Scientometrics (2023) 128:6357–6371
https://doi.org/10.1007/s11192-023-04874-4

Magnitude decrease of the Matthew effect in citations: a study based on Nobel Prize articles

Guoqiang Liang[1] · Yaqin Li[1] · Lurui Song[1] · Chaoguang Huo[2]

Received: 16 November 2022 / Accepted: 29 October 2023 / Published online: 4 November 2023

Abstract

The Matthew effect is widely used by researchers across disciplines. However, few studies have focused on this effect's magnitude variation on the background of the open access movement and expanded avenues to obtain information. Citation is the most widespread and basic form of scholarly recognition in the reward system of science, therefore, scientists are motivated to refer to the work of their peers where reference is due. This study assumes that the Matthew effect may not play a major role in science anymore and uses citations as a proxy to measure this effect, and calculates the citation fluctuation of Noble Laureates' key publications before and after winning the award during 1901–2016. The results show that the coefficient of variation of citations is smaller for publications published after 1980 than for those published before. The median of citations in chemistry is higher than that for in physics, physiology, or medicine. Additionally, over 90% of publications published after 1980 were recognized by their community pre-award, while the ratio consisted of 84% and 75% for 1940–1980 and 1900–1940, respectively. Furthermore, the time range between publication and year awarded plays a role in this phenomenon. The study suggests a potential magnitude decrease in the Matthew effect, which is a reminder that most researchers nowadays will recognize the importance of scientific breakthrough in its early stage.

Keywords Matthew effect · Nobel Prize · Citation analysis · Scientific breakthrough

An ancient Chinese philosopher in 500 B.C., Lao Tzu, pointed out in the Tao Te Ching: "It is the heaven's divine law to take from what has in excess in order to make good what is deficient. The way of man is otherwise: it takes from those who are in want in order to offer this to those who already have more than enough." In 1968, the "Matthew effect" in science was coined by sociologist Robert K. Merton (Merton, 1968); the name was taken from the parable of the talents or minas in the biblical Gospel of Matthew. According to

✉ Guoqiang Liang
Lianggq@bjut.edu.cn

✉ Chaoguang Huo
huochaoguang@ruc.edu.cn

[1] College of Economics and Management, Beijing University of Technology, Beijing 100124, China

[2] School of Information Resource Management, Renmin University of China, Beijing 100872, China

Merton, an abrupt change in rank owing to a prestigious award for past contributions will result in a corresponding jump in the future visibility of those contributions. Therefore, a publication will have greater citations when it is published after the author has won a prestigious award rather than when he has not won the award yet, considering that greater visibility will lead to more citations (McGillivray & Astell, 2019). Researchers have investigated whether receiving prestigious academic awards is associated with higher subsequent research productivity and status (Chan et al., 2014), and explored the institutional Matthew Effect in economics (Medoff, 2006).

Citation is the most widespread and basic form of scholarly recognition in the reward system of science; therefore, scientists are motivated to refer to the work of their peers where reference is due. With the rapid development of science and technology, the struggle for priority and the demand for scientific assessment in the reward system prompts researchers to read papers after working hours and far into the night (Wang et al., 2012). Scientists are more likely to pay timely attention to their peers' research and reference-related work when it was published online. The Matthew effect may be weakened under this assumption. This study analyzed the key publications of Nobel Prize laureates from 1901 to 2016, exploring the citation fluctuation before and after they won an award (pre- and post-award). We found that the Matthew effect diminished in magnitude after 1980; this may deepen our insight into this effect and provide a reference for the scientific assessment system.

Literature review

Matthew effect on citations

In his seminal paper, Merton (Merton, 1968) developed a concept based on Zuckerman's interviews with Nobel laureates. He stated that specific psychosocial factors affected the reward and the communication systems of science. In the reward system, eminent scientists receive disproportionately higher credit for their contribution to science than relatively unknown scientists do. Similarly, a scientific contribution will have a greater visibility when it was introduced by a high-ranking scientist in the communication system of science.

Literature on the Matthew effect has proven its explanatory value in multiple areas, and an abundance of studies on the Matthew effect have focused on citations. Some researchers (Guo et al., 2011) argue that the accumulated citations of Nobel Prize-winning articles increase in number after the prize. This was based on data from the 37 Nobel laureates who were awarded from 2003 to 2008 physics and chemistry as well as those who were awarded from 2006 to 2008 physiology or medical science. Moreover, Frandsen and Nicolaisen (Frandsen & Nicolaisen, 2013) pointed out that winning a Nobel Prize did not only boost the citations of the winner's monograph but also the citations of its references. They called this phenomenon the "ripple effect" of the citation chain, after exploring publications by Robert Aumann, who was a Nobel laureate of economics in 2005. Another study was implemented by McCabe and Babutsidze (McCabe & Babutsidze, 2020) to examine how Nobel Prize announcements in economics influenced the attention given to laureates' publications. After analyzing 1,171 pre-award articles by 50 Nobel Prize laureates from 1956 to 2010, as well as its benchmark papers, the authors found an approximate 23.3%

increase in annual citations compared to the pre-award period. Furthermore, the impact of the Prize on outsider citations exceeded that of insider citations.

