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How research funding AMPS up citations and science diffusion : Insights from Nobel laureates in physics and physiology

Mario Coccia
Mahsa Rajabzadeh
Saeed Roshani

Mario Coccia *
CNR—National Research Council of Italy
IRCRES-CNR
Turin Research Area of the National Research Council
Strada delle Cacce 73-10135
Turin
Italy

Mahsa Rajabzadeh †
Department of Technology and Entrepreneurship Management
Allameh Tabataba'i University
Tehran
Iran

Saeed Roshani §
Department of Management Science and Technology
Amirkabir University of Technology
Tehran
Iran

E-mail
* mario.coccia@cnr.it
† Mahssa.rajabzadeh@gmail.com
§ Saeedroshani@aut.ac.ir

* (Corresponding Author)

Foundations and implications of science diffusion clarify how knowledge spreads within and between scientific communities and societies. This study focuses on examining the link between research funding and the citation rates of papers authored by Nobel laureates. The study uses a power-law model to investigate the connection between citation counts and the total number of papers published by Nobel laureates in physics and physiology (or medicine) in 2020, comparing research publications from funded and unfunded projects. The statistical analysis reveals that, in medicine, papers of Nobel Prizes' scholars from funded research, mainly on problem-driven topics, tend to receive more citations than publications from unfunded research. Conversely, in physics, a hard science, highly cited papers of Nobels are more often the result of unfunded research, originated by a curiosity-driven approach. When overall papers of scholars in research fields of physics and medicine are considered, in general papers based on funded research outclass papers with unfunded research. These findings underscore the pivotal role of research funding in facilitating the spread of scientific knowledge through citations and in shaping science dynamics over time and space. Implications of science policy and optimal allocation of financial resources for greater impact of research in science and society are discussed.

Keywords: *Nobel laureates, Nobel prizes. Research funding, Citations, Science diffusion, Knowledge creation. Medicine, Physics.*

This article has been corrected with minor changes. These changes do not impact the academic content of the article.

1. Introduction

Citations of scientific publications are a crucial measure of knowledge dissemination, for the progression of scientific fields, and of the performance of scholars, journals, and academic institutions [1-2]. Li et al. [3] highlight the role of authorship networks in influencing publication performance, while Petersen [4] investigates how collaboration between institutions impacts citation rates. Additional studies explore other factors, such as the contribution of multiple funding sources to citation performance [5], and the effect of research sponsorship on citation outcomes [6]. Yan et al. [7] argue that publications based on funded projects tend to attract more citations compared to those without funding. Similarly, Quinlan et al. [8] emphasize that funded research tends to receive more citations when published than unfunded studies (see also [9-11]). Zhao et al. [12] point out that research funding is crucial to the scientific reward system (cf. [13]), while Heyard et al. [14] show that funded research gains more public attention compared to non-funded studies. Roshani et al. [11] analyze specific fields, such as computer science, medicine, and economics, finding that funded research generally garners more citations than unfunded work. Additionally, Mosleh et al. [1] examine key disciplines—including agricultural and biological sciences, biochemistry, genetics and molecular biology, immunology and microbiology, neuroscience, and pharmacology, toxicology, and pharmaceutics—demonstrating that funded research not only receives more citations but also exhibits a higher scale factor in publications compared to articles having unfunded research.

Numerous studies in the fields of social studies of science and scientometrics have explored various aspects related to Nobel laureates. Hu et al. [15] examine the contributions of Nobel laureates to better understand how scientific breakthroughs occur. Turki et al. [16] focus on the scientific output of Nobel Prize winners to elucidate the nature of their discoveries. Li et al. [17] demonstrate that papers by scholars with Nobel Prize tend to exhibit lower levels of interdisciplinarity compared to those authored by non-Nobel laureates. Bjørk [18] finds that papers of Nobel winners in physics publish predominantly in specialized journals, such as *Physical Review Letters* and *Astrophysical Journal*, rather than in multidisciplinary journals like *Science* and *Nature* (cf., Ma et al. [19]). Kosmulski [20] investigates the contributions of Nobel laureates during the 2010s, finding that around thirty-two of them ranked among the top 6,000 scientists in terms of total citation counts. Kademani et al. [21] highlight the unique characteristics of these laureates' research activities, attributing their discoveries to a combination of factors such as education, scientific institution, intuition, serendipity, and luck [22-30]. Additionally, Nobel laureates tend to have a high number of multi-authored papers due to their extensive network of collaboration with prominent scholars and institutions (see also [31-35]). Bjørk [36] observes that research leading to Nobel Prize is generally conducted by scholars at around the age of 45 years, with the exception of physics, where discoveries are often made at a younger age and within a shorter time frame. Furthermore, the average time between a discovery and the awarding of the Nobel Prize is approximately 22 years. Heinze and Fuchs [37] highlight that Nobel laureates typically receive their education in countries such as the USA, the

