Online Resource 1

Is China the New Dominant Scientific Powerhouse?

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Materials and Methods

Appendix A: Descriptive Statistics

Table A.2, Panels A, B, and C show summary statistics of our "article x year" panel database over the period 1980 - 2022. Panel A reports publishing output by geographic region and field of output, while Panel B presents the above-mentioned data disaggregated by journal quality. Panel C reports citation data.

Panel A of Table A.2 reports productivity across 4 regions, China, U.S., Europe, and Rest of World. We show mean, median, standard deviation, minimum, and maximum, per year. Data is organized by field, and within each field, we rank regions by mean productivity. In chemistry, for example, we see that Europe has the highest mean number of articles, where they have published 32,717 author-equivalent articles in a given year. In fact, Europe is the highest in each of the Nobel fields of chemistry, mathematics, medicine, and physics. The "rest of the world" comes first in the "other" category that spans all publications outside the Nobel fields. Panel A also reports that China is the lowest of all the regions in every single category. This is expected given that these descriptives span a period of 42 years, and China's ascent has been notable only in the last 20 years of our sample period.

Panel B reports results by journal quality, the top 1%, top 2 - 10%, and the bottom tier journals. Within each category of journal quality, we rank regions by the mean number of yearly publications. We see that when it comes to the top 1%, there are a total of only about 17,000 articles published annually, globally. Of these, the highest share is the U.S., followed by Europe, the rest of the world, and finally China. When it comes to lower-quality journals, we see that Europe consistently comes at the top. China is always last.

Appendix B: Research Design and Methodology

This section outlines the methodological framework not covered in the main text underlying our empirical analyses, with particular relevance to Figure 1 (analysis of productivity in all journals) and Figure 2 (analysis of productivity in Top-3 journals)**.**

For the analyses below, productivity is reported for four regions, China, U.S., Europe, and Rest of World, and across the Nobel-aligned fields of physics, chemistry, mathematics, and medicine. We do not further split the main analyses into regions and countries, although Australia, Japan, India, and Brazil show consistent patterns of academic success in the underlying data.

All regional productivity measures use author-equivalent scoring: each paper is allocated across regions in proportion to the authors' affiliations. Citation-based journal tiers are used to distinguish overall output from higher-impact publication activity.

Journals are grouped into three citation-based tiers: the top 1%, the top 2 - 10%, and the remaining journals. This classification is used only as a proxy for journal quality, and our inferences are robust to reasonable alternative cutoffs. We further delineate our data by journal quality to better understand the impact of China on the academic research landscape. To do so, we rely on citation analysis. Developed more than 75 years ago (Garfield, 1955, 1972), article

citations offer an easy to calculate measure of the diffusion and acceptance of ideas, and as a result, a research article's impact on the next generation of scientific innovation. Einstein's work on relativity and quantum mechanics has cumulatively garnered more than 22,189 citations (Einstein, 1905; Einstein et al., 1935), while Watson and Crick's work on the DNA's double helix has been cited 11,000 times (Watson & Crick, 1953). Citation analysis has become an established tool in the evaluation of scientific productivity (Wade, 1975), and especially in ranking articles and journals (Garfield, 1972).

The top 1% of journals include a select group of 155 journals that are widely recognized for their academic excellence and impact. They include journals such as Science, Nature, the New England Journal of Medicine, Lancet, Chemical Society Review, Review of Modern Physics, Cancer, Nature Materials, and Advances in Physics. All these journals have consistently high citations in our sample period. The middle-tier journals whose citations are in the top 2 - 10% get cited on average 47 times per paper in our sample period and indicate moderate impact. Finally, our remaining 90% of journals get minimal citations in our sample period (median citation per article is zero).

Journal rankings are constructed using age-adjusted, within-field citation scores after excluding journals with very low publication counts. This preserves the field-specific basis for the supplementary analyses without repeating the full ranking procedure from the main text.

A second quality categorization identifies the Top-3 journals in each field. This benchmark captures a small set of field-leading outlets that are especially relevant for analyses of elite scientific output.

This categorization into the Top-3 is important because of the Chinese government's drive for top quality. Chinese researchers can receive up to $165,000 bonuses for publishing in either Science or Nature (Quan et al., 2017). Large bonuses for scientific publishing were prevalent for the period 2000-2020, until the Chinese science and education ministries banned academic institutions from such practices, citing the rise of perverse incentives and concerns about academic integrity (Mallapaty, 2020). However, China is not alone in this practice of encouraging top publications, many other countries provide incentives for top publications including India, Turkey, and Saudi Arabia, among others (Abritis & McCook, 2017).

For Figure A.1, citation intensity is calculated on an author-equivalent basis and standardized by year and field so that citation patterns are comparable across disciplines and time.

Appendix C: Research Productivity by Geographical Regions

Figure 2 provides additional detail on regional productivity patterns. To get a finer understanding of the productivity of Chinese research, we next examine scientific productivity in the Top-3 journals in each of the respective Nobel fields. Figure 2 presents these results. The quadrants are organized by field: chemistry, medicine, mathematics, and physics. We also present results on economics and the remaining fields for completeness. In Top-3 journals, China dominates only in mathematics, and this progress has occurred exclusively in the years 2018-2022. These results are in sharp contrast to Figure 1 in the paper, where we see that China has shown significant strides forward over the period 2000-2022. In Figure 2**,** we see that such progress has not yet fully translated to domination of the Top-3 journals.

Appendix D: Scientific Impact of Chinese Research

In Figure A.1**,** we examine the impact of Chinese research as measured by citation intensity. We use standardized citation data adjusted by year and field, where the data points for the four regions add up to 1. As argued by Van Noorden (2023), we report analyses only on the Top-3 journals to eliminate noise in the citation patterns in lower-level journals.

Figure A.1 reports that citations for Chinese authors have been increasing over time, occupying the space traditionally held by scientists based in Europe and the U.S. These include the fields of chemistry, physics, and mathematics. Figure A.1 complements well the results obtained in Figures 1 and 2: in addition to the rise of Chinese scientific productivity, its impact has been commensurately increasing. It is of note that citations follow publication often by a 1-10 year lag, hence it is not surprising that the rise of Chinese science in the last two decades is exhibiting its impact only now.