However, some researchers have had opposing viewpoints. Azoulay et al. (Azoulay et al., 2018) explored the effect on citation to articles published before the researcher became the investigator for a revered biomedical institution. They found evidence of a small and limited post-appointment citation boost effect. Similarly, Amin and Wani (Amin & Wani, 2021) observed peak in citations before Nobel Prize after analyzing the accumulated citation fluctuation 5 years pre- and post-Prize, based on articles written by Nobel laureates in the chemistry from 2005 to 2008. Li et al. (Li et al., 2020) argued that, when comparing the average impact of Prize-winning papers in each of the 4 years before and after the Nobel Prize, a significant drop (11.1% on average) in the 2 years following the Nobel Prize was found; they called this phenomenon “Nobel dip”. In 2021, Hou et al. (Hou et al., 2021) found a similar phenomenon in which the Price Medal award may not necessarily boost the medalist’s academic impact, based on the structural variation analysis of 5241 articles written by medalists.

The most recent updates of the Matthew effect on citations focus on the causal inference aspect; Erfanmanesh and Moghiseh (Erfanmanesh & Moghiseh, 2018) found no statistically significant difference in citations in the post-medal period compared to the pre-medal one, based on the Wilcoxon tests on 26 Price medalists’ publication records in the Web of Science (WoS) database. A more comprehensive study was conducted by Farys and Wolbring (Farys & Wolbring, 2021), who analyzed the causal effect of the Nobel Prize compared to a synthetic control group. They found evidence of a Matthew effect on citations—this effect was more obvious for papers published within 5 years before the award.

Research on Nobel Prize articles (NPs)

Alfred Nobel mentions in his will that his entire estate should be endowed to those who brought the highest benefit to humankind: three for the sciences, one for champions of peace, and one for literature. The first Nobel Prize was awarded in 1901. Currently, the Nobel Prize has been considered a pinnacle of scientific achievement.

Research on NPs has been a hot topic in the scientific community for decades. Scientists have explored characteristics of sleeping beauties (Jiang Li & Shi, 2016; Ye & Bornmann, 2017), fundamental scientific breakthroughs (Liang et al., 2022; Hu & Rousseau, 2016b; Liang et al., 2020a, 2020b; Xu et al., 2022), and success or innovation (Chan et al., 2017; Wang et al., 2019), based on NPs. Two different types of NPs exist among the aforementioned research—some scholars regard all articles written by Nobel laureates as the NPs (Liang et al., 2019a, 2019b; Min et al., 2018), others regard the publications for which the authors win a Nobel Prize as the NPs (Jichao Li et al., 2019, 2022; Xi et al., 2021).

Hu and Rousseau et al. (Hu & Rousseau, 2016a, 2016b) divided research into two types according to the difference between the number of direct citations of NPs and their expectations: one, sparking articles with a low number of direct citations of the first generation but a high number of citations of the second generation; second, an igniting paper widely cited immediately after publication. Through a survey of 31 NPs in physics, physiology, and medicine in 2020, they found about 70% of NPs were igniting papers, and nine of the 10 Nobel Prize winners’ articles in chemistry were igniting articles published after 2011 (Xi et al., 2021).

The author (Liang et al., 2020a, 2020b, 2019a, 2019b; Min et al., 2021) used the innovation diffusion theory to study the diffusion breadth of NPs in the early stage of publication, and found that most NPs affected more disciplines in that stage. It is therefore feasible to use entropy to measure the disciplinary diversity of the literature cited in NPs.

Citation impact after awarded

Currently, relevant research on the relationship between awards and citation influence focuses on whether awards elicit an increase in the number of citations and the source of citations, the fluctuation of citation curves before and after winning awards, and the causal relationship between awards and the increase in the number of citations.

