered 73%.

In her review of development in Informetrics between 2000 and 2006 Bar-Ilan (2008) verified Google Scholar coverage for the 598 articles used in the review; all but one of these articles could be found using Google Scholar. In a further exploration of the results of their 2007 study, Kousha and Thelwall (2008) analysed Google Scholar and Web of Science unique citations for four Science disciplines. 41% of the Web of Science unique citations in Chemistry were found in journals published by Elsevier and 28% came from ACS publications. This is likely to be caused by the fact that ACS and Elsevier refused to collaborate with Google Scholar (Kousha & Thelwall, 2008, Neuhaus & Daniel, 2008). Hence Google Scholar directly indexes bibliographic information and abstracts of journal articles from Elsevier and ACS publications, but cannot access the references of those articles. Levine-Clark and Gil (2009) studied 114 journals in the Social Sciences and, for a total of 3,425 articles, found Google Scholar citations to be more than twice as high as Web of Science citations. Bornmann, Marx, Schier, Rahm, Thor & Daniel (2009) examined 1837 papers published in Chemistry, mostly in the journal Angewandte Chemie. Although Google Scholar found 95.1% of the articles, its total citation counts were only a fraction (21%) of Web of Science citation counts, mainly because Google Scholar returned zero citations for half of the sample.

When studying citations to the book "Introduction to informetrics" in Google Scholar, Web of Science and Scopus, Bar-Ilan (2010) concluded that the databases supplemented each other and had comparable performance. When limiting the publication year to 1996 onwards Google Scholar's coverage was "surprisingly good, and its accuracy was also better than expected" (pp. 505–506). Studies by Franceschet (2010) for 13 Computer Science scholars, Garcia-Perez (2010) for four Spanish Psychologists, and Mingers & Liptakis (2010) for all publications of academics at three UK Business Schools over 2001-2007 confirmed earlier findings, i.e. Google Scholar reporting substantially higher publication and citation metrics than the Web of Science. Harzing (2010a) studied ten professors at the University of Melbourne in different fields of study and found that, with one exception, Google Scholar citations exceeded Web of Science citations.

The most comprehensive recent study on Google Scholar coverage was conducted by Chen (2010). Between February and April 2010, Chen searched for fifty randomly selected records each from eight databases that had shown low coverage in the first study reported in this literature review (Neuhaus et al., 2006). Only two records were not retrieved by Google Scholar. Chen also found 100% coverage of the non-English articles included in their samples. He also finds Google Scholar updating to be very frequent, with in press articles for two journals posted in April found in a Google Scholar search on 8 May.

Since 2011 we have not found any comprehensive studies comparing Google Scholar with the Web of Science, although two studies compared Google Scholar with Scopus. Kousha et al. (2011) examined citation counts to 1,000 books submitted in the 2008 UK Research Assessment Exercise and found citation counts in Google Scholar to be more than three times as high as in Scopus. Thornley, Johnson, Smeaton and Lee (2011a) and Thornley, McLoughlin, Johnson & Smeaton (2011b) compared the scholarly impact of the TRECVid conference in Scopus and Google Scholar (using Publish or Perish). All results were manually verified and cleaned. The authors conclude that: "Publish or Perish, based on Google Scholar, has almost astonishingly better coverage" Thornley et al. (2011a: 626). For the year 2007, Google Scholar provided 1.5 times as many publications and 3 times as many citations.

There is considerable evidence, however, that Google Scholar does not perform as well for older publications since these publications, and the publications that cite them, have not (yet) been posted on the web. For example, Belew (2005) found Google Scholar to be competitive in terms of coverage for references published in the last 20 years, but the Web of Science superior before then. Pauly & Stergiou (2005) found that Google Scholar had less than half of the citations of the Web of Science for a specific set of 114 papers published in a variety of disciplines (mostly in the Sciences) between 1925 and 1989. However, for papers published in the 1990-2004 period both sources gave similar citation counts. Neuhaus et al. (2006) found that Google Scholar coverage of PsychINFO articles was nearly twice as high for articles published since 2000 than for articles published between 1960 and 1980 and four times as high than for articles published before 1960. Meier and Conkling (2008) compared Google Scholar's coverage of the engineering literature. They found that coverage of Google Scholar has increased over time, from 33% for articles published in the 1950s to nearly 90% for articles published after 1990. However, these studies are now fairly old with data collected at least 5 years ago. We could expect Google Scholar's performance to improve for older articles as journals' back issues are posted on the web.

Although the above studies differ in their specifics, we can draw three broad conclusions. First, Google Scholar coverage differs substantially by discipline, with the Social Sciences and Computer Sciences drawing more citations in Google Scholar than in the Web of Science and most of the other disciplines showing comparable citation scores in both sources. The notable exception is Chemistry, which in all studies showed lower Google Scholar than Web of Science citations. Second, Google Scholar coverage is better for recent publications than for older publications. Third, Google Scholar coverage has increased substantially over time. Even the most recent studies, however, were published in 2011 and collected their data 1-2 years earlier. Hence, this study will provide a much more recent assessment of coverage. In addition, it will extend our knowledge in two important areas: the level of stability of Google Scholar over time and the extent to which citation metrics sourced from Google Scholar differs from Web of Science metrics in four different disciplines.