Appendix E: Univariate *t*-tests on Scientific Output

Table A.3 presents univariate *t*-tests on scientific output. These analyses complement the graphical analysis presented in Figures 1, 2, and A.1, and provide scientific solidity to our inferences. We compare Chinese research productivity to papers published by scientists based in the U.S., since they are traditionally the largest producers of academic research output (Leydesdorff & Wagner, 2009). In Panel A of Table A.3, we present tests on the difference in means for (1) total scientific output over the five-year period 2018-2022, China versus the U.S., (2) comparing productivity in the top 1% of journals, (3) comparing in 2 - 10% of journals, (4) comparing in the bottom tier journals. Results are presented in Table A.3.

Table A.3 reports results for the period 2018-2022. U.S.-based authors constitute 13.9% of all academic papers published, while Chinese authors are 26.4%. This difference is statistically significant ($p < 0.01$). However, when we examine the top journals, the results shift, where the U.S.' share is 38.5% while that of China is 16.2%. However, China is by far the highest producer in the world when it comes to scientific output below the top 1% of journals. We see that in the Top 2 - 10% of journals, and bottom tier journals, Chinese output is 27.6% and 26.7%, respectively, while that of North America is 19.6% and 11.3%. All these differences are statistically significant at the 1% level.

In Panel B of Table A.3, we take our analyses one step further by examining only Top-3 journals for each of the Nobel fields. Results show an even starker difference. The U.S. produces anywhere from one-third to one-half of all top scientific articles globally. The numbers are 38.9%, 51.5%, 30.7%, 32.9%, and 48.9% for chemistry, medicine, physics, mathematics, and "other," respectively. U.S. productivity is significantly higher than that of China, which has 12%, 2.2%, 11.7%, 21.9%, and 8.3%, respectively, in these same categories. When we aggregate all these scientific fields into one, as we do in the last row, the U.S. produces 44.9% of all scientific publications in the top 3 journals, while the same number is a quarter of that for Chinese researchers, at 10.3%. All these differences are statistically significant at the 1% level.

In Panel C of Table A.3, we examine citation data for Top-3 journals. Citations are counted using the methodology employed in Appendix B, and data are on a per-paper basis. We see that in chemistry, the mean Top-3 publication by a U.S. author gets cited an average of 57.05 times, while the corresponding number for Chinese authors is 24.33 times. The numbers are 196.58 versus 61.72, 51.58 versus 29.02, 25.75 versus 16.36, 88.67 versus 23.84, for medicine,

physics, mathematics, and "other," respectively. All these differences are statistically significant at the 5% level or better (with the difference in mathematics being significant at the 10%-level). The final row, "All Disciplines Combined," aggregates the data above, and the results are stark: each paper in the Top-3 authored by a U.S.-based team of authors gets cited roughly three times more than a corresponding team of Chinese authors.

In sum, looking at Panels A, B, and C of Table A.3, we conclude that although China has significantly increased its scientific output and dominates in total publishing volume. This applies to both the number of publications in premier journals and their impact as measured through citations.

Appendix F: Quality and Quantity of Chinese Research Productivity

Table A.4, Panel A, presents descriptive statistics on our dataset, where we look at Top-3 publications by time period and by field. We compare the citation impact of papers authored by a majority of Chinese researchers to those from the U.S., and other countries ("*Other Majority*"). We see that in the earlier period, 1980-1994, China had only 53 author-adjusted articles in premier journals. This number increased to 497 in the middle time period, while it stands at 2,624 articles. This is significantly less than that of the U.S. in the 2010 - 2022 period, at 20,050. However, we see that the citations per article, for China-authored research papers, in the most recent time period, are higher than those of the U.S. (363 citations per article, versus 311). We note that these are unstandardized citations, and there is a large heterogeneity in citations across scientific fields. Medicine, for example, where the U.S. dominates, has a higher citation rate than mathematics, where China excels. To arrive at a field-adjusted citation measure, we report *Citations (standardized)* in Column 3. We standardize citations by the total number of citations in a year-field combination to ensure comparability across years and disciplines. When comparing this number, we see that Chinese papers have a value of 0.28% as compared to 0.12% for U.S. authored papers. The average Chinese paper published in a Top-3 publication outlet gets cited ~2.3 times as much as a paper authored by a team from the U.S., a surprising and unexpected result. These results are a large contrast to the earlier time period, where Chinese authored papers received much less citations than U.S. ones (e.g., 1980-1994).

In Panel B of Table A.4, we present descriptive statistics in the most recent time period 2010-2022, breaking down results by the Nobel fields. We see that the citations per article is similar across U.S. and China (e.g., 515 for China and 481 for U.S., in chemistry), except for medicine - where China has roughly 4 times more citations. However, when we examine standardized citations, we see that papers authored by Chinese scholars have uniformly higher citations. These range more than 3 times for medicine (the highest differential), to slightly higher in chemistry (0.5976% versus 0.59%). This much higher citation impact in the field of medicine, for China, is surprising, since it is long embedded that the research with the highest impact originates in the U.S. (MacLeod & Urquiola, 2021). However, when we do supplementary analysis (unreported), we find that the effect is mainly explained by Covid-19 papers that were authored by Chinese authors, published at the height of Covid-19 and the immediately ensuing period.

To examine whether these descriptive results translate into significant statistical differences, we conduct multivariate analyses. We present our results in Table A.4, Panel C. The dependent variable is citation per article (*Citation_Article*), standardized by the total number of citations in a year / field combination to make citations comparable across various disciplines

and years. Our independent variables of interest are *China_Authors* (the percentage of Chinese authors per article), *USA_Authors* (the percentage of U.S. authors per article). We include a number of control variables, including the extent of internationalization of a paper (*International*), where a more global team garners higher impact, the number of authors (*log_Authors*, used in logarithmic form), as more authors imply a bigger network and citation pattern. Finally, we use an indicator variable for each of our 14 journals (journal fixed effects). Given that we utilize *China_Authors* and *USA_Authors* simultaneously, all other author teams from other countries constitute the baseline effect absorbed in the constant. Hence, all results are in comparison to "other countries."