The current research is disputed regarding whether an award causes an increase in the number and source of citations. Some scholars (Guo et al., 2011) studied the papers written by 37 Nobel laureates in physics and chemistry from 2003 to 2008 as well as medicine or physiology from 2006 to 2008. They collected the papers signed by the first author or corresponding author of the above winners in the WoS database; the number of citations of these papers each year before and after the award was tested by paired *t*-test. It was found that the cumulative number of citations of papers after the award was higher than before the award. Additionally, Frandsen et al. (Frandsen & Nicolaisen, 2013) selected citation data from 2011 for research. The data source comprised conference papers, journas, chapters, monographs of Robert Aumann and the WoS database. It was found that winning the Nobel Prize did not only affect the number of citations of the achievements but also led to an increase in citations of the references of achievements.

However, several studies state that the role of awards in increasing the number of citations is limited. According to the analysis of 58 Nobel Prize-awarded papers in physics and chemistry from 2000 to 2010, the number of citations of papers published after the authors won an award did not increase significantly (Bao & Ma, 2015). Some studies (Pierre Azoulay et al., 2014), after investigating the winners of the Howard Hughes Medical Research Institute (HHMI) from 1984 to 2003, found than an award increased the number of citations, but the impact was little and short-lived. They questioned whether scientists who won the prestigious honor at home and abroad would change their status. Simultaneously, the study found that the promotion of awards on the number of citations was greater when the quality of the articles was uncertain (Pierre Azoulay et al., 2014). Additionally, some studies (Amin & Wani, 2021) took all papers collected in the WoS database and written by the winners of the Nobel Prize in Chemistry in 2005–2008 as examples, explored the changes in the number of citations in 5 years before and after the award, and found that the number of citations were the highest before the award.

To further clarify the impact of the award on the number of citations, relevant research (McCabe & Babutsidze, 2020) explored the impact of winning the Nobel Prize in Economics on the number of citations of the winning authors' papers before the award using strict randomized controlled experiments. After selecting 100 authoritative journals in economics and business, they matched the citation data of the Nobel Prize winner's key papers in the WoS database and found that the award promoted an increase in the number of citations of papers in the later period. Moreover, scholars outside the field of economics contributed significantly to an increase in the number of citations—the Nobel Prize can attract researchers outside of the field. However, this research focused on economics and did not analyze physics, chemistry, physiology, and medicine. Li et al. (Li et al., 2020) found in their research on key papers in the aforementioned fields that the average influence of the papers within 2 years after winning the Nobel Prize declined significantly, with an average decline of 11.1% in the first year after winning the prize, especially in physics (down to 18.1%), followed by medicine (13.4%) and chemistry (4.8%). This suggests that winning the prize did not increase the number of citations of these papers. Recently, Hou et al. (Hou et al., 2021) analyzed 5241 papers included in the WoS database written by 29 scientists who won The Derekde Solla Price Award. They explored the changes in the influence of these papers before and after the award using network structure variation method. They found that the award did significantly affect the number of citations of these papers.

Most studies believe that the award has little impact on abnormal fluctuations of the citation curve before and after the award. Some studies (Li et al., 2014) analyzed the citation curves of 4,4086 papers published by 341 Nobel laureates. They assume that if the mutation in the citation curve was not attributable to the award, it could be considered that the award did not profoundly affect the citation curve. Based on the symbolic test method, the author analyzed the relationship between the mutation in the citation curve and the Nobel Prize winning time and found that the citation curve was not significantly when the author won the Nobel Prize. Additionally, Bjork et al. analyzed the citation curves of the papers published by 57 Nobel laureates in economics using the Bass model and found that the citation curves of most papers conformed to a bell-shaped distribution, and that the number of citations before the award was the highest.

Research on the causal inference between awards and citations received much attention in recent years, but the research has been inconclusive. For example, Farys et al. (Farys & Wolbring, 2021), based on the key papers of 23 Nobel laureates in the WoS database from 2000 to 2011, studied the causal relationship between the change in citation influence in the Nobel Economics Prize and awards. Furthermore, they explored the impact of the awarding on this discipline and others. Through a randomized controlled trial, they found that winning a prize promoted a significant increase in the number of citations and confirmed the existence of the Matthew effect. However, Erfanmanesh et al. (Erfanmanesh & Moghiseh, 2018) did not support this conclusion. In their research on the number of citations of papers published by the Derekde Solla Price Award winners from 1984 to 2017, based on the WoS database, they tested the number of citations of the papers during 5 years before and after the award through the Wilcoxon rank sum test, and found that the number of citations after the award increased slightly than before the award; however, there was no statistical difference.