METHODS

Sample

We used Nobel Prize winners as our sample in order to ensure that we were studying a comparable group of high-performing researchers, who are likely to see their citation levels increase over time. We included Nobel Prize winners in each field, except Peace and Literature as these prizes are not awarded based on academic performance. For each field we selected five Nobelists. We concentrated on recent years (2008-2010), but also included one Nobelist each from 2000 and 1990, in order to establish whether Google coverage differed by the relative age of publications. Of course, more recent Nobel prizes can also be awarded for work done several decades ago. However, having some spread over the years gives us a better chance to capture a larger variety of publication ages. In years where there was more than one Nobel Prize winner in a particular field, we selected the first Nobel Prize winner unless this person had a particularly common name. For both Google Scholar and the Web of Science, the more common a name is, the more difficult it is to establish an accurate citation record.

Table 1: List of Nobel prize winners included in our study

Name	Field	Year of Award	Year of first Google Scholar publication
EJ Corey	Chemistry	1990	1950
AJ Heeger	Chemistry	2000	1961
O Shimomura	Chemistry	2008	1954
A Yonath	Chemistry	2009	1966
E Negishi	Chemistry	2010	1965
H Markowitz	Economics	1990	1952
J Heckman	Economics	2000	1972
P Krugman	Economics	2008	1976
E Ostrom	Economics	2009	1965
P Diamond	Economics	2010	1964
JE Murray	Medicine	1990	1953
P Greengard	Medicine	2000	1954
H zur Hausen	Medicine	2008	1965
EH Blackburn	Medicine	2009	1972
RG Edwards	Medicine	2010	1954
JI Friedman	Physics	1990	1955
Z Alferov	Physics	2000	1963
Y Nambu	Physics	2008	1948
WS Boyle	Physics	2009	1951
AK Geim	Physics	2010	1981

Our final sample of Nobelists can be found in Table 1. It reproduces their name, field, year of award and the year of their first publication listed in Google Scholar. Although, there doesn't seem to be a close relationship between the year of award and the year of first publication, Table 1 shows that our sample represents a wide range of publication ages, with the Nobelists' first publications running from 1948 to 1981. All but two of the Nobelists published their first work four decades or more ago, and most of the Nobelists are still publishing at present. Hence, our sample is very suitable to assess Google Scholar coverage.

Data sources

The data sources used in this article are the Web of Science and Google Scholar. The Web of Science has long been considered the gold standard for citation analysis, and hence its use does not need further justification. Web of Science data were collected with version 5.4 of the Web of Knowledge, accessed through our university library. For Google Scholar, Jacsó's many studies (see e.g. Jacsó 2010) have documented serious doubts about the level of accuracy of citation counts. Hence the choice of Google Scholar deserves further explanation.

Although large-scale investigations of Google Scholar accuracy are rare, Vaughan and Shaw (2008) found 92% of Google Scholar citations in the field of library and information science to represent intellectual impact, primarily citations from journal articles. In the largest published verification project to date, the LSE project on impact in the Social Sciences (2011), Google Scholar citations were collated for all traceable publications of a sample of 120 academics spread across five social science disciplines (including Economics). Publications listed and the citing sources were verified manually for duplicate entries, unacknowledged citations, publishers' publicity materials etc. These were removed to produce a completely 'cleaned' score. The correlation between the original PoP scores and the cleaned scores was 0.95. Hence, it would appear that the level of accuracy displayed by Google Scholar is sufficient for broad level comparisons. Moreover, the recent introductions of Google Scholar Citations in November 2011 and Google Scholar Metrics in April 2012 show that Google Scholar is starting to take citation analysis seriously. We therefore expect the service to continue to improve over the next couple of years, because more and more users will turn to Google Scholar for citation analysis. As a result its accuracy will further improve through a process of crowdsourcing.

As Google Scholar on its own is not very suitable for bibliometric analyses, Publish or Perish (Harzing, 2007) was used to collect citation data from Google Scholar. There are now more than 250 published articles referring to the Publish or Perish program. This provides further evidence that – in spite of its limitations – Google Scholar is perceived to be a useful source of bibliometric data. Publish or Perish is a software program that retrieves and analyses academic citations. It uses Google Scholar to obtain the raw citations, then analyses these and presents a wide range of citation metrics in a user-friendly format. The results can also be saved to a variety of output formats (for future reference or further analysis). We used this option to export results to Excel in order to perform various calculations and create graphs.

In Publish or Perish, we followed a comprehensive search strategy; we didn't use year exclusions and only used field exclusions and more than one initial when the name was really common (RG Edwards, JE Murray). In all other cases, false matches were removed manually by a comprehensive review of publication outlets, co-authors, and publication titles. We paid special attention to publications included in the h-index. These were verified individually to ensure they were published by the Nobelist in question. Publications in the h-index were also checked for stray publications that had enough cites to be listed as a separate publication in the h-index (usually books with and without subtitle). Incidental stray cites were not merged, but any publications with substantial stray records were merged, especially if they were on the h-index threshold. Because of the flexible user interface of Publish or Perish, that allows sorting publications by author, year, title, source and publisher, and performs a publication merge with a simple drag and drop, this process was surprisingly quick. For most Nobelists the verification and merging process took well under half an hour. Only those with namesakes in other disciplines required a bit more time. The merging process did not substantially change the h-index. In most cases it stayed the same, for half a dozen Nobelists it increased or decreased by one.