UK, Germany, and France. In this context, an important but often overlooked question is to clarify the citation patterns of leading scholars in the natural sciences, with a focus on their funded or unfunded research described in papers. The objective of this study is to investigate how research funding influences the citation rates of papers authored by Nobel laureates across specific fields in the year 2020.

This work is part of a broader research effort aimed at understanding, explaining, and predicting the factors driving scientific progress to design research policies that foster the productive evolution of science and create a positive societal impact (cf., [1], [11], [28], [33], [34], [38-46]). Next section presents the methodology to analyze these interesting topics of social studies of science and scientometrics.

2. Methodology of research and data

Principal research questions

- What is the relationship between research funding and the citation rates of articles authored by Nobel laureates? And the similar relation of papers in between main research fields?

Data

This study examines articles published up until 2018 by Nobel laureates who were awarded in 2020 in the fields of physics and physiology or medicine (these terms are used interchangeably). The data were obtained from the Web of Science [47]. We searched for each Nobel laureate's name using the "RESEARCHERS" search module within the Web of Science database, limiting the publication types to "articles" and "reviews" published in journals. Articles published after 2018 were excluded, as the process generally takes from three to five years for a paper to accumulate a meaningful number of citations [48].

- *Sample and Data Sources for articles published in Medicine and Physics*

  The results for Nobel laureates are compared to the broader dataset in physics and medicine, utilizing publications from the Web of Science [47]. Articles within these key disciplines are categorized as follows:

  - Physics=("Physics, Applied" OR "Physics, Atomic, Molecular & Chemical" OR "Physics, Condensed Matter" OR "Physics, Fluids & Plasmas" OR "Physics, Mathematical" OR "Physics, Multidisciplinary" OR "Physics, Nuclear" OR "Physics, Particles & Fields") to find the articles related to Physics.

  The number of articles was 127,409.

  - The string search used to retrieve data for articles in Medicine was: WC=(Medicine, General & Internal" OR "Medicine, Legal" OR "Medicine, Research & Experimental" OR "Physiology").

  The total number of articles retrieved in Medicine was 55,419.

- *Measures*

In this study, we examined the articles and citations of Nobel laureates in medicine and physics who were awarded in 2020, comparing these results to the overall body of articles and citations within these fields. The number of papers published by Nobel laureates, as well as the total number of articles in the fields of medicine and physics, serve as the independent variables in the model, which will be explained in detail in the following section. The dependent variable is the total number of citations received by publications by Nobel laureates and overall articles in medicine and physics based on funded and unfunded research projects. The citation data were obtained from the "Time Cited" (TC) field for each article in the Web of Science [47] database.

Three data sets are analyzed in this study:

- Articles from studies that received funding for scientific research.
- Articles originating from studies that were not supported by research funding.
- Total: the combined number of articles published in journals including funded and unfunded research.
- *Scientometric modelling and data analysis procedure*

  The study utilizes a log-log power-law model (1) to analyze the relationship between citation counts and the total number of papers authored by Nobel laureates in physics and medicine, encompassing both funded and unfunded research. This model is also applied to the broader data set of articles within these disciplines under study here (cf., [49]).

$$\log(\mathrm{C}) = \log(\mathrm{k}) + \alpha \log(\mathrm{P}) \qquad [1]$$

  - C represents the number of citations.
  - P is the number of articles (funded, or unfunded research, or total with the sum of both).
  - k is the constant (intercept).α (regression coefficient) represents the scaling factor (the slope).
  - The parameter $\boldsymbol{\alpha}$ provides insights into the magnitude of the Matthew effect (i.e., the intensity of recognition or credit; cf., [50]) reflected by the total citations of articles across the categories of funded and unfunded research (cf., [51], [52]). Specifically, the scaling exponent ($\boldsymbol{\alpha}$) helps to predict the patterns of scientific diffusion and development ([1], [11], [49], [53]). The parameter $\boldsymbol{\alpha}$ can be:
- $\alpha > 1$, *super-linear growth*: Citations increase at a faster rate than the number of articles published, indicating a strong Matthew effect, where credit and citations accumulate more rapidly as the number of papers grows.
- $\alpha < 1$, *sub-linear growth*: Citations grow at a slower rate than the number of publications, suggesting a weak Matthew effect or even a cumulative disadvantage, where

credit and citations accumulate more slowly despite an increase in the number of papers.