Results support our conjectures. We see that *China_Authors* is insignificant in Column 1 (full time period), whoever, when we split the data into 3 distinct time periods, 1980-1994, 1995-2009, 2010-2022, inferences change. In the earlier time period, *USA_Authors* is positive and significant, while *China_Authors* is negative and significant. In the latest time period, results switch. Now, Chinese papers are the ones that are highly cited, while papers authored by U.S. scientists are no different than baseline publications in the Top-3 journals. This is a surprising result. Next, in Panel D, we conduct the same regressions for each Nobel field, and only for the most recent time period 2010-2022. Here we see that citations by Chinese authors exceed those of the U.S. in chemistry and in physics. While in medicine, mathematics, and in "other," citation patterns are similar.

In sum, results in Table A.4 indicate that the quality of Chinese academic research has been uniformly increasing in our time period, where the latter period, 2010-2022, exhibits higher impact as compared to the earlier period. These results are surprising and support our findings in Tables A.6 and A.7, showing there has been a remarkable rise in Chinese productivity in the top journals. Results in this table also suggest that within the top tier of academic innovation, the so-called premier journals, the impact of Chinese science within these papers has increased, and exceeds that of the U.S., driven by the strong impact of Chinese papers in physics and chemistry.

Appendix G: Measuring China's Scientific Influence Factoring in the Diaspora

Our analyses thus far have focused on researchers based in China. However, this understates the influence of Chinese researchers on the global innovation landscape. It is well known that China exports a large number of its scientists abroad, whether to pursue advanced education or to work (Cyranoski et al., 2011; Franzoni et al., 2012; Jia, 2020).

To be able to examine this issue and construct Figures 3 and 4, we use a nationality-name dictionary to conduct a name-based author disambiguation, where we filter out family names such as "Wang," "Zhang," or "Chen" if they are located at a non-China based university. We count Chinese-name authors in each region and compute the share of Chinese-linked science abroad, enabling us to estimate the global footprint of the Chinese scientific diaspora. We are not able to distinguish between first versus second generation Chinese authors. However, it is likely that such data points refer to first-generation Chinese, rather than second, third, or older immigrants. Most education-based immigration started after Premier Xiaoping's reforms, and numbers grew rapidly starting in the 1980s (Bound et al., 2009; Zweig et al., 2004).

Table A.5 presents our results. We again examine papers appearing in the Top-3 journals, where from 140,376 published articles, 31,202 have at least one Chinese author (22.2%). This data is distributed as follows, with 15.2% of these 140,376 papers from Chinese researchers located in the U.S., 4.2% of authors located in China, and 2.7% located in Europe. To compare

this to the U.S., from the 140,376 papers appearing in Top-3 publications, 84,918 papers include at least 1 U.S. author, while 21,381include a Chinese co-author.

Using the example of mathematics, Chinese researchers have a notable penetration. 34.1% of math papers have at least one Chinese-surname author globally. 26.1% of mathematics papers have a Chinese first author, and on average, 22.8% of total authors in mathematics papers are Chinese. The penetration in Europe is low, with 3%, while it is substantial in the U.S. (18.2%). 13.5% of global mathematics papers are published by authors based in China, where 3.6% of these are researchers with non-Chinese names. When it comes to international collaborations, there are 560 papers in teams including European and Chinese scientists, while 2,080 papers involve U.S. and Chinese researchers.

Chinese researchers are the most prominent in mathematics and the least in medicine. A large number of Chinese researchers are based in the U.S. rather than China itself. The low numbers in medicine are not surprising, most likely due to language-related barriers (medicine is language-intensive) and the regulated Chinese medical fields do not enable Chinese doctors to homologate licensing and pursue advanced medical training in the U.S. Chinese students make up roughly 40 - 45% of science and engineering doctoral candidates (National Center for Science and Engineering Statistics, 2025), while they comprise less than 5% of medical school students (Boulet et al., 2006). This low number is expected since the majority of U.S. universities offering medical degrees do not accept international students (Association of American Medical Colleges, 2026).

To better understand the distribution of Chinese researchers abroad, we provide further details in Panel B of Table A.5. Of the 401,465 authors who have published at least one paper in the premier journals, 41,584 have a Chinese surname, amounting to 10.4% of the total. The corresponding number is 1.8% in Europe and 6.8% in other countries. It is evident that the U.S. is the favorite destination for Chinese scientists residing abroad, with 75% of them working in the U.S. To get a global overview, from the 810,741 authors based outside of China who have published in top journals, 6.8% have Chinese surnames.

Figure 3 shows the overall time series of Top-3 journal paper counts for the USA and China from 1980 to 2022, before and after reassigning USA-affiliated papers with at least one Chinese-surnamed author to China. Light-colored lines represent original counts based on institutional affiliation, while dark-colored lines indicate adjusted values. Prior to adjustment, the USA consistently leads. From 2018 to 2022, the USA averaged 2,079.6 papers per year compared to 606.8 for China. After reassignment, China surpasses the USA in recent years, averaging 1,659.8 papers per year versus 1,026.6 for the adjusted USA. The adjustment reallocates 50.6 percent of the USA's Top-3 output. This surname-based method provides an upper-bound estimate of diaspora contributions and may involve some misclassification. Results using author-equivalent scores show a similar pattern, although the USA retains a slight lead under that metric.

Figure 4 breaks this analysis down by field to examine disciplinary variation in the diaspora effect. It presents annual Top-3 journal paper counts from 1980 to 2022 for the USA and China across four fields: (a) Chemistry, (b) Physics, (c) Biology/Medicine, and (d) Mathematics. Light-colored lines indicate original counts, while dark-colored lines reflect adjusted counts after reassigning USA-affiliated papers with Chinese-surnamed authors to China. Across all four disciplines, the USA leads throughout most of the pre-adjustment period. However, following reassignment, relative positions shift substantially in recent years.

In Chemistry, adjusted China averages 112.8 papers per year from 2018 to 2022, compared to 37.8 for the adjusted USA, reversing the original ordering. In Physics, adjusted averages are 52.6 for China and 37.8 for the USA. In Biology/Medicine, the USA maintains a lead after adjustment, 243.4 versus 155.0, though the gap is markedly smaller than under original counts, 367.0 versus 31.4. In Mathematics, the shift is most pronounced. Adjusted China averages 353.4 papers per year compared to 121.6 for the adjusted USA, representing a clear reversal of the original ranking.