Following Bar-Ilan (2008), in the Web of Science we used the general search function, rather than the Cited Reference search function. As Bar-Ilan indicates nearly all prior studies in this field used the general search function. There are five good reasons to do so. First, the Web of Science generally has even more stray cites than Google Scholar. [3] Therefore, the Cited Reference function is very unwieldy to use, especially as (unlike Publish or Perish), there is no way to merge stray cites. One cannot even assess the extent of the problem easily through sorting by author/year/publication as the Web of Science has *no* sort functions in the Cited Reference Search and only limited sort functions in the general search. The lack of export functions means that it is not possible to do this using external means either. Second, the Web of Science Cited Reference Search does not display the full bibliographic information of cited works that are not included in the Web of Knowledge. The abbreviations used are often cryptic and not used consistently; the same journal or book title might be abbreviated in different ways. Hence, even ignoring the lack of sorting options, it is very difficult and sometimes impossible to match titles. Third, the Cited Reference Search has no author identification function, nor any other way to further analyze results [the analyze function works with *citing* articles, not *cited*

[3] This was clearly illustrated when we attempted to do a rough assessment of how much a Cited Reference Search would add to our results. For Chemist EJ Corey, more than 2200 of his nearly 3300 entries were to non-ISI listed publications, but 90% of these were stray citations to three journals that **are** in fact ISI listed. For Physicist Geim, stray citations made up a third of his records for less than 1% of his citation count.

works]. This means that for authors with common names, it is next to impossible to separate them from their namesakes in the Cited Reference Search function. Given that the Web of Science subject classification isn't flawless[4], one would even need to search in both the SCI and the SSCI and their conference and book citation equivalents, making it even more difficult to uniquely identify authors. Fourth, the Cited Reference Search does not provide a calculation of the h-index, hence this would need to be calculated manually, which – given the aforementioned problems – is almost impossible for most researchers included in our sample. Finally, international rankings of universities using citation data are all based on the Web of Science general search, hence it is not unreasonable to use the same search function for individuals. [5]

In the Web of Science general search, the author profile function was used only when the author had many namesakes. We had to run most of the searches manually though as author profiles were far from comprehensive or even correct. For authors with slightly longer names, the names were sometimes abbreviated (e.g. Greengard P became Greengar.P). Publications under these abbreviated names were not included in the profile. To illustrate the extent of this problem, for Paul Greengard, this resulted in the loss of some 12,000 citations. Some author profiles also included publications that were clearly not written by the relevant Nobelist.

Measures

In order to test stability of Google Scholar coverage over time, we collected the total number of citations and the h-index for each of our 20 Nobelists at three points in time: April 2011, September 2011 and January 2012. We chose the total number of citations as the most comprehensive measure of citation impact and the h-index as the best indication of the number of publications that had achieved a significant impact. The added advantage of the h-index is that it is relatively robust, hence reducing the need for time-consuming manual merging of all stray citations. For the second and third data-point we calculated the proportional increase in the number of citations and the h-index. If Google Scholar coverage was stable over time, we would not expect to find a decline in citations or the h-index over the three time periods, nor

[4] Economist Paul Krugman for instance had 567 entries in the Science databases, even though all of these publications were books or publications in Economic journals.

[5] We are fully aware that a Cited Reference Search would provide a higher citation count and h-index for Economics. However, it still provides a **very** incomplete citation record for these Nobelists as it only measures citations **in** ISI listed journals and it only reports citations **to** non-ISI listed publication for the first author. For the two Economists where we could reliably search in the Cited Reference search, it provided 8 to 10 times as many items as the General Search, but as most of these were stray citations, the Cited Reference Search found only 10-20% of the additional Google Scholar citation count. Moreover, our analysis for the Nobelists top-20 journal articles shows that even for ISI-listed publications Google Scholar provides 3 to 5 times as many citations.

find huge increases over time. Of course, a modest increase in the h-index and a more noticeable increase in the total number of citations are to be expected over a period of respectively 5 and 4 months for a group of high-performing researchers.

In order to test the comprehensiveness of Google Scholar coverage in terms of finding significant publications, we used the Web of Science as an authoritative source. For each of the 20 Nobelists, we verified whether their top-20 most cited articles in the Web of Science were found in Google Scholar. As this was an extension of the original design of our project, we performed this analysis for the September 2011 and January 2012 data points only, hence verifying 800 articles in total. For January 2012, we also compared the number of citations that these articles had accumulated in Google Scholar and the Web of Science.

Finally, in order to compare citation metrics between Google Scholar and Web of Science, we simply tabulated citations and the h-index for each Nobelist in both Google Scholar and Web of Science and calculated the proportional difference between the two scores. Again, we were able to perform this analysis only for the September 2011 and January 2012 data points.

RESULTS

Stability of Google Scholar over time

Our first research question asked whether Google Scholar coverage was stable over time. If Google Scholar coverage was stable, we would not expect a decrease in the h-index and the number of citations over time, nor a strong increase. Table 2 shows that these expectations are generally confirmed, but that the four disciplines show quite different patterns.

Table 2: Proportional increase in citations and h-index over time for different disciplines.