Theory of citation behavior

In 1927, at the Department of Chemistry of Pomona College in the United States, Gross began using the number of citations to evaluate scientific research achievements. Since then, citation analysis has been used to evaluate science and technology policies and discipline development (Bornmann & Daniel, 2008; Gross & Gross, 1927; Liang et al., 2018). As more studies use the citations as an indicator to evaluate the influence of scientists, institutions, papers, etc., the scientists' citation behavior has gradually attracted scholarly attention (Cronin, 1981; Nigel Gilbert, 1977). In summary, the citation behavior of scientists includes: honoring pioneers, affirming works, providing background materials, criticizing others' works, and so on. However, the exact citation behavior has long been a contentious issue among scholars.

According to the citation norm theory proposed by Robert K. Merton, citation behavior implies recognition of peer work, and only articles helpful for scientific research can be listed as references. Therefore, citation behavior is an important part of researchers' formal mandatory activity after careful consideration, and a norm followed by the academic community (Goodwin & Garfield, 1980; Small, 2004). Furthermore, it represents the importance or popularity of articles. The number of citations of papers or authors in most fields is positively related to the degree of peer recognition (Franceschet & Costantini, 2011; Wainer & Vieira, 2013). Based on this theory, Wang Lin (Wang & Yue, 2019) of Clarivate Analytics stated that from 1970 to 2019, the WoS database included nearly 46 million papers, but only two were cited more than 100,000 times, and more than 200 papers were cited more than 10,000 times. They believed that these papers are widely recognized by their peers and are popular research achievements.

The Social constructivist theory states that the citing behavior is first a rhetorical and persuasive tool, and the second function is influence (Cozzens, 1989). According to this theory, citation behavior has the dual attributes of being both rhetorical and influential. It falls at the intersection of the rhetorical and reward systems of the scientific community, for it reflects the influence of the two systems simultaneously. When introducing their research results, scholars need anecdotes to prove the differences between their research and that of the previous ones. They need to consider whether the research conforms to the traditional values of readers and logic to make it more persuasive. Second, citations are seen as a "currency" or "reputation" in the scientific community. Owing to this, recent studies (Teplitskiy et al., 2022) have explored the influence of citations from subjective and rhetorical aspects, as well as the importance or emotional polarity of citations (Aljuaid et al., 2021).

In summary, the extensive research on the "Matthew effect" in scientific activities has laid a solid foundation for this study. However, relevant studies have not been conclusive. Most studies based on small datasets and lack a time serious analysis of this effect. For example, is the magnitude of "Matthew effect" in scientific activities changes in recent years, or it always keep consistent? This becomes the starting point of this study.

Data source and method

Data sources

The data for this research was derived from the open data set "Prize winning paper records" of NPs (Li et al., 2019). This data set was jointly released by Dashun Wang of the Northwestern University and Santo Fortunato, director of the Institute of Network Science of Indiana University in 2019, and was introduced to the academic community in the form of open access. It contains 754 key papers by 545 Nobel laureates from 1900 to 2016 (the articles were published between 1887 and 2007). The accuracy of the results was verified using Nobel laureates. Based on the WoS database (covering the period from 1900 to 2016), this study matched the WOS number and citation information of NPs in the above data set, and 708 (93.9%) NPs were finally included in this study, all of which were published from 1900 to 2007.

Research hypothesis

As for the magnitude decrease of the Matthew effect, it can be interpreted in two ways: (1) fewer publications are influenced by the Matthew effect. In other words, the number of papers affected by the Matthew effect will decrease over time. (2) Fewer additional citations are brought about by the Matthew effect. Considering that the awarding time point may fall on different periods on the citation curve, it should be divided into two situations: first, when the award time point falls on the declining period of the citation curve, the cumulative citation times of the NPs in the 5 years after the award should be lower than the cumulative citation times in the 5 years before the award. Second, when the award time point falls on the rising period of the citation curve, the cumulative number of citations of NPs in the 5 years after the award should be higher than the same number in the 5 years before the award; however, most articles' numbers will not be several times higher. Figure 1 shows the conceptual model of these two types of the magnitude decrease of the Matthew effect.

If the Matthew effect does not exist, prestigious academic awards will not associate with higher subsequent research performance. Therefore, the following conclusion can be deduced: The cumulative number of citations of NPs in the 5 years after winning the prize will not increase significantly compared to the 5 years before winning the prize. If the situation does not conform to this assumption, the Matthews effect can be countered. In this study, we focus on the first type that "fewer publications are influenced by the Matthew effect", the second type that "fewer additional citations are brought about by the Matthew effect" was not included in the current version.