Bar charts summarize 2018 to 2022 averages for each field. The surname-based reassignment reallocates a substantial share of USA Top-3 output across disciplines, with particularly large proportional effects in Mathematics and Chemistry. As in the aggregate analysis, this approach provides an upper-bound estimate of the diaspora effect and may misclassify some non-Chinese East Asian authors. Overall, the field-level results indicate that the magnitude of the diaspora effect varies across disciplines, being especially strong in mathematically intensive and physical sciences fields and comparatively smaller, though still substantial, in Biology/Medicine.

Appendix H: Ranking of Scientific Innovation in Top-3 Journals

Table A.6 reports country-level Top-3 productivity using fractional publication counts, calculated by author location and academic discipline over the recent periods shown in the table.

When it comes to the Top-3 journals, we see that over the most recent period, the U.S. comes first with a score of 1,539 publications, followed by China, the UK, Germany, France, Japan, Switzerland, Australia, Canada, and the Netherlands, forming the top 10 whose constituents remain the same in both periods analyzed. We see that after the country ranked 20th (India over 2015 - 2022 and Brazil over 2020 - 2022), countries have less than 1% the productivity of the top-ranked U.S., and provide a negligible contribution to total scientific production.

Panel B of Table A.6 summarizes changes in the regional distribution of Top-3 publications between 2000 and 2022, providing context for how China's growth relates to changes in the U.S., Europe, and the Rest of World.

Table A.6, Panel C, reports countries with the highest number of publications in the Top-3, over the most recent period (2020 - 2022). We see that the U.S. has the highest number with 1,539 publications, which is roughly four to six times higher than both China and the United Kingdom, at 413 and 277 publications, respectively. Germany and France complete the top 5, while the rest of the top 10 comprises the usual suspects of the relatively rich developed nations (Japan, Switzerland, Australia, Canada, and the Netherlands).

To provide a better perspective, we standardize these results by the size of the population of each country. Panel C indicates that there is a large variability where three countries with similar wealth, France, the U.S., and Switzerland, show different scientific productivity. The U.S. has a population roughly 5 times the size of France, however, it has a scientific output that is 15 times higher. In contrast, Switzerland, a relatively small country with 9 million inhabitants, has a scientific productivity that is more than double the size of the U.S., adjusted for its size. This table also shows that China, although it has the second-highest aggregate number of publications, comes last in terms of publications per inhabitant.

Panel C also reports a relative innovation index that combines total scientific output with per-capita efficiency, allowing aggregate publication volume to be compared with output relative to country size.

Results in Panel C of Table A.6 also indicate that there is an uneven country-size relation to scientific output. This indicates that the drivers of scientific productivity are complex and cannot be explained by the size of the population alone, as there are a variety of unobserved factors that drive productivity. Thus, to investigate this further, we conduct multivariate analyses in the section below.

Appendix I: Performance of China in Relation to its Fundamentals

We next conduct formal multivariate tests to understand the rise of China in scientific publishing, factoring in the structural drivers of scientific productivity, and distinguish whether China's success is naturally organic (i.e., determined in part by its large population and economic growth), or it is due to strategic governmental investment into key areas to drive national goals.

The uneven country-size relation to scientific output displayed in Table A.6 suggests that a multitude of factors could drive productivity.[1] Given that there is no formal and definitively accepted model of country-level scientific innovation, we draw inspiration from the extant literature and cast a wide net. In the section below, we estimate a structural model of country-level scientific productivity starting with more than 50 potentially causal characteristics, and optimize for predictive value and fit, using statistical estimation techniques.

For the country-level analyses in Table A.7, we convert the article-year data into a country-year panel for Top-3 journals and focus on the 2000 - 2022 period, when China's scientific output began to rise sharply.

The predictive model uses country-year variables covering economic, institutional, educational, social, geographic, and political characteristics. LASSO is used to select a tractable set of predictors, with multicollinear variables removed after selection.

Table A.7 estimates country-level scientific productivity in Top-3 journals using the selected predictors, excluding China from the estimation so that China can be evaluated out of sample.

In Model (2) of Table A.7, we repeat the same analysis using year fixed effects to better control for inter-temporal variability in scientific production (since our variable, *Articles_Top3*, has a positive time trend). Our inferences remain the same, and year fixed effects do not provide additional incremental explanatory power.

[1] There is a rich literature examining the determinants of scientific innovation at the country level. In early work, Price (1963) suggests that scientific output is dependent on the wealth of the country, where the richest countries produce the most science. May (1997) indicates that size and wealth are joint determinants of innovation. Ben-David (1984) argues for a structural theory of scientific advance, based on a variety of factors. These could include education (Aghion et al., 2008), institutional quality factors such as the rule of law and property rights (Crespi & Geuna, 2008), and the openness of societies (Hofstede, 2001). Finally, in a seminal paper, Furman et al. (2002) examine country-level innovative capacity using the strength of a nation's innovation infrastructure and its environment for innovation, considering ten causal factors as determinants of the production of patents. The studies above indicate that country-level innovation is a function of a variety of factors, including size, wealth, and a host of cultural and political factors.

The fitted values from Table A.7 provide the benchmark for comparing China's predicted and actual Top-3 publication output.

Figure 5 graphs the evolution of China's predicted versus actual scientific innovation. Both lines exhibit an increase in time, as China became richer and less corrupt, its predicted innovation also grew (grey dashed line). However, its actual performance simultaneously grew at a much sharper rate (red dotted line).[2]

In sum, the results in this section indicate that China's scientific growth is strategic, not merely a simple outcome of country-specific determinants of growth and prosperity. Our results indicate systematic overperformance, which increases through time. We take this as evidence of policy-driven innovation, not natural development, which we formally examine next.

Appendix J: Explaining China's Performance

We show the rise of China as a scientific powerhouse, as compared to its country level fundamentals. We estimated a global model of scientific productivity, using LASSO to obtain the significant variables that explain the dependent variable, and provide for a maximum fit. However, the *i* factors explaining global scientific productivity might not include factors *j*, *k*, and *l* that are unique to China only, and explain its particular context and research strategy. A natural question to ask is what are the factors that are helping drive such an ascent.