Time period	**Increase April-Sept**		**Increase Sept-Jan**	
Field	**Citations**	**H-index**	**Citations**	**H-index**
Chemistry	36.8%	15.6%	18.4%	8.8%
Economics	4.0%	0.0%	9.7%	3.8%
Medicine	7.4%	3.0%	13.1%	6.2%
Physics	23.0%	10.6%	11.1%	5.9%
Total	**17.8%**	**7.3%**	**13.1%**	**6.2%**

Overall, citations are clearly increasing over time, at a rate of about 3% per month. For the period for which we have both Google Scholar and Web of Science data, the increase in Google Scholar citations for our sample is about double the increase in Web of Science citations. Hence, we can assume that part of the increase in Google Scholar citations is due to a further increase in coverage in one or more disciplines. For two out of the four disciplines (Medicine and Economics), Google Scholar citations increased at a modest rate of 4-7% between April and September. As expected, the h-index didn't increase as much, and in six out of ten cases, there was no change at all. For Physics and Chemistry, the increase in citations was much more substantial, on average 23% for Physics and 37% for Chemistry. Again, the increase in h-index was much smaller. Given that these two disciplines have traditionally had a lower Google Scholar coverage, the increase in citations can probably be attributed to an increase in Google Scholar coverage in these fields and hence is not necessarily problematic. It should not be seen as a sign of instability, but rather as a catch-up in coverage for Physics and Chemistry. This means that the traditional disadvantage that Google Scholar had for these two disciplines has now been substantially reduced. Between September and January, the increase in citations and h-index is more similar across disciplines, although Chemistry still shows a larger increase than the other disciplines.

Studying the citation records of the individual Nobel Prize winners in Chemistry and Physics, we found the bulk of the increase in citations and the h-index for the Chemists to be due to Heeger, Negishi and Corey. Over the 9 months, Negishi's citations increased by 150%, whereas Heeger's and Corey's citations increased by 50-70%. Yonath and Shimomura showed modest increases comparable to those of Nobelists in Economics and Medicine. In Physics, the increase was mainly due to three individuals: Boyle, Geim, and Alferov, whose citation levels increased by 30-90% over the 9 month period. Friedman and Nambu showed modest citation increases in line with the other Nobelists. We therefore investigated these six individuals in more detail.

Two of the three Chemists (Negishi and Corey) published the bulk of their highly cited work in American Chemical Society (ACS) journals, with Elsevier journals coming second in terms of highly cited work. Heeger published his highly cited work predominantly in American Physical Society (APS) journals, but with an important secondary presence in both ACS and Elsevier journals. In contrast, Yonath and Shimomura published the majority of their work in medical or biological journals. Kousha & Thelwall (2008) showed that Web of Science unique citations in Chemistry – which in their study had the least comprehensive Google Scholar coverage – mainly came from Elsevier and ACS journals. A comparison of the citation records for Negishi, Corey and Heeger between April 2011 and January 2012 showed that citations to publications in ACS and Elsevier journals have increased 2 to 4-fold, substantially more than the already high overall increase in citations for these Nobelists. Given the dominance of these two publishers in Chemistry, citations to these publications are likely to come from ACS and Elsevier journals as well. Hence, it is likely that Google Scholar has substantially improved its ability to access and correctly parse citations in ACS and Elsevier publications over the past year.

The Physicist Boyle displayed a very low number of citations overall, reflecting his non-academic career. The higher than average increase of 30% was largely due to an increased coverage of citations to US Patents, as well as a more than doubling in citations to papers published in IEEE journals. Alferov's citation increase is also caused by the increased coverage of citations in IEEE journals as well as Springer journals. In both cases citations increased by more than 2.5 fold. Apparently, Google Scholar has improved its ability to access and correctly parse citations from these publishers. The other three Physicists hardly have any publications in IEEE or Springer journals and were less affected by this increased coverage. The strong (45%) increase for Geim over 9 months is due to a natural increase. Geim's h-index has increased by only 10%, indicating that most of the citations went to work that was already highly cited. The strong increase in citations is likely to be due to the recentness of his highly cited work. In the Web of Science, nearly two thirds of Geim's citations occurred in the last 2 years. A fourth search conducted 4 weeks after the January data collection showed that Geim's citations had increased by another 3.6% (i.e. close to the average monthly increase in the previous 9 months), whereas citations for the other Physicists only increased by 0.4-0.8%.[6]

Overall, our results show that for the bulk of our sample Google Scholar shows a gradual increase over time, which is likely to be caused both by a natural increase in citations and a marginal increase in Google Scholar coverage. However, several Nobelists in Chemistry and Physics have benefitted from an apparently increased ability of Google Scholar to access and correctly parse citations from publishers that were traditionally poorly covered by Google Scholar: ACS, Elsevier, Springer and IEEE. As a result, Google Scholar's traditional disadvantage over the Web of Science in terms of coverage for Chemistry and Physics seems to have been reduced. We will further explore this finding in our analysis of research questions 2 and 3.

[6] Citations for the other Nobelists in our sample also increased with a similar magnitude (between 0.3% and 1.4%, with most sitting around 0.6%-0.7%). This seems to suggest that there was no further expansion of coverage in these four weeks and that any increase in citations was caused by the natural increase in citations over time. This presents additional evidence of the stability of Google Scholar.