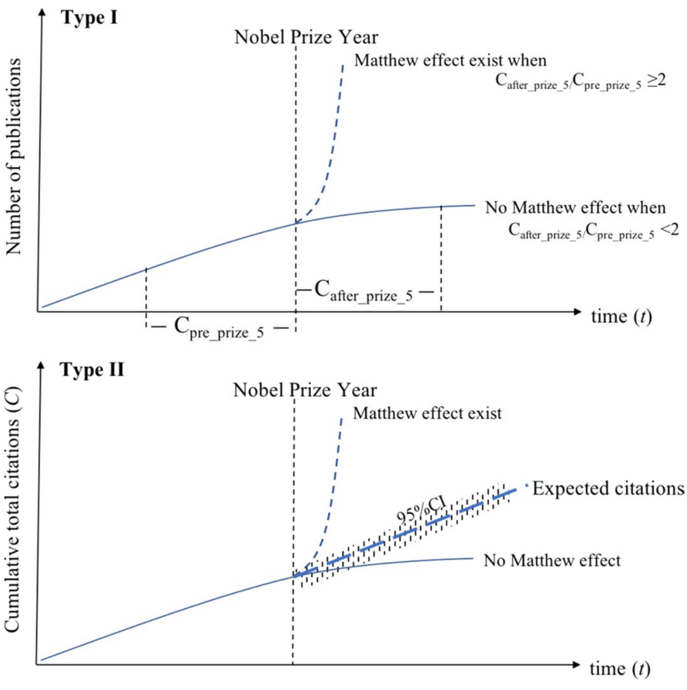

Fig. 1 Conceptual model of the magnitude decrease of the Matthew effect

Research indicators

Inspired by previous research (Amin & Wani, 2021, Rocciolo et al., 2022) and Fig. 1, this study calculated the following indicators: publication time ($Y_{\_Pub}$), cumulative citations (C), cumulative citations before awards (C_{Pre}), cumulative citations after awards (C_{After}), citations 5 years after publication (C_{Pub_5}), cumulative citations 5 years before awards ($C_{pre\_prize\_5}$), and cumulative citations 5 years after awards (C_{after_prize} _5). C_{Pre}/C_{After} is the ratio of the number of citations before and after the award, which reflects whether the number of citations of the NPs increased sharply after the award. However, to reduce the impact of citation inflation, this study uses $C_{after\_prize\_5}/C_{pre\_prize\_5}$ to measure the abnormal fluctuation in the number of citations after winning the award. The value less than or equal to 1 indicating the Matthew effect may not exist. Values between 1 and 2 indicate that the Matthew effect may exist. When the value is greater than or equal to 2, clear existence of a Matthew effect is indicated (We justified the thresholds from 1.5, 2.0 to 2.5, and the conclusion were in basic agreement on this point, therefore we set the value that greater than or equal to 2 to indicate the Matthew effect).

Research results

General information of Nobel Prize thesis

Statistical analysis of the general information of NPs reveals differences in the number of NPs cited in different disciplines: the median of NPs cited in the chemical field is 603, higher than that in the physical, physiological, or medical fields. However, the number of NPs cited in the chemical field fluctuated the most. The number of citations of NPs varied greatly in different years. The median of citations of NPs published after 1980 was the highest, followed by that of articles published in 1940–1980, and those before 1940. This indicates the existence of the factor of citation inflation. At the same time, the variation coefficient implies that the number of citations of NPs published after 1980 fluctuates less than those for the NPs of the other two periods. Regarding different time cutting points, the median number of citations after the award is higher than that before it; in addition, it fluctuates greatly. The median number of citations in the 5 years after the award, the 5 years before the award, and the 5 years after the publication, have little differences, as shown in Table 1.

Fluctuation of cited times of NPs in different years

Considering the potential impact of different years on the number of citations, this study divides NPs into three periods: before 1940, 1940–1980, and after 1980. We found that most Nobel Prize-winning achievements were concentrated between 1940 and 1980 ($n=400$). From the C_{Pre}/C_{After} ratio, 466 papers had a value less than 1, accounting for 65.82%. Among them, 170 papers before 1940 accounted for 93.41% (170/182), 253 papers from to 1940–1980 accounted for 63.25% (253/400), and 43 papers after 1980 accounted for 34.13% (43/126), as shown in Fig. 2A.

