On the Shoulders of Giants: The Growing Impact of Older Articles

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Abstract

In this paper, we examine the evolution of the impact of older scholarly articles. We attempt to answer four questions. First, how often are older articles cited in scholarly papers and how has this changed over time. Second, how does the impact of older articles vary across different fields of scholarship. Third, is the change in the impact of older articles accelerating or slowing down. Fourth, are these trends different for much older articles.

To answer these questions, we studied citations from articles published in 1990-2013. We computed the fraction of citations to older articles from articles published each year as the measure of impact for the study. For this study, we considered articles that were published at least 10 years before the citing article as older articles. To explore how changes in citation behavior differ across areas of research, we computed these numbers for 261 subject categories and 9 broad areas of research. Finally, we repeated the computation for two other definitions of older articles, 15 years and older and 20 years and older.

There are three major conclusions from our study. First, the impact of older articles has grown substantially over 1990-2013. Our analysis indicates that, in 2013, 36% of citations were to articles that are at least 10 years old and that this fraction has grown 28% since 1990. The fraction of older citations increased over 1990-2013 for 7 out of 9 broad areas of research and 231 out of 261 subject categories.

Second, the change over the second half (2002-2013) was significantly larger than that over first half (1990-2001) — the increase in the second half was double the increase in the first half.

Third, the trend of a growing impact of older articles also holds for articles that are at least 15 years old and those that are at least 20 years old. In 2013, 21% of citations were to articles ≥ 15 years old with an increase of 30% since 1990 and 13% of citations were to articles ≥ 20 years old with an increase of 36% over the same period.

Now that finding and reading relevant older articles is about as easy as finding and reading recently published articles, significant advances aren’t getting lost on the shelves and are influencing work worldwide for years after.
1 Introduction

The last two decades have seen several dramatic changes in scholarly communication. First, scholarly journals have largely moved from physical distribution of print issues to online availability of individual articles. A large number of journals have also digitized older articles and made them available online. Second, search services now index the entire text of articles instead of just abstracts and keywords. The common ranking approach has moved from reverse chronological (most-recent-first) to relevance ranking (most-relevant-first). Third, many journals now make articles available much sooner - often, soon after acceptance. Furthermore, several disciplines have developed large preprint collections which include articles before they have been accepted for formal publication. Consequently, researchers can learn about new results much sooner than was possible earlier. Fourth, the number of articles and journals has grown rapidly – between 1990 and 2013, the number of scholarly articles published per year grew close to 3-fold. As a result, there is much more recent work for researchers to learn from, build upon and cite.

The first two changes have made it easier for researchers to find the most relevant articles for their work regardless of the age of the articles. Finding and reading relevant older articles is now about as easy as finding and reading recently published articles. If these were the only changes, it would be reasonable to expect that the fraction of citations to older articles would increase.

The second set of changes have greatly expanded the amount of concurrent and recent work that researchers need to situate their work in relation to. If these were the only changes, it would be reasonable to expect that fraction of citations to recent articles would increase and the fraction of citations to older articles would decrease.

To understand the evolution of the impact of older scholarly articles, we studied citations from articles that were published in 1990-2013. We attempted to answer four questions. First, how often are older articles cited in scholarly papers and how has this changed over time. Second, how does the impact of older articles vary across different fields of scholarship. Third, is the change in the impact of older articles accelerating or slowing down. Fourth, are these trends different for much older articles.

We computed the fraction of citations to older articles from articles published each year as the measure of impact for the study. For this study, we considered articles that were published at least 10 years before the citing article as older articles. To explore how changes in citation behavior differ across areas of research, we computed these numbers for 261 subject categories and 9 broad areas of research. Finally, we repeated the computation for two other definitions of older articles, 15 years and older and 20 years and older.

There are three major conclusions from our study. First, the impact of older articles, as measured by citations, has grown substantially over 1990-2013. Our analysis indicates that, in 2013, 36% of citations were to articles that are at least 10 years old and that this fraction has grown 28% since 1990. While there were field-specific variation in the evolution, the fraction of older citations increased over 1990-2013 for 7 out of 9 broad areas of research and 231 out of 261 subject
Second, the change over the second half (2002-2013) was significantly larger than that over first half (1990-2001) — the increase in the second half was double the increase in the first half. For context, most archival digitization efforts as well as the move to fulltext relevance-ranked search occurred over the second half (2002-2013).

Third, the trend of a growing impact of older articles also holds for articles that are at least 15 years old and those that are at least 20 years old. In 2013, 21% of citations were to articles ≥ 15 years old with an increase of 30% since 1990 and 13% of citations were to articles ≥ 20 years old with an increase of 36% over the same period.