Comprehensiveness of Google Scholar

Our second research question asked how comprehensive Google Scholar is. Although, it is reassuring to see an increase in coverage over time, we do not yet know whether specific articles can be found in Google Scholar. In a more fine-grained comparison, we therefore identified the top-20 most cited articles in the Web of Science for each Nobelist. Subsequently, we verified whether the article could found in Google Scholar. In September 2011, out of the total of 400 highly cited Web of Science articles (20 for each of the 20 Nobelists), only two articles, i.e. 0.5%, could not be found with an author search in Google Scholar. One of these, an article in the Lancet by RG Edwards, *was* listed in Google Scholar, but was only ascribed to the first author (PC Steptoe). In our January 2012 search, this article was found with RG Edwards listed correctly as the second author. The second paper that could not be found was one by Physicist JI Friedman. Only a few stray cites could be found in Google Scholar. This is most likely due to the fact that references to this paper generally did not refer to any of the more than 3,000 authors, but referred to the research groups instead. In our January 2012 search, the paper *was* found under a search for JI Friedman, but the number of citations was still lower than in the Web of Science.

We repeated this analysis in January 2012. As indicated above, the two missing articles in September 2011 could now be found in Google Scholar. Unfortunately, there were now two other papers, both written by Physicist Y Nambu, for which Google Scholar coverage was problematic. Although both articles could be found in Google Scholar, one of them had zero citations recorded in Google Scholar and the other one could not be found under Nambu's own name. The article without any citations is Nambu's second most highly cited article. Its title is identical to his first most cited article, save for a roman 1 instead of a roman 2 at the end of the title. In the April and September 2011 search Google Scholar was able to find both articles correctly. However, in January 2012, it had subsumed the second article as one of the online versions of the first article. Nambu's sixth most cited article in the Web of Science – a 1965 paper Physical Review – could not be found under his name as Google Scholar had mangled his last name to Namsv. In April and September 2011, the article was found under Nambu's correct name. Although this regression of coverage is rather disturbing, the mistake for the first article is understandable given the similarity in titles. It must also be acknowledged that both papers were published five decades ago. Overall, the error rate for Google Scholar was only 0.5%. In each sample only two of the 400 articles could not be found correctly in Google Scholar.

Chemistry journals

In both our study and other studies, Chemistry has the least comprehensive coverage in Google Scholar. This is partly due to the fact that many of the key publications of our Nobelists in this field were more than four decades old. However, Bornmann et al.'s (2008) study also provided evidence of disastrously low coverage for "Angewandte Chemie International Edition" for articles published between 2000 and 2006. Hence, we performed a small-scale study of chemistry journals to establish the extent of the coverage problem early 2012.

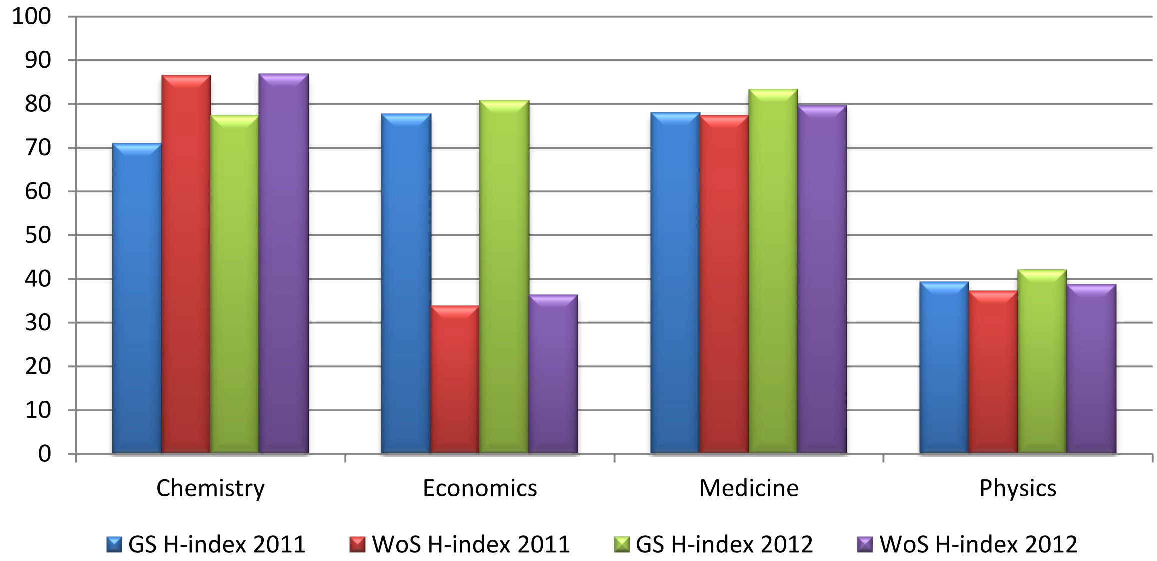
First, we provided a very partial replication of Bornmann et al.'s study by searching for citations to articles published in Angewandte Chemie between 2000 and 2006. Note that our study followed a different approach. We conducted bulk searches for the journal title in each year, rather than searching for individual articles. Hence the results are not directly comparable. However, they do provide a broad indication of the level of coverage relative to Bornmann's study. For each of the seven years Google Scholar reported fewer citations than the Web of Science. On average it reported 72% of the citations of Web of Science, but this ranged from 88% for 2000 articles to 61% for 2006. As many studies are now focusing on the h-index as a summary metric rather than the total number of citations, we also compared the h-index for the journal for each of the years. Again, Google Scholar reported lower h-indices, but the difference with Web of Science was much smaller than with the number of citations. On average, Google Scholar reported 91% of the Web of Science h-index (109 vs 120), ranging from 84% for 2006 to 99% for 2000.