Figure 2B represents the distribution of C_{Pre}/C_{After} ratios of NPs in different fields in different years. The results showed that 54 of the 58 NPs in the chemical field from 1900

Table 1 Basic Information on the Cumulative Citation Times of NPs

Variable		Number of cases	*C*			Coefficient of variation (CV)
			Q_{25}	Q_{50}	Q_{75}	
Subject	Chemistry	216	182	603	1392	3.02
	Physics	215	196	550	1344	1.95
	Physiology or medicine	277	241	560	1271	1.77
Years	< 1940	182	49	134	365	2.38
	1940–1980	400	292	623	1386	2.78
	≥ 1980	126	732	1327	2738	1.42
Time cutoff	C_{Pre}	708	37	152	519	2.03
	C_{After}	708	97	263	771	3.37
	C_{pub_5}	708	14	46	132	2.46
	$C_{pre\_prize\_5}$	708	9	44.5	164.75	2.43
	$C_{after\_prize\_5}$	708	11	44	162	3.37

C is the cumulative total number of citations. Q25, Q50, and Q75 are the percentiles, which are the lower quarter, half quarter, and three-quarters, respectively

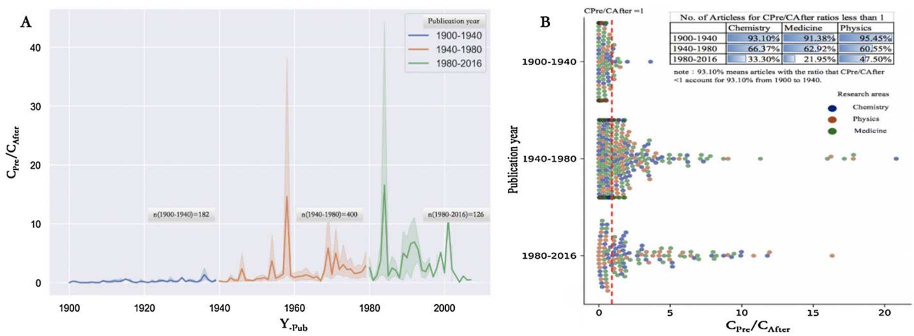

Fig. 2 Number of citations of NPs in different years

to 1940 had a value less than 1, so did 53 of the 58 NPs in physiology or medicine, and 63 of the 66 NPs in physics. As many as 75 of the 113 papers in chemistry from 1940 to 1980 had values less than 1, so did 112 of the 178 papers in physiology or medicine, and 66 of the 109 papers in physics. In 1980, 15 of the 45 papers published in the field of chemistry had a value less than 1, as did 9 out of 41 papers in physiology or medicine and 19 of the 40 papers in physics.

Fluctuation of cited times of NPs after 1980

Considering the coverage of the citation information in the WoS database, this section analyzes the fluctuation in the number of citations before and after the NPs in 1980. Since 1980, 126 NPs had been published, including 45 in chemistry, 41 in physiology or medicine, and 40 in physics. Figure 3 shows that the median number of citations in the 5 years

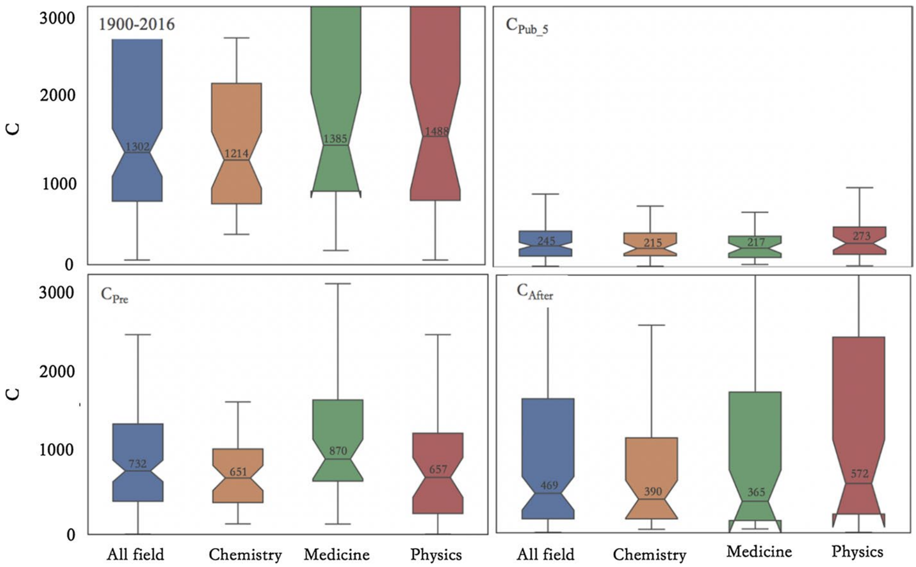

Fig. 3 The number of citations of NPs in different fields in different time periods after 1980 ($n = 126$)

after publication is lower than that before the award, and the median number of citations in various fields after the award is lower than that before the award.

Furthermore, the C_{Pre}/C_{After} ratio of 43 of NPs is less than 1, including 15 in chemistry, 9 in physiology or medicine, and 19 in physics. Figure 4 analyzes this phenomenon from different perspectives. Scatter- and line-plots indicate that an increasing number of NPs in recent years have C_{Pre}/C_{After} ratios larger than 1.