Top Chinese research universities are government funded (e.g., Fudan, Tsinghua, Peking, Zhejiang), and additional research funding comes from the Ministry of Education or the Chinese Academy of Sciences, who invest into key technologies with national and state-level R&D programs (Sun & Cao, 2014). In its 2010 educational reform, the Communist Party of China explicitly put doctoral education central to its ten-year plan: "Strengthen management and continuously improve the quality of graduates, especially doctoral candidates" (Center for Security and Emerging Technology, 2019). Thus, the government has made substantial investments into doctoral education (Yang, 2012), funding international exchange programs (Xu & Huang, 2024). Therefore, in order to better understand China's unique context, we gather data points that explicitly capture the Chinese government's investments into academic research, and use them to explain Chinese academic productivity in top journals (*Articles_Top3*).

The explanatory variables are *Research Spending*, which is the total dollar value of governmental research expenditures. and *Education Spending / GDP*, which is the government's yearly education budget, normalized by GDP. We focus on these two variables as they represent the most direct channels of state investment into scientific capacity and provide the most parsimonious specification given the limited number of annual observations per country (Marginson, 2022; Mayer, 2012; Tollefson, 2018; Zhu & Liu, 2020). To ensure that our results are not driven by common time trends in both the dependent and independent variables, we employ three trend-robust specifications: error correction models (ECM), a panel regression with country fixed effects, and 5-year long-differenced regressions. Results are presented in Table A.8.

Panel A of Table A.8 reports error-correction models that examine whether changes in government research expenditure and education spending are associated with changes in elite scientific output across the seven countries with consistent data.

[2] In additional unreported analysis, we utilize a statistical approach similar to that of Card et al. (2022), who utilize a prediction model to examine the role of gender in academic success. Using a statistical approach similar to theirs, we obtain similar inferences.

The Panel A results are retained in Table A.8 to show whether the short-run association between research spending and Top-3 publications is specific to China or appears similarly in other countries.

Panel B pools the seven countries and includes China interaction terms to test whether the relationship between state investment and elite scientific output is stronger for China than for the comparison countries.

As a further robustness check, the long-differenced specifications examine whether multi-year changes in investment predict multi-year changes in publications after common trends are removed.

Panel C provides an additional descriptive specification for China and the comparison countries using research spending, doctoral graduates, and education spending/GDP as predictors of Top-3 productivity.

Before we discuss the results, we start by a caveat. There are time trends in the three variables and the dependent variable, and establishing firm causality is difficult. However, given that education, research, and doctoral funding are prime determinants of research success, we present these results for illustrative purposes. Results in Panel C, Model (1) show a significant model with a high R-squared. Additionally, the *F*-statistic, 142.5, is large for the Chinese sample, indicating that the independent variables are jointly informative in explaining Top-3 scientific productivity, and that the explained variation in the dependent variable is large compared to the unexplained portion, hence the high R-squared of 97%.

To show that we have succeeded in explaining Chinese research productivity, we need to demonstrate that our explanatory variables have particularly strong predictive power for China only, where we are capturing its unique strategic choices. To do so, we repeat the same equation for 7 other countries who are major producers of research. Models (2) to (8) in Panel C repeat the same regression for the USA, Germany, Japan, Netherlands, Spain, and Sweden. We choose these countries because they are the only 6 with the requisite data, as the rest do not publish yearly data on the number of doctoral graduates going back 20 years.

China exhibits substantially higher explanatory power (adjusted $R^2 = 0.97$) than all other countries in the sample. The same variables give an *F*-statistic and R-squared of only 8.76 and 61% for the USA, and 3.58 and 39% for Germany. The results are also similar for the rest of the countries as seen in Models 4 - 8. We see that government spending on education and research strongly correlates in explaining Chinese scientific excellence, while the same variables fail to do similarly, for the rest of the countries examined.

In sum, these results indicate that strategic governmental investment, as captured by research spending and education expenditure, has a uniquely strong effect on China's scientific output. Such an effect is absent or negligible in Western countries, where elite scientific production is shaped by decentralized university systems, private R&D, and corporate funding.

Appendix K: Sample Data and Replication Code

We provide the full Python code and underlying data, where possible, to replicate our tables. Please see the files below. We don't provide data / code for the supplementary material, but these are fully available upon request.
The link is here:
https://osf.io/e67kp/overview?view_only=28a95b04aa7b4d87b18866d97c147ea9

Figure 1:

Replication Code:	Figure 1 - Science - Replication.ipynb
Data:	2 TB underlying data, available upon request

Figure 3:

Replication Code:	Figure 3 - Science - Replication.ipynb
Data:	Top 3 for Python.csv
Auxiliary data:	Figure 3 disaggregated excel for 1 year (we provide a 1-year representative excel, that provides an easy-to-visualize depiction of our author disambiguation procedure)

Figure 5:

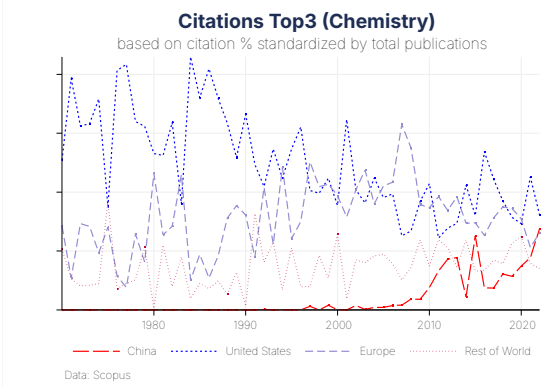
Replication Code:	Figure 5 & 6 - Science - Replication.ipynb
Data:	merged_innovation_data.csv

Figure 6:

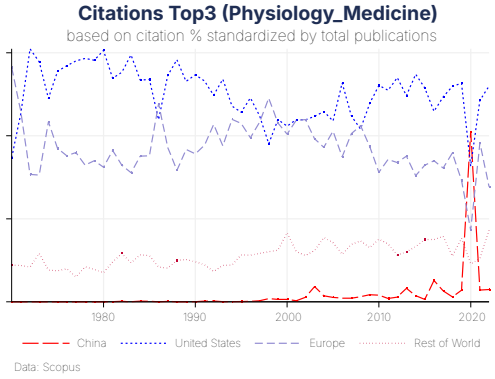
Replication Code:	Figure 5 & 6 - Science - Replication.ipynb
Data:	merged_innovation_data.csv

Figure A.1

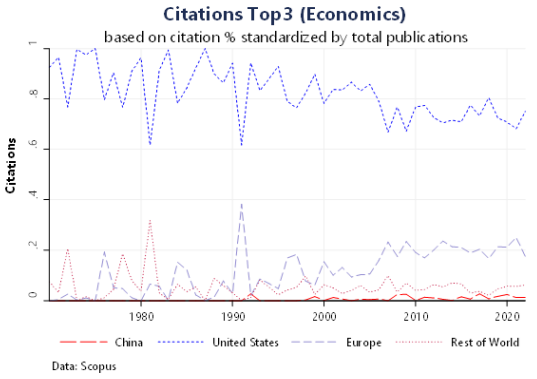
China's Citation Intensity for Articles Published in Top-3 Journals, by Field (1970-2022). This figure shows citation intensity across regions: China, United States, Europe, and Rest of World. Data are obtained from Scopus, covering 39 million publications from 22,189 journals over 42 years (1980-2022). Citations are standardized by year and field, such that the total across the four regions sums to one. Figures are organized in rows from the top left: Figures (A)-(F) reports citations in the top-3 journals in chemistry, medicine/physiology, economics, physics, mathematics, and "other," respectively. Citation intensity is measured as citation percentage standardized by total publications, and accounts for the percentage of author contributions from a given region. Methods and analysis are explained further in "Appendix D: Scientific Impact of Chinese Research."



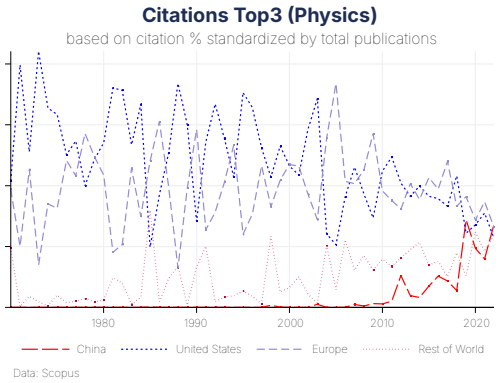
(A) Top-3 Journals in Chemistry



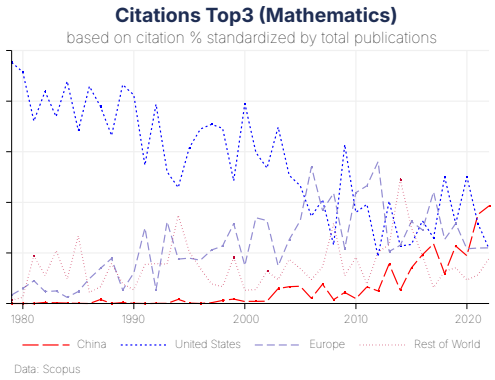
(B) Top-3 Journals in Physiology - Medicine



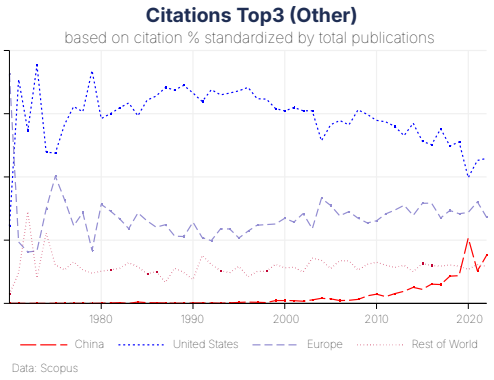
(C) Top-3 Journals in Economics



(D) Top-3 Journals in Physics



(E) Top-3 Journals in Mathematics



(F) Top-3 Journals in Other Fields

Table A.1

This appendix reports the journals designated as the top-3 in each field (chemistry, mathematics, medicine, physics,
and multidisciplinary), based on Scopus citation counts during 1995-2000. The table lists each journal with its citation count in this window, with totals per field. These journals form the benchmark set of elite outlets used throughout the paper.

Field	Journal	# of Citations
Chemistry	Chemical Reviews	2,661
	Chemical Society Reviews	2,590
	Nature Materials	3,101
	Total	*8,352*
Mathematics	IEEE (Pattern Analysis and Machine Intelligence)	6,934
	Journal of Machine Learning Research	2,864
	Journal of Statistical Software	1,197
	Total	*10,995*
Medicine	Cancer, Journal for Clinicians	1,025
	Lancet	23,511
	New England Journal of Medicine	19,316
	Total	*43,852*
Physics	Advances in Physics	448
	Nature Photonics	1,775
	Reviews of Modern Physics	1,463
	Total	*3,686*
Multidisciplinary	Nature	58,531
	Science	42,218
	MIS Quarterly (Mgmt. Information Systems)	1,259
	Total	*102,008*

Table A.2

Descriptive Statistics: This Table shows research productivity across regions: China, United States, Europe, and Rest of World. Data are obtained from Scopus, covering 39 million publications from 22,189 journals over 52 years (1970-2022). Panel A presents data by field of study, Panel B presents data by various journal quality tier, and Panel C presents citation data. Further analysis is provided in "Appendix A: Descriptive Statistics."

Panel A: Total Research Productivity

This panel shows total research productivity, for all regions and across all fields. Data is aggregated annually (in other words, mean publications indicate the mean number per year). Within each field, data are ranked by the mean number of annual publications.