As previous studies reported particular problems with coverage of ACS journals, we investigated two ACS journals: "Journal of the American Chemical Society" and "Journal of Organic Chemistry". For the first, we could only compare h-indices as the number of yearly articles was too large to be accommodated by the Google Scholar 1000 results limitation. The h-indices provided by the two data-sources were very similar, with the Google Scholar h-index ranging from 98-103% of the Web of Science h-index. For the "Journal of Organic Chemistry", we calculated both the yearly citations and the yearly h-index for each of the data sources. On average, Google Scholar reported 81% of the Web of Science citations, ranging from 77% to 84%. The Google Scholar h-index was on average 93% of the Web of Science h-index, ranging from 89%-97%. Coverage in Chemistry seems to have improved considerably over the years and is now at a level where Chemistry can be included in comparative searches, especially for summary metrics such as the h-index.

Citations metrics across disciplines in different data sources

Our third research question asked how citations metrics across disciplines *compared* between Google Scholar and the Web of Science. In order to answer this question, we compared the h-index and the number of citations between the Web of Science and Google Scholar for twenty Nobelists in September 2011 and January 2012. As shown in Figure 1, the average h-index for our Nobelists in Medicine and Physics is fairly similar in Google Scholar and the Web of Science. In both disciplines Google Scholar h-indices are slightly higher, but at most there is a 3-point difference between the two data-sources.

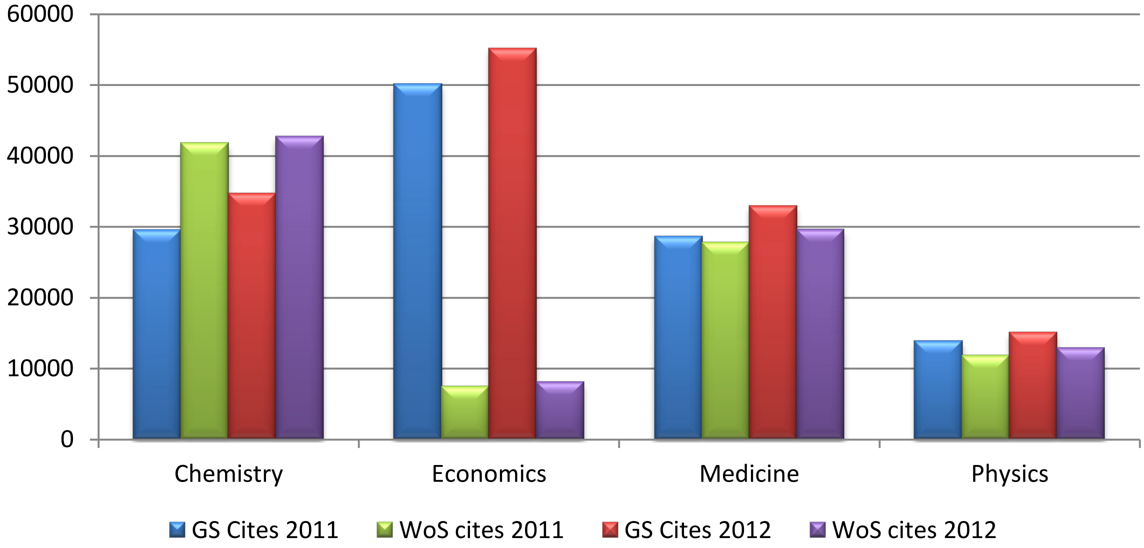
Figure 1: Average h-index in Google Scholar and the Web of Science for four disciplines.



For Chemistry, the average h-index in the Web of Science is higher than in Google Scholar, although the difference is more pronounced in September 2011 (86 vs. 71) than in January 2012 (87 vs. 77), reflecting Google Scholar's increased coverage in Chemistry. For Economics, however, the differences between Google Scholar and the Web of Science are fairly dramatic. In Google Scholar, Economics Nobel prize winners have an h-index that is as high as Nobel Prize winners in Medicine and Physics. In the Web of Science, their average h-index is reduced by more than half and falls below that of the Nobel Prize winners in Physics.

Figure 2 compares average citations between Google Scholar and the Web of Science. The patterns here are similar to those found in comparing the h-index: lower average citations in Google Scholar in Chemistry, slightly higher average citations in Google Scholar in Medicine and Physics and substantially higher average citations in Economics. The drop in the average number of citations when going from Google Scholar to Web of Science is 83% for Economics.

Figure 2: Average total number of citations in Google Scholar and the Web of Science for four disciplines.



When drilling down to individual Nobel Prize winners, we find that in our latest round of data collection, January 2012, the number of Google Scholar citations is higher than the number of Web of Science citations for all but three of our Nobelists, all in Chemistry (Heeger, Negishi & Corey). For Heeger, the difference is marginal; Web of Science citations are 2.7% higher than Google Scholar citations. For Negishi & Corey, the differences are still substantial: Web of Science citations are respectively 37% and 63% higher than Google Scholar citations, in spite of the substantial increase of Google Scholar citations for these Nobelists between April 2011 and January 2011. However, the Web of Science h-index for these two Nobelists is only 21% and 30% higher than their Google Scholar h-index.