The aforementioned results can only roughly reflect the fluctuation trend of the number of citations of NPs before and after the award, and these results may be affected by citation inflation factors because of the long time window before and after the award. To reduce this potential impact, this study calculated the $C_{after\_prize\_5}/C_{pre\_prize\_5}$ ratio, that is, the fluctuation of citation times of NPs in the 5 years before and after the award. Figure 5 shows the proportion of $C_{after\_prize\_5}/C_{pre\_prize\_5}$'s ratio of ≤ 1, 1–2, and ≥ 2 in different publishing periods. The proportion of papers with a ratio ≥ 2 was the lowest after 1980, which

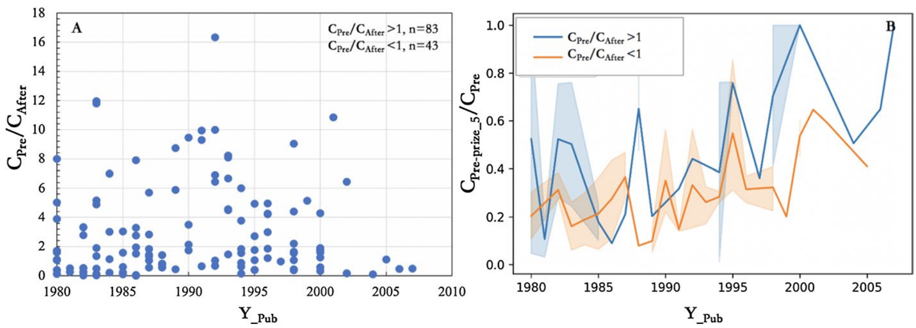

Fig. 4 The number of citations of NPs before and after the award in 1980

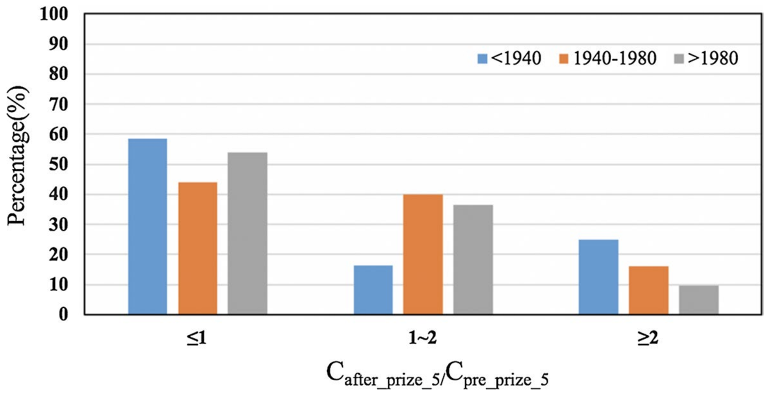

Fig. 5 Percentage of $C_{after\_prize\_5}/C_{pre\_prize\_5}$'s ratio in different periods

indicates that scientists, nowadays, are more likely to pay timely attention to their peers' research and reference- related work when it was published online.

This study also considers the time interval and discipline factors from NPs' publication to winning the Prize, to explore the potential influencing factors on the ratio. Table 2 shows there are 114 NPs with a $C_{after\_prize\_5}/C_{pre\_prize\_5}$ ratio of less than 2, accounting for more than 90% of the papers. This result shows disciplinary differences as well as the effect of the time interval between article publication and winning the award. The shorter the time interval, the greater the fluctuation of citation of the papers.

Figure 5 and Table 2 suggest that winning the prize has little influence on the fluctuation of citation times of NPs. To examine this, the correlation between the number of citations in the 5 years before and after the award is shown as $C_{after\_prize\_5}$ and $C_{pre\_prize\_5}$. As

Table 2 The fluctuation of cited times of NPs after 1980

T award—T publication/field	$C_{after\_prize\_5}/C_{pre\_prize\_5}$			Total
	≤ 1(*n* = 68)	1–2(*n* = 46)	≥ 2(*n* = 12)	
< 10				
Chemistry	− 1153	268	1013	128
Medical science	/	5919	/	5919
Physics	− 450	433	18,382	18,365
10–20				
Chemistry	− 902	500	/	− 402
Medical science	− 2041	2220	/	179
Physics	− 538	1029	170	661
≥ 20				
Chemistry	− 316	625	45	354
Medical science	− 664	988	52	376
Physics	− 210	75	/	− 135
Total	− 6274	12,057	19,662	25,445

"/"There is no eligible Nobel Prize thesis in this column; The figures in the table are the difference between the number of citations of qualified NPs in the five years after the award and the five years before the award the data we used here are not rank order, here, the Spearman correlation coefficient was used to measure the correlation. Results show that the correlation between $C_{after\_prize\_5}$ and $C_{pre\_prize\_5}$ is 0.91, exhibiting a high positive correlation and indicating that awards have little impact on the number of citations of NPs, as shown in Fig. 6.