- $\alpha = 1$, *linear growth*: Citations and publications grow at a similar rate, indicating an average Matthew effect, where the accumulation and growth of citations are proportional to the number of papers published.

The Ordinary Least Squares (OLS) method is utilized to estimate the relationship outlined in equation (1) and to calculate the parameters **k** and **α** [54]. Following this, a *t*-test is conducted to assess the statistical significance of the scaling exponents (multipliers) within the power-law relationship (1).

Results and analysis of findings

Table 1 presents data on the documents retrieved from the Web of Science [47], categorized by their funding status (cf. also Figure 1).

Table 1

Number of Documents and Citations for Articles Published by Nobel Laureates in Medicine and Physics based on Funding Status of Research Project in 2020

Field	Sources of Research Project	Papers	%	Citations	%	Nobel Laureates in 2020 (names)
Medicine	Funded + Unfunded	836	100	132,520	100	Michael Houghton Harvey J. Alter Charles M. Rice
	Funded	522	62.44	70,831	53.45	
	Unfunded	314	37.56	61,689	46.55	
Physics	Funded + Unfunded	364	100	38,168	100	Andrea M. Ghez Roger Penrose Reinhard Genzel
	Funded	142	39.01	13,821	36.21	
	Unfunded	222	60.99	24,347	63.78	

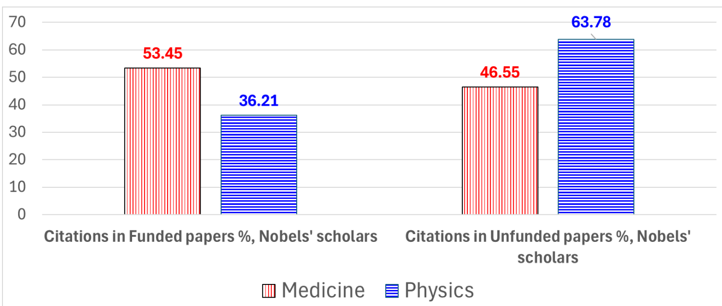

Figure 1

Citations concerning articles having funded and unfunded research of the Nobel laureates in medicine and physics in 2020

Table 1 demonstrates that, in 2020, in publications by Nobel laureates in medicine with funded research garnered a larger proportion of citations compared to their unfunded counterparts (53% vs. 47%). Conversely, in the field of physics, papers with unfunded research (*curiosity-driven science*) received a higher share of citations (64% vs. 36%). The scaling exponent (α) for both fields indicates that papers with unfunded research have a greater impact on citation than funded ones. In the case of medicine, the substantial citation advantage of funded research underscores a pronounced Matthew effect, suggesting that research funding plays a pivotal role in the dissemination of scientific knowledge, likely due to the applied nature of medical research, and *problem-driven approach* (e.g., treatment of diseases, cf., [55], [56]) having commercial implications, particularly within the pharmaceutical industry (cf. [57], [58]). By contrast, in physics, the citation impact of Nobel laureates' papers appears to be less dependent on research funding, which may be attributable to the discipline's focus on basic, rather than applied, that is a *curiosity-driven scientific inquiry.*

Table 2

Estimated Power-Law Relationship Between Citations and Articles of Nobel Laureates by Research Field and Funding Status

Research field of Nobel Laureates and year	Funding status of Research published in papers	α, scaling factor	R^2	*t*	N	2^α
Medicine 2020	Total (Funded + Unfunded)	1.45***	0.56	3.66	171	2.73
	Funded	1.44***	0.58	3.38	103	2.71
	Unfunded	1.62**	0.49	3.08	110	3.07
Physics 2020	Total (Funded + Unfunded)	1.34	0.45	1.83	53	2.53
	Funded	1.14	0.68	1.47	16	2.20
	Unfunded	1.37*	0.33	2.13	51	2.58

Note. ***α is statistically significant at p-value <0.001; ** α is statistically significant at p-value <0.01; * α is statistically significant at p-value <0.05; Total refers to the sum of funded and unfunded research; R^2 represents the coefficient of determination, while 2^α reflects the anticipated increase in citation impact when the number of articles doubles. The t-value corresponds to the student's t-statistic, and N indicates the sample size.