The vast difference in Web of Science and Google Scholar citations for Nobelists in Economics is largely due to their book publications. Books are a very significant part of research output in the Social Sciences and Humanities (Nederhof, 2006; Huang & Chang, 2008). Google Scholar captures book citations much more comprehensively than Scopus (Kousha, Thelwall & Rezaie, 2011), whereas the coverage of book citations in the Web of Science general search function is almost non-existent, in spite of the recent introduction of the Book Citation Index. For Nobel Prize winners in the Sciences and Medicine, the top 10 publications were nearly always journal articles, often in prestigious journals such as Nature, Science, Cell, The Lancet and Physical Review. Four out of the five Economist Nobel prize winners had books amongst their top-10 publications; all four had a book in their top-3 most cited publications: for Ostrom all top-3 publications were books; for Krugman and Markowitz two out of the top-3 publications were books.

In addition to a more comprehensive coverage of book citations, Google Scholar also has the advantage over the Web of Science in terms of timeliness. Thomson Reuters are not very quick in updating their data-base as this is a manual process. In terms of published issues, the Web of Science is usually *at least* one issue behind Google Scholar. In this respect, Google Scholar has a clear advantage in having automated processes. Publications and citations are available as soon as the information is online and Google Scholar parses the website. In most cases, this means that even “online first” articles are processed. Given that some journals have nearly a year’s worth of articles in their “online first” sections, Google Scholar could effectively be 9-12 months ahead of Web of Science. Since highly cited researchers could expect their citations to increase by 10-20% a year, this alone could easily explain Google Scholar’s slightly higher citation counts for the Nobel Prize winners in Medicine and Physics.

Top-20 articles

To investigate the differences between the two data-bases in more detail, we also compared the number of January 2012 citations in Google Scholar and Web of Science for the top-20 most cited articles in the Web of Science articles. Overall, the comparative results were similar to the results that were reported above, that is, in most cases the number of Google Scholar citations to the top-20 articles was higher than the number of Web of Science citations. There were some differences across disciplines though.

For the Chemists, the relationship between Web of Science citations and Google Scholar citations is very similar regardless of whether one looks at the overall citation record or the citations to the top 20 articles only. This meant in three of the five cases that the results were either very similar (Heeger) or 15-20% higher (Yonath & Shimomura) in Google Scholar. For the remaining two (Negishi & Corey), citation levels were on average 30-40% lower in Google Scholar. Articles with particularly low levels of citations in Google Scholar were either published in ACS or Elsevier journals and were generally published in the fifties, sixties or early seventies. Articles published in *Science* or in one of the medical journals generally had similar citation levels in Google Scholar and Web of Science. Elsevier and ACS articles published in the eighties or later also fared better than earlier publications from the same publishers.

For the Economists, the relationship between Web of Science citation and Google Scholar citations is very different for the top-20 articles. The Economists have between three and five times as many citations for their top-20 articles in Google Scholar than in the Web of Science, a difference which is much larger than for the other disciplines. However, this difference is dwarfed by the difference for their entire citation record, which shows four to twelve times as many citations in Google Scholar. Hence, Economists not only profit from the larger number of citing journal articles in Google Scholar, but also from Google Scholar's extended coverage for books, book chapters, conference papers, and working papers.

For three of the five Medical Nobelists, the relationship between Web of Science citations and Google Scholar citations is very similar regardless of whether one looks at the overall citation record or citations to the top-20 articles only. For both the overall record and top-20 articles, citation scores were either similar or 10-15% higher in Google Scholar. For H zur Hausen and RG Edwards, the Google Scholar advantage is 27%-38% for their overall record, but only 18% for their top-20 articles. In the case of H zur Hausen this is caused by the fact that this Nobelist has published several books and reports that are included in Google Scholar, but not the Web of Science general search. In the case of RG Edwards, this might be caused by the extreme difficulty in finding reliable citation counts in both the Web of Science and Google Scholar, because of his many namesakes. Hence neither the Google Scholar, nor the Web of Science citation record might be completely reliable.

For three of the Physicists, the relationship between Web of Science citations and Google Scholar citations is very similar, regardless of whether one looks at the overall citation record or citations to the top-20 articles only. For both their overall record and the top-20 articles, citation scores were 5-35% higher in Google Scholar. For Y Nambu the results for his top-20 articles were different from his overall citation profile, as one of his most highly cited articles did not have any citations in Google Scholar. As indicated above, it is likely that Google Scholar inaccurately parsed this article because it was so similar to another article. As a result the 11% advantage for Google Scholar is turned into a 6% disadvantage for the top-20 articles. In the case of WS Boyle, Google Scholar finds slightly fewer citations (4%) for his top-20 articles, but this is amply compensated by the citations to his patents that are counted in Google Scholar, but not in Web of Science, giving him 11% more citations in Google Scholar overall.

Overall, we therefore find that the comparison between Google Scholar and Web of Science Web of Science shows very similar results across disciplines, regardless of whether one focuses on overall citation records or top-20 articles only. The only exception are the Economists, for whom the already much more comprehensive citation count for top-20 articles is dwarfed by the added benefits of including citations to their books, conference and working papers.