Now that finding and reading relevant older articles is about as easy as finding and reading recently published articles, significant advances aren’t getting lost on the shelves and are influencing work worldwide for years after.

For the rest of this paper, we refer to citations to older articles as older citations for the sake of brevity. In the following section, we describe the analysis steps. Next, we present and discuss the results. After that, we describe related work.

2 Methods

For this study, we included all journals and conferences that were assigned to one or more categories in the 2014 release of Scholar Metrics. The Scholar Metrics inclusion criteria for publication venues were [3]: (1) publish 100 or more articles over 2009-2013, (2) at least one article must receive at least one citation over 2009-2013, (3) follow Google Scholar indexing guidelines. Scholar Metrics limits categorization into subject categories to English publications. Accordingly, this study covers all the English language journals and conferences included in Scholar Metrics. Scholar Metrics displays up to 20 top publications per subject category, and makes the remaining ones available via keyword search. This study covers all the categorized journals and conferences, not only the top 20 per category. Scholar Metrics also includes selected preprint repositories. Preprint repositories are not included in this study.

We used all the 261 subject categories from the 2014 release of Scholar Metrics. To explore trends in broad areas, we also grouped subject categories into nine broad research areas. We used the broad areas from Scholar Metrics for this, with one change — we separated Engineering and Computer Science. The citation patterns in these two areas are significantly different and this separation allowed us to explore the differences. We also added All articles as the union of all broad areas.

We created a group of articles for each subject-category-year and broad-area-year combination, such as Immunology for the year 2000 or Physics & Mathematics for the year 2004. Each category-year/area-year group included all articles published in the given year in all publications in the given category/area.

For each publication, we included all articles with a publication date within 1990-2013, both
inclusive. Note that each journal or conference can be associated with more than one subject category. Such publications are included in the computation for each category they are a part of.

For each category-year/area-year group, we computed the total number of citations as well as the number of citations to articles published in each preceding year. These citation counts (total citations as well as the number of citations for each preceding year) included all the citations from these articles, not just the citations to articles included in this study. We used this matrix to compute the fraction of citations to older articles. We used three different thresholds for older articles, $\geq 10$ years old, $\geq 15$ years old, and $\geq 20$ years old.

To see if the rate of change in the fraction of older citations is speeding up or slowing down, we computed the aggregate change for 1990-2001 (first half) and 2002-2013 (second half) for every category.

### 3 Results

Figure 1 presents the evolution of the fraction of citations to articles that are at least ten years old. It covers all publications included in this study. It shows that the fraction of older citations has grown steadily over 1990-2013. It also shows that the growth rate was roughly fixed over 1990-1999 and has accelerated after that.

Figure 2 presents the evolution of the fraction of older citations for all broad areas. It shows that 7 out of 9 broad areas saw a substantial increase in the fraction of older citations over 1990-2013. Two broad areas, *Chemical & Material Sciences* and *Engineering*, did not see a significant change.
bio: Life Sciences & Earth Sciences; bus: Business, Economics & Management; cs: Computer Science; chm: Chemical & Material Sciences; eng: Engineering; hum: Humanities, Literature & Arts; med: Health & Medical Sciences; phy: Physics & Mathematics; soc: Social Sciences

Figure 2: Fraction of citations to older articles for broad areas of research.

in the fraction of older citations.

Table 1 presents the fraction of older citations as well as the change since 1990 in numerical form (for ease of comparison). The change over 1990-2013 is computed as a percentage:

\[
\left( \frac{\text{fraction in 2013} - \text{fraction in 1990}}{\text{fraction in 1990}} \right) \times 100
\]

It shows that, in 2013, four broad areas had at least 40% citations to older articles, Humanities, Literature & Arts being the highest at 51%. Five broad areas had an increase of over 30% in the fraction of older citations over 1990-2013, the highest being the 56% growth seen by Business, Economics & Management.

Table 2 presents a histogram of the variation in the growth in the fraction of older citations for each of the broad categories. Buckets in the histogram count the number of subject categories whose growth is within a given range. It shows that, overall, 231 out of 261 categories (89%) saw an increase in the fraction of older citations. That is, the growth in the fraction of older articles has occurred over diverse fields - which vary greatly in terms of their publication frequency and citation patterns.