Field	Region	Mean	Median	SD	Min	Max
Chemistry	Europe	28,528.25	32,717.62	15,356.61	8,277.43	56,022.58
	Rest of World	27,436.02	22,032.64	22,397.83	3,904.72	78,549.34
	China	17,308.60	3,859.78	25,286.29	1.00	98,650.68
	USA	13,114.36	13,393.04	4,147.74	6,932.77	19,720.20
Mathematics	Europe	10,843.77	9,780.27	7,068.04	1,708.96	21,714.14
	Rest of World	8,036.71	5,476.80	7,159.15	834.67	26,966.48
	USA	5,868.72	5,652.40	1,959.97	2,860.38	9,046.73
	China	4,603.38	1,140.55	6,263.29	0	22,906.10
Medicine	Europe	77,895.44	79,537.66	35,188.86	10,818.37	147,477.50
	Rest of World	64,562.68	51,659.53	49,568.27	4,003.58	176,203.70
	USA	51,773.65	52,674.11	25,042.38	8,090.05	101,493.20
	China	16,376.27	3,192.39	23,735.57	0	97,772.88
Physics	Europe	37,120.83	43,668.26	21,781.97	7,164.63	70,268.93
	Rest of World	27,734.49	26,185.99	20,134.54	3,778.16	68,599.70
	USA	20,018.33	22,483.14	7,062.56	9,056.21	28,608.18
	China	17,784.22	5,183.24	23,473.97	0	88,818.78
Other	Rest of World	87,121.93	51,086.59	90,916.73	6,087.89	332,927.90
	Europe	85,057.84	77,785.61	63,109.86	11,182.91	231,952.30
	USA	65,317.21	69,119.93	27,072.19	18,048.47	111,699.20
	China	54,803.61	7,451.16	84,381.18	0	334,783.50

Panel B: Research Productivity across Various Breakdowns of Journal Quality

This panel shows research productivity, for all regions, in various breakdowns of journal quality. Data is aggregated annually (in other words, mean publications indicate the mean number per year). Within each journal quality breakdown, data are ranked by the mean number of annual publications.

Journal Quality	Region	Mean	Median	SD	Min	Max
Top 1% of Journals	USA	8,315.28	8,967.52	2,698.27	2,981.43	12,332.51
	Europe	5,311.95	5,980.81	2,734.03	1,115.75	9,253.70
	Rest of	2,416.46	2,264.85	1,424.59	504.57	4,817.60
	China	788.66	56.68	1,466.33	0	6,801.27
Top 2-10% of	Europe	57,775.14	55,566.51	41,012.82	6,161.71	129,101.50
	USA	56,163.25	58,245.99	22,583.79	17,170.65	90,594.75
	Rest of	42,703.44	34,338.05	35,326.08	3,534.24	119,614.90
	China	21,333.39	1,906.01	38,565.21	0.25	170,626.30
Bottom Tier Journals	Europe	176,359.00	178,823.00	97,531.55	31,533.34	389,246.70
	Rest of	169,771.90	119,838.60	152,454.50	14,478.89	559,678.80
	USA	91,613.73	95,397.63	39,786.12	24,554.44	166,974.80
	China	88,754.03	18,864.43	123,952.70	7.73	465,504.40

Panel C: Total Citations across Various Breakdowns of Journal Quality
This panel shows total citations, for all regions, in various breakdowns of journal quality. Data are aggregated annually (in other words, mean citations indicate the mean number per year). Within each journal quality breakdown, data are ranked by the mean number of annual citations.

Journal Quality	Region	Mean	Median	SD	Min	Max
Top 1% of Journals	USA	285,476.6	112,444.4	408,766.4	0	1,688,447.0
	Europe	149,353.5	71,965.5	183,894.5	0	781,060.9
	Rest of World	64,618.5	27,196.1	89,173.4	0	399,646.7
	China	18,300.7	1,194.6	41,269.8	0	266,247.3
Top 2-10% of Journals	USA	624,088.4	422,459.5	647,754.7	7,718.5	2,785,869.0
	Europe	533,926.9	263,556.7	595,253.2	14,818.8	2,398,863.0
	Rest of World	354,019.3	158,725.5	440,165.5	4,017.5	1,917,332.0
	China	168,115.9	11,466.8	350,384.1	0	1,908,966.0
Bottom Tier Journals	Europe	587,350.4	391,588.9	573,153.8	22,680.7	2,273,645.0
	Rest of World	484,620.5	239,795.3	570,594.9	8,105.8	2,462,093.0
	USA	438,696.3	238,370.0	469,105.7	7,183.3	1,806,391.0
	China	187,467.9	20,667.3	364,225.1	0	2,272,408.0

Table A.3

Univariate *t*-Tests Comparing Chinese and U.S. Research Productivity and Citations

This table reports univariate *t*-tests comparing the scientific output of China and North America over the period 2018-2022. Panel A compares mean productivity across all journals, the top 1%, the top 2-10%, and bottom-tier journals. Panel B narrows the focus to productivity in the Top-3 journals across Nobel fields (chemistry, medicine, physics, mathematics, and other), as well as all disciplines combined. Panel C examines citations per paper in the Top-3 journals, using fractional attribution of citations by author region. Differences in means are reported from the perspective of China. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. Method and analysis are further explained in "Appendix E: Univariate *t*-tests on Scientific Output."

Panel A: Univariate *t*-Tests for Article-level Productivity

	U.S. Mean	China Mean	Difference in Means	*p*-value
Full	0.139	0.264	0.125***	<0.01
Top 1%	0.385	0.162	-0.223***	<0.01
Top 2-10%	0.196	0.276	0.080***	<0.01
Bottom Tier	0.113	0.267	0.154***	<0.01

Panel B: Univariate *t*-Tests for Article-level Productivity (Top-3)

	U.S. Mean	China Mean	Difference in Means	*p*-value
Chemistry	0.389	0.120	-0.269***	<0.01
Medicine	0.515	0.022	-0.493***	<0.01
Physics	0.307	0.117	-0.190***	<0.01
Mathematics	0.329	0.219	-0.111***	<0.01
Other	0.489	0.083	-0.406***	<0.01

Panel C: Univariate *t*-Tests for Article-level Citations (Top-3)

	U.S. Mean	China Mean	Difference in Means	*p*-value
Chemistry	57.05	24.33	-32.72***	<0.01
Medicine	196.58	61.72	-134.86***	<0.01
Physics	51.58	29.02	-22.56**	<0.05
Mathematics	25.75	16.36	-9.39*	<0.10
Other	88.67	23.84	-64.83***	<0.01
All Disciplines Combined	90.07	28.52	-61.55***	<0.01

Table A.4

Quality of Chinese Research: Evidence from Citations

The table presents analyses examining the quality of Chinese scientific output in elite journals from 1980-2022. We use Top-3 publications in our analyses, and utilize Scopus provided citation data. Panel A presents descriptive statistics, across time period, region. Panel B presents citation data by field. Panel C presents multivariate regressions by time period, while Panel D presents multivariate regressions by field. Further analysis is provided in "Appendix F: Quality and Quantity of Chinese Research Productivity."