Comparison of Ranking with different data sources

When individuals are compared in terms of their h-index and total number of citations, this is often done with the purpose of creating rankings (see e.g. Bornmann & Daniel, 2005; Cronin & Meho, 2006). In addition to comparing the actual h-index and total number of citations between the two data sources, it is therefore interesting to compare the ranking of our Nobelists according to the two data sources. We first compared their rankings *within* their disciplines and found this ranking to be nearly identical for Google Scholar and Web of Science data, both in terms of the h-index and in terms of the total number of citations. The ranking was completely identical for Medicine, whereas for the three other disciplines numbers 1 and 2 were swapped between the two databases. As a result the correlation between the two rankings was very high at 0.93. *Across* disciplines, the rankings were far less stable. Economists and Medical scholars dominated the top-10 with Google Scholar data; with the Web of Science data the Medical scholars kept their dominant position, but the Chemists largely replaced the Economists. As a result the correlation between Google Scholar and Web of Science rankings *across* disciplines was only 0.70 for the h-index and 0.59 for the number of citations.

DISCUSSION AND CONCLUSION

This article assessed the validity of Google Scholar as a tool for academic evaluation through a longitudinal study of Nobel Prize winners. Most governmental research assessment exercises do not use citation data for the Social Sciences as Web of Science or Scopus coverage in these disciplines is considered to be insufficient. We therefore investigated to what extent Google Scholar could be used as an alternative source. In order to provide a credible alternative, Google Scholar needs to be stable over time, display comprehensive coverage, and provide non-biased comparisons across disciplines. This article evaluated these conditions through a longitudinal study of 20 Nobel Prize winners in Chemistry, Economics, Medicine and Physics.

If Google Scholar coverage is *stable*, we would not expect a decrease in the h-index and the number of citations over time, nor a strong increase. Our results showed that Google Scholar displayed considerable stability over time. Overall, the h-index only showed modest increases, except for Chemistry. As expected, citations showed a larger increase over time, at a rate of about 3% per month, about double the increase in Web of Science citations. Hence, of the increase in Google Scholar citations appears to be due to a further increase in coverage in one or more disciplines. A fine-grained analysis showed that several Nobelists in Chemistry and Physics have benefitted from an increased ability of Google Scholar to access and correctly parse citations from publishers that were traditionally poorly covered by Google Scholar: ACS, Elsevier, Springer and IEEE. As a result, Google Scholar's traditional disadvantage over the Web of Science in terms of coverage for Chemistry and Physics has reduced. However, as this was the first longitudinal study of Google Scholar coverage, we would recommend continued monitoring of coverage in these fields.

We tested the *comprehensiveness* of Google Scholar coverage through a search for our Nobelists 800 most cited publications and a small-scale study of Chemistry journals. All 800 publications could be located in Google Scholar, although in four cases there were some problems with the results. In three cases, the article could not be found when searching for the Nobelist's name, whereas in the last case the article could be found for under the Nobelist's name, but displayed zero citations. Therefore, the overall error rate for Google Scholar in terms of coverage was only 0.5%. Even though Google Scholar coverage is not yet comprehensive for Chemistry, the small-scale study of Chemistry journals showed that the Google Scholar h-index for these journals for the 2000-2006 period is 84%-103% of the Web of Science h-index. Given the significant improvement in Google Scholar coverage that was established for Chemistry in 2011, it might only be a matter of time before Google Scholar can be considered to be sufficient for comparative analyses for all disciplines. We clearly need to revisit the idea that Google Scholar coverage is only greater in the Social Sciences (Harzing & van der Wal, 2008). However, again we would recommend that studies continue to monitor Google Scholar coverage, especially in Chemistry.

Our third research question asked how citations metrics across disciplines *compared* between Google Scholar and the Web of Science. In order to answer this question, we compared the h-index and the number of citations between the Web of Science and Google Scholar for each of the twenty Nobelists. The average h-index and citations for our Nobelists in Medicine and Physics were fairly similar in Google Scholar and the Web of Science. For Chemistry, the average h-index and total citations were higher in the Web of Science than in Google Scholar, although the difference was more pronounced in September 2011 than in January 2012. For Economics, the differences between Google Scholar and the Web of Science were fairly dramatic. Their average h-index was reduced by more than half and citations were reduced by more than 80% when moving from Google Scholar to the Web of Science. This was due to both the increased number of citations to journal articles in Economics and the far more comprehensive coverage of citations to books, conference and working papers. Google Scholar also has the advantage over the Web of Science in terms of timeliness. We argued that Google Scholar could effectively be 9-12 months ahead of Web of Science in terms of publication and citation coverage. Further systematic studies comparing the timeliness of Web of Science and Google Scholar might be able to shed light on this.

Finally, with regard to the ranking of Nobelists Google Scholar and Web of Science give very similar results *within* disciplines. However, when comparing *between* disciplines, different data source result in very different rankings. We therefore argue that Google Scholar might provide a less biased comparison across disciplines than Web of Science. The use of Google Scholar as a tool for academic evaluation could therefore redress the traditionally disadvantaged position of the Social Science in citation analysis. However, it should be noted that comparisons across disciplines remain problematic, regardless of the data source used, and should hence be applied with caution.

Our preliminary study provided a positive verdict on the stability and comprehensiveness of Google Scholar and showed that in terms of comparability between disciplines Google Scholar might provide less biased results than Web of Science. However, it was based on a relatively small sample of high-performing researchers. Additional studies based on a larger and more representative set of researchers are necessary before we can draw any definitive conclusions on the usefulness of Google Scholar in research assessment exercises.

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