Table 2 reveals that the scaling exponent (α) for funded research in publications by Nobel Prize laureates in both medicine and physics exceeds 1 (one), yet remains lower than that of unfunded research in papers. This significant finding implies a stronger Matthew effect in documents based on unfunded research compared to funded ones. The elevated citation rates observed in unfunded research within papers may stem from the emphasis on basic research, the main natural curiosity approach to explain phenomena and the well-established reputations of leading scholars in these fields, which facilitate the accumulation of citations regardless of financial support [57-60].

In the broader field of medicine, we analyzed a total of 55,419 articles, which collectively received 1,124,936 citations across 377 journals. The analysis shows that 33,494 articles (60%) were based on funded research, accounting for 80% of the total citations. Conversely, the remaining 40% of articles, which were based on unfunded research, accumulated 219,956 citations, constituting 20% of the total. Similarly, in the field of physics, we examined 127,409 articles, with a total of 2,144,450 citations spread across 387 journals. Of these, 104,041 articles (81.65%) were based on funded research, generating 88.82% of all citations, while 18.35% of articles were based on unfunded research, contributing to 11.18% of the total citations (see Table 3 and Figure 2).

Table 3

Research Fields, Funding Status, Number of Papers, and Citations with Related Percentages

Research fields	Status of research published in papers	Number of Papers	%	Citations	%
Medicine	Funded + unfunded	55,419	100	1,124,936	100
	Funded	33,494	60	904,980	80
	Unfunded	21,925	40	219,956	20
Physics	Funded + unfunded	127,409	100	2,414,447	100
	Funded	104,041	81.65	2,144,540	88.82
	Unfunded	23,368	18.35	269,907	11.18

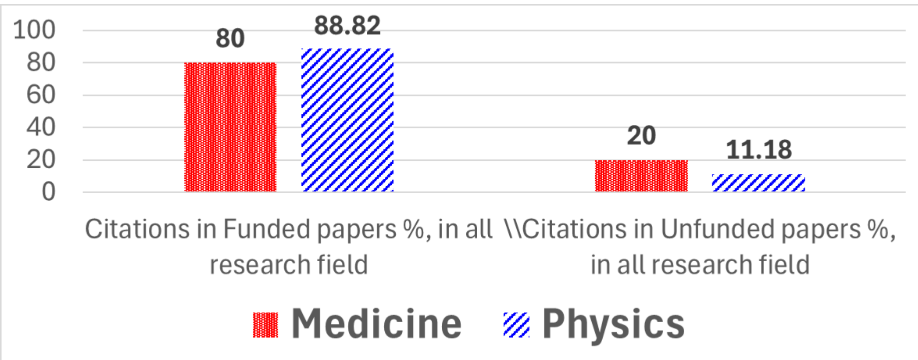

Figure 2

Citations concerning articles having funded and unfunded research in the fields of medicine and physics,2020.

Results suggest that funding is a source of citations and diffusion of science in scientific and social ecosystems. Table 4 displays the scaling exponent (α) of the estimated power-law relationship between citations and the number of articles across the categories of total, funded, and unfunded research for both medicine and physics. In medicine, the findings suggest a stronger Matthew effect for articles with funded research compared to articles with unfunded research. Specifically, the scaling exponent for unfunded research in articles is below 1, indicating a lower Matthew effect and a slower accumulation of citations as the number of papers increases. In physics, the scaling exponent for funded research in papers is 1.17, meaning that doubling the number of articles with funded research leads to a roughly 2.25-fold ($2^{1.17}$) increase in citations. For papers with unfunded research, the exponent is 1.02, showing that doubling the number of articles with unfunded research results in a 2.03-fold ($2^{1.02}$) rise in citations, suggesting an almost proportional growth between the number of papers and citations (α = 1.02).