Discussion and conclusion

Scientists' work is full of complexity, and is a high specialized activity. Most of the readers in other field is hard to fully grasp their research content, therefore, scientific contributions have to be evaluated by peers. Scientific community have carefully designed a scientific reward system to those who meet normative requirements, and the core essence of this activity can be regard as an assignment of credits. However, a complex relationship exists between scientists' contributions and their awards: do scientists' contributions lead to peer recognition and awards, or do these awards and approvals affect scientists' citation impact, such as owing to international awards? While many studies examine the "Matthew effect" in the scientific research system, the topic remains disputed.

Based on previous studies, our research examined key publications that won Nobel Prize from 1900 to 2016, matched the citation information based on the WoS database, and analyzed the fluctuation in the cited times of the above key publications before and after the award. According to the basic idea of the small probability inverse method in statistics, a hypothesis was established and verified. The results showed significant differences in the number of citations of NPs in different disciplines: the number of citations of NPs in chemistry was higher than that in physics, physiology or medicine; however, the number of citations of NPs in chemistry fluctuated the most, while the same for papers published after 1980 did not fluctuate as much than those in the other two periods. Our results suggest that the proportion of papers with the ratio value less than 1 gradually decreased from 1900 to 1940, 1940–1980, and after 1980; this implies that more recently published NPs have accumulated a higher number of citations before winning the award, which is similar to the research conclusions of Azoulay et al. (Pierre Azoulay et al., 2014). Additionally, the analysis of the fluctuation in the number of citations of NPs before and after receiving the

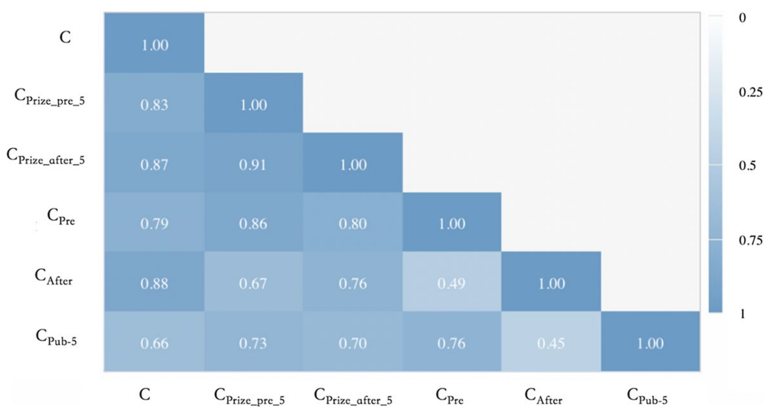

Fig. 6 Spearman correlation of citation of NPs at different times after 1980

award in different periods suggests a Magnitude decrease of Matthew effect in the science award system, and scientists are more likely to pay timely attention to their peers' research.

In addition, fewer publications influenced by Matthew effect, as well as fewer additional citations brought about by the Matthew effect are good proxies to decompose the Matthew effect. The former proxy emphasizes the number of publications. For instance, there are N1 and N2 articles influenced by the Matthew effect in the early and later periods, respectively (N1 > N2). This proxy does not focus on citations but on publication numbers. The latter proxy focuses on the number of citations, i.e., there are C1 and C2 citations for an article in the early and later periods, respectively (C1 > C2). In this study, the number of publications influenced by the Matthew effect was determined by comparing the citation counts before and after winning a Nobel Prize.

This study had a few limitations. In addition to factors associated with awards, the fluctuations in the number of citations may also be affected by publicity of results, authors and journals related factors, as well as the threshold for take-off stage of the papers (Kong et al., 2020; Liang et al., 2019a, 2019b). We also confront the fact that older studies may have been uploaded to the Internet by their publishing journals and/or other online services, and some nuance as how authors search for references should be considered. Finally, we assumed that a threshold value of 2 for $C_{after\_prize\_5}/C_{pre\_prize\_5}$ would indicate a clear existence of the Matthew effect; however, a more robust test should be conducted. The future research should analyze the characteristics of documents cited immediately after winning the award, which would be conducive to providing ideas for the identification of different citation motivations.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by GL, YL and CH. The first draft of the manuscript was written by GL, LS and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding This work was supported by National Natural Science Foundation of China (Project No. 72204014) and Beijing Natural Science Foundation Project (Project No.9232002).

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