Looking more closely, it shows that 102 out of 261 subject categories saw a growth in the fraction of older citations that was over 30%, 44 of them with an increase over 50%. For two broad
Table 1: Change in the fraction of older citations over 1990-2013.

| Broad area                                      | Older citations in 2013 | Change since 1990 |
|------------------------------------------------|-------------------------|-------------------|
| Humanities, Literature & Arts                  | 51%                     | 18%               |
| Business, Economics & Management               | 46%                     | 56%               |
| Social Sciences                                | 43%                     | 31%               |
| Physics & Mathematics                          | 40%                     | 29%               |
| Life Sciences & Earth Sciences                 | 39%                     | 36%               |
| Engineering                                    | 34%                     | 3%                |
| Chemical & Material Sciences                   | 33%                     | 2%                |
| Health & Medical Sciences                      | 33%                     | 30%               |
| Computer Science                               | 28%                     | 39%               |
| All articles                                   | 36%                     | 28%               |

The count in each column is the number of subject categories whose growth is within the given range.

Table 2: Histogram of change in fraction of older citations for broad areas.

| Broad area                                      | < 0% | 0-20% | 20-30% | 30-40% | 40-50% | > 50% |
|------------------------------------------------|------|-------|--------|--------|--------|-------|
| Humanities, Literature & Arts                  | 2    | 10    | 5      | 5      | 2      | 2     |
| Business, Economics & Management               | 0    | 0     | 3      | 1      | 2      | 10    |
| Social Sciences                                | 4    | 10    | 11     | 8      | 9      | 10    |
| Physics & Mathematics                          | 2    | 3     | 10     | 4      | 2      | 3     |
| Life Sciences & Earth Sciences                 | 6    | 10    | 9      | 7      | 2      | 5     |
| Engineering                                    | 10   | 15    | 4      | 7      | 2      | 2     |
| Chemical & Material Sciences                   | 11   | 5     | 1      | 0      | 0      | 2     |
| Health & Medical Sciences                      | 3    | 30    | 17     | 8      | 2      | 9     |
| Computer Science                               | 1    | 2     | 2      | 0      | 2      | 11    |
| All articles                                   | 30   | 73    | 56     | 36     | 22     | 44    |

Note that some subject categories are included in more than one broad category. For example, Development Economics and Human Resources & Organizations are a part of both Business, Economics & Management and Social Sciences. As a result, the sum of the counts in a column in Table 2 e.g., number of subject categories that saw 0-20% growth, is expected to be larger than the number in the same column for All articles.
### Table 3: Change in the fraction of citations to older articles over 1990-2001 and 2002-2013.

| Broad area                                | Change over 1990-2001 | Change over 2002-2013 |
|-------------------------------------------|------------------------|-----------------------|
| Humanities, Literature & Arts             | 4%                     | 14%                   |
| Business, Economics & Management          | 19%                    | 37%                   |
| Social Sciences                           | 5%                     | 26%                   |
| Physics & Mathematics                     | 11%                    | 18%                   |
| Life Sciences & Earth Sciences            | 11%                    | 25%                   |
| Engineering                               | 2%                     | 1%                    |
| Chemical & Material Sciences              | -1%                    | 3%                    |
| Health & Medical Sciences                 | 4%                     | 26%                   |
| Computer Science                          | 8%                     | 31%                   |
| All articles                              | 9%                     | 19%                   |

Baseline for all growth percentages is the fraction of older citations in 1990.

3.1 Change in growth rate

Table 3 presents the change in the fraction of older citations over 1990-2001 and 2002-2013. Note that the baseline for all growth percentages in the table is the fraction of older citations in 1990. Using a common baseline allows us to compare the growth percentages directly.

It shows that, overall, the increase in the second half was a little more than double the increase in the first half. For all broad areas that had a non-trivial increase in the fraction of older citations over 1990-2013, the increase in the second half was substantially larger than the increase in the first half. For 6 out of 9 areas, the increase in the second half was at least double the increase in the first half.

3.2 What about even older articles?

Figure 3 presents the change in the fraction of older citations for two other definitions of “older” — at least 15 years old and at least 20 years old. It shows that the fraction of citations to even older articles grew continually over 1990-2013 and that the growth for the second half (2002-2013) was significantly larger than the growth for the first half (1990-2001).

Figure 4 presents the evolution of the fraction of citations to even older articles for all broad areas. It shows that 7 out of 9 broad areas saw a substantial increase in the fraction of citations to even older articles over 1990-2013. Two broad areas, Chemical & Material Sciences and Engineering, did not see a significant change.

4 Related Work

The study of citation age in scholarly articles has had a long history. Initial work in this area explored citation age as a way to measure the rate of “obsolescence” in scholarly literature [1, 6, 7]
Figure 3: Fraction of citations to even older articles across all papers.