Table 4

Estimated Power-Law Relationship Between Citations and Articles in Medicine and Physics by Funding Status

Research Fields	Funding status of Research published in papers	α, scaling factor	R^2	*t*	N	2^{α}
Medicine	Total (Funded + Unfunded)	1.11***	0.57	6.45	375	2.16
	Funded	1.25***	0.83	5.61	364	2.37
	Unfunded	0.71***	0.5	9.28	373	1.64
Physics	Total (Funded + Unfunded)	1.16***	0.78	7.35	385	2.24
	Funded	1.17***	0.82	6.87	382	2.25
	Unfunded	1.02***	0.66	9.56	382	2.03

Note: ***α is statistically significant with a p-value < 0.001; **α is statistically significant with a p-value < 0.01; *α is statistically significant with a p-value < 0.05. Total is the sum of funded and unfunded research. R^2 represents the coefficient of determination, 2α reflects the projected increase in citations based on the number of articles, t corresponds to the student's t-statistic, and N represents the sample size.

- *Inductive implications of results*

The findings from this analysis indicate several broad features of scientific dissemination and development:

- 1st Empirical Property: overall articles with funded research tend to receive more citations than papers with unfunded research in both physics and medicine.
- 2nd Empirical Property: articles with funded research exhibit super-linear citation growth, leading to a stronger Matthew effect, characterized by a greater accumulation of citations as the number of papers increases.
- 3rd Empirical Property: Funding has a greater influence on citation growth in fields that emphasize applied research and problem-driven topics (e.g., medicine) rather than in fields that are centered on basic research and curiosity-driven approaches (e.g., physics).

Additionally, key observations include:

- Empirical Observation 1: In medicine, which is more focused on applied research, *problem-driven topics*, articles with funded research by Nobel laureates receive more citations than unfunded ones. Conversely, in physics, where research is oriented toward basic science, and *curiosity-driven approaches*, articles with funded research tend to receive fewer citations than unfunded papers.

- Empirical Observation 2: The relationship between articles with funded research and citations for Nobel laureates exhibits super-linear growth, with a stronger citation growth in medicine (applied research) compared to physics, which is more focused on basic research.
- Empirical Observation 3: The relationship between papers based on unfunded research and citations for Nobel laureates in both physics and medicine shows a super-linear growth of citations that exceeds the growth seen in articles with funded research.

- *Theoretical and science policy implications*

  A theoretical implication of this study is that the nature of academic disciplines—whether they are more aligned with applied (soft) or basic (hard) research—appears to significantly impact the citation growth associated with research funding [61], [62]. Physics, as a key example of hard science, is marked by a high level of rigor and a strong emphasis on theoretical and curiosity-driven research. In such fields, citations and the dissemination of knowledge within scientific communities seem to be less reliant on funding sponsors and more associated with curiosity issues [60], [62]. In contrast, medicine, which serves as a hybrid field combining both applied and basic research elements, tends to benefit more from funding, primarily due to the practical and commercial applications of its research activities directed to the solution of problems, such as emerging diseases, mutant cancers, etc. [62-69].

Hence, the pivotal role of funding in driving citation growth and the dissemination of knowledge is particularly pronounced in fields focused on applied research, such as medicine, compared to those centered on basic research, like physics. This effect is often linked to the involvement of opportunistic stakeholders who leverage new knowledge and innovations in applied sciences to develop solutions to problems for societal challenges, frequently resulting in commercial applications in markets to satisfy needs and problems in society ([22], [28], [41], [70-75]).

Conclusions, limitations and ideas for future research

Our findings align with previous studies, reinforcing the idea that research funding is a key driver of citations in scientific publications and diffusion of knowledge. The statistical analysis reveals that, in medicine, papers of Nobel Prize laureates based on funded research tend to receive more citations than those from unfunded research. Conversely, in physics, a hard science, highly cited papers of scholars having Nobel Prize are more often the result of unfunded research, associated with a curiosity-driven approach. When overall papers of scholars in research fields of physics and medicine are considered, in general papers based on funded research outclass papers with unfunded research. The novelty of this study lies in demonstrating that this effect is more pronounced in applied research fields ([1], [11]). Another new insight is that in fields focused on basic research, such as physics, citations and the diffusion of knowledge occur even in papers with unfunded research (about curiosity-driven issues), independent of sponsorship. This aspect can be attributed to the unique nature of fields in basic sciences, which explore universal topics, benefit from extensive international collaboration networks, and are supported by countries aiming to maintain global leadership and competitive advantage in specific scientific areas, reinforcing innovation and economic systems to face competitive environments and crises [40]. These fields in hard sciences also possess an inherent strength in the scientific community, bolstered by various situational factors (external environmental elements that can unintentionally influence outcomes, (cf. [2], [40], [57], [59], [60], [76-77]).

The novelty and significance of the results are summarized in general properties that highlight key factors influencing scientific development:

- Research funding is a driver of science diffusion by higher citations
- Overall articles with funded research receive more citations than papers based on unfunded research in both physics and medicine
- Research funding has a greater impact on citation growth in fields oriented towards applied (and problem-driven) research compared to fields focused on basic research and curiosity-driven topics, such as physics.

These findings help clarify the role of funding in shaping the dissemination and recognition of scientific work. What this study contributes to the existing body of research in the field of the "science of science" is an understanding of the fundamental driving forces, such as research funding, that shape the patterns of scientific diffusion, considering the publications and citations of Nobel laureates, and comparing the dynamics under study to overall research field. The findings highlight that while funding is a crucial driver of citations in applied research fields, other factors can contribute to the citation impact and knowledge dissemination of papers having unfunded research, particularly in basic research fields like physics. These insights have important implications for research policy, offering guidance to policymakers on how to more effectively allocate R&D investments across various research areas to support diffusion of science and new ideas. By optimizing funding strategies, policymakers can better foster scientific progress, technological development, and, consequently, diffusion of science and new knowledge in society for sustainable human progress.

- *Limitations*

  These conclusions, while valuable, are tentative due to some limitations in the study:

  - The sources analyzed may only capture certain aspects of the ongoing relationship between citations and the scientific output of Nobel laureates, as well as within the broader research fields, both with and without funding. This aspect may leave out other critical dimensions of this science dynamic that deserve to be further investigated.

- Various situational and confounding factors, such as institutional characteristics, collaboration networks, and the autonomy of leading scholars, could play a crucial role in citation patterns related to research funding. These factors need further exploration (e.g., [30], [35]).
- Statistical analyses are restricted to specific years and disciplines. Future studies should expand the sample size to enhance the robustness of the findings. Furthermore, the study only considers articles published by Nobel laureates in 2020, representing a narrow timeframe that may not fully capture the broader scientific output of leading scholars. Extending the research to include laureates from other disciplines, such as chemistry or economics as well as additional years, would improve comprehensiveness. The reliance on Web of Science data, which may not cover all relevant publications or citations, could be addressed by incorporating other databases, like Scopus or PubMed, etc. Additionally, excluding articles published after 2018 may affect the robustness of the results, warranting caution when generalizing these findings.
- The study does not investigate the role of key funding sponsors in specific fields (e.g., Wellcome Trust, Bill and Melinda Gates Foundation, European Commission, etc.), the nature of funding (public vs. private), or the amount of research funding over time or funding to issues that have generated global crises, such as pandemic, to find rapid solutions. Analyzing these aspects could provide further insights into how different types of funding impact citation patterns and scientific development and diffusion over time and specific period having emergencies.

- *Ideas for future research*

  Despite these limitations, the results of this study clearly underscore the critical role of funding in driving citation growth, leading to a greater scientific impact and the diffusion of new knowledge in science and society. This aspect is especially evident in fields oriented toward applied research and problem-driven approaches, such as medicine, compared to basic research oriented also to curiosity-driven issues, like physics. While these conclusions are tentative, future research should incorporate more data and employ new methodologies to strengthen the findings presented here. A deeper investigation into the relationship between research funding and citations would aid in refining science and research policies to suit the unique needs of fields ranging from physics and chemistry to medicine and economics, with the goal of fostering vast diffusion of main studies for long-term scientific development and societal benefits. Moreover, further studies could examine the interaction between funding and other socioeconomic factors that influence the level of publication and citation rates across research fields, such as collaboration networks, emerging global challenges, crises, and conflicts [78-86]. In conclusion, much more detailed research is required to explore the intricate relationships between funding, scientific output, citations, and the subsequent diffusion of science and new knowledge in society. Understanding these driving forces will help to improve the research policies of nations that effectively promote the advancement of science and, ultimately, the progress of human society.

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