Figure 4: Fraction of citations to even older articles for broad areas of research.

\textbf{bio}: Life Sciences & Earth Sciences; \textbf{bus}: Business, Economics & Management; \textbf{cs}: Computer Science; \textbf{chm}: Chemical & Material Sciences; \textbf{eng}: Engineering; \textbf{hum}: Humanities, Literature & Arts; \textbf{med}: Health & Medical Sciences; \textbf{phy}: Physics & Mathematics; \textbf{soc}: Social Sciences
One of the goals of studying obsolescence was to provide guidance to libraries regarding retention policies for older journal volumes. Early metrics for citation age included “half-life” and “Price’s Index”. Line pointed out the potential effect of the growth in the number of articles published on citation age metrics – if the number of articles grows rapidly, one would expect the fraction of citations to recently published articles to grow rapidly as well.

Exploring the notion of obsolescence from a usage perspective, rather than a citation perspective, Sandison found that, after an initial period, the usage of older issues of Physics journals at MIT didn’t decrease with age.

In an early paper exploring the potential impact of online access on scholarly communication, Odlyzko reported that after an initial period, frequency of access to online articles from several collections did not vary with age of articles. Based on this, he speculated that easy online access to digitized collections, as they become available, would lead to much wider usage of older materials.

More recently, Evans studied the impact of online availability of journal articles on the age of citations. Based on an analysis of citation indices from Thomson Reuters and a database of online availability of journal articles from Information Today Inc., he concluded that as more journal issues came online, the articles referenced tended to be more recent. He speculated that the shift from browsing print collections to searching online collections facilitated avoidance of older literature.

These results are in direct contrast with ours. We have found no evidence that online availability leads to a reduction in citations to older articles. To the contrary, we have found that, for most fields, the growth in the fraction of older citations accelerated over the period in which substantial numbers of articles became available online and full-text searchable.

These results are also contradicted by two other studies that were published around the same time as and that took different analysis approaches. Huntington et al studied article usage patterns based on web access logs for OhioLink’s journal collections. They found that there were two stages in access history of scholarly articles. The first stage spanned the first 8 to 9 years from publication date. Usage often declined over this period, the decline being sharpest in the first 2 to 3 years (a third over the first year and by about 60% by the third year). The next stage usually had a relatively stable level of usage. Analyzing HTTP Referer headers for journal article requests, they found that users arriving from search services were far more likely to view older articles than users arriving from a browse environment. They speculated that this difference occurred due to the relevance ranking approach used by web search services.

Larivière et al studied the citations from a large collection of articles published over 1900-2004. They concluded that the useful life of scientific publications has been increasing steadily since the 1970s. And that, in the aggregate over all scholarship, and for natural sciences and engineering in particular, the fraction of older citations has been steadily increasing. Our results are in agreement with theirs.
5 Conclusions

There are three major conclusions from our study. First, the impact of older articles, as measured by citations, has grown substantially over 1990-2013. Our analysis indicates that, in 2013, 36% of citations were to articles that are at least 10 years old and that this fraction has grown 28% since 1990. The fraction of older citations increased over 1990-2013 for 7 out of 9 broad areas of research and 231 out of 261 subject categories.

Second, for most areas, the change over the second half (2002-2013) was significantly larger than that over first half (1990-2001). Overall, the increase in the second half was double the increase in the first half. Note that most archival digitization efforts as well as the move to fulltext relevance-ranked search occurred over the second half.

Third, the trend of a growing impact of older articles also holds for articles that are at least 15 years old and those that are at least 20 years old. In 2013, 21% of citations were to articles \( \geq 15 \) years old with an increase of 30% since 1990 and 13% of citations were to articles \( \geq 20 \) years old with an increase of 36%.

In the introduction, we mentioned two broad trends that have the potential to influence the fraction of older citations. First, finding and reading relevant older articles is now about as easy as finding and reading recently published articles. This has made it easier for researchers to cite the most relevant articles for their work regardless of the age of the articles. Second, there has been a dramatic growth in the number of articles published per-year. This has significantly increased the number of recent articles that researchers need to situate their work in relation to by citing.

Our results suggest that of the two trends, the ease of finding and reading the most relevant articles, irrespective of their age, has had the larger impact. For most fields, retrospective digitization as well as inclusion in a broad-based search service with relevance ranking occurred in the second half of the period of study. As mentioned earlier, this is also the period that saw a larger growth in the fraction of older citations.

Now that finding and reading relevant older articles is about as easy as finding and reading recently published articles, significant advances aren’t getting lost on the shelves and are influencing work worldwide for years after.

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