Panel A: Descriptive Statistics Across Time Periods

This panel presents descriptive statistics across time period and field. *Citations (standardized)* is citations per article, standardized by the total number of citations in a year-field combination to ensure comparability across years and disciplines, while *Citations* is the mean total citation per article. We provide data for articles where the majority of the authors are from mainland China, USA, and other countries.

Year	Region	Author Adjusted Publications	Citations	Citations (standardized)
1980-1994	China Majority	53	129.53	0.0517%
	USA Majority	25,693	251.13	0.1712%
	Other Majority	19,125	170.54	0.1339%
1995-2009	China Majority	497	393.17	0.2114%
	USA Majority	23,669	491.66	0.1549%
	Other Majority	19,434	368.39	0.1529%
2010-2022	China Majority	2,624	363.62	0.2810%
	USA Majority	20,050	311.46	0.1244%
	Other Majority	13,927	248.56	0.1417%

Panel B: Descriptive Statistics Across Fields, for the Most Recent Time Period

This panel presents descriptive statistics across fields for the time period 2010-2022. *Citation (standardized)* is citations per article, standardized by the total number of citations in a year-field combination to ensure comparability across years and disciplines, while *Citations* is the mean total citation per article. We provide data for articles where the majority of the authors are from mainland China, USA, and other countries.

Field	Region	Publications	Citations	Citations (standardized)
Mathematics	China Majority	435	146.57	0.5744%
2010-2022	USA Majority	828	160.57	0.4729%
	Other Majority	1,109	142.65	0.4220%
Chemistry	China Majority	311	515.58	0.5976%
2010-2022	USA Majority	682	481.72	0.5900%
	Other Majority	1,363	372.30	0.3871%
Physics	China Majority	170	341.35	0.8102%
2010-2022	USA Majority	931	336.12	0.5016%
	Other Majority	1,143	256.16	0.3840%
Medicine	China Majority	128	1553.23	0.5022%
2010-2022	USA Majority	4,174	376.24	0.1407%
	Other Majority	2,549	238.03	0.0873%
Other	China Majority	1,580	301.15	0.0631%
2010-2022	USA Majority	13,435	290.28	0.0480%
	Other Majority	7,763	244.30	0.0407%

Panel C: Quality of Chinese Research: Time-Series Evidence from Citations

The table presents analyses examining the quality of Chinese scientific output in elite journals from 1980-2022. We use Top-3 publications in our analyses, and utilize Scopus provided citation data. The dependent variable, *Citation_Article*, is citations per article, standardized by the total number of citations in a year-field combination to ensure comparability across years and disciplines. The main research variable is *China_Authors*, measuring the share of Chinese authors per article, ranging from 0 to 1. We also utilize *USA_Authors*, which measures the share of USA based authors per article, ranging from 0 to 1. *International* is an indicator variable equal to one if authors from at least two nations are involved, *log_Authors* is the natural log of the number of authors per article. We also include journal fixed effects for each of the Top-3 journals in each field. Column (1) presents results for all time periods, while Columns (2) - (4) present separate regressions for each of our three time periods. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels. *t*-statistics in brackets.

	(1) **All Years**	**(2)** **1980-94**	**(3)** **1995-2009**	**(4)** **2010-22**
China_Authors	0.0001	-0.0029***	-0.0005	0.0009**
	[0.28]	[-4.98]	[-1.41]	[2.57]
USA_Authors	0.0004***	0.0003**	0.0004***	0.0001
	[6.18]	[2.32]	[5.26]	[1.65]
International	0.0001	0.0002*	-0.0000	0.0000
	[1.07]	[2.12]	[-0.16]	[0.20]
log_Authors	0.0006***	0.0003***	0.0006***	0.0006***
	[18.20]	[5.04]	[16.47]	[16.58]
1995_2009	-0.0007***			
	[-6.49]			
2010_2022	-0.0013***			
	[-12.90]			
Observations	140,376	48,008	48,480	43,888
Adj. R-squared	0.09	0.15	0.11	0.06
Journal Fixed Effects	Yes	Yes	Yes	Yes

Panel D: Multivariate Analyses: Citations in Various Fields for the Years 2010 - 2022

This table presents results on multivariate regressions where the dependent variable, *Citation_Article*, is citations per article, standardized by the total number of citations in a year-field combination to ensure comparability across years and disciplines. The main research variable is *China_Authors*, measuring the share of Chinese authors per article. We also utilize *USA_Authors*, which measures the share of USA based authors per article. *International* is an indicator variable equal to one if authors from at least two nations are involved, *log_Authors* is the natural log of the number of authors per article. We also include journal fixed effects for each of the top-3 journals in each field. Columns (1) - (5) presents results for chemistry, physics, medicine, mathematics, and other disciplines, respectively. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels. *t*-statistics in brackets.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	Chemistry	**Physics**	**Medicine**	**Mathematics**	**Other**
	2010-22	**2010-22**	**2010-22**	**2010-22**	**2010-22**
China_Authors	0.0024***	0.0039***	0.0036	-0.0002	0.0001
	[3.35]	[3.78]	[1.18]	[-0.11]	[1.65]
USA_Authors	0.0001	0.0010***	0.0001	0.0007	0.0000
	[0.09]	[3.19]	[1.14]	[0.62]	[1.71]
International	-0.0008	-0.0001	0.0009***	-0.0005	-0.0001***
	[-1.25]	[-0.25]	[3.72]	[-0.71]	[-3.18]
log_Authors	0.0029***	0.0020***	0.0008***	0.0019*	0.0002***
	[4.18]	[8.35]	[9.50]	[2.12]	[27.64]
Observations	2,636	2,672	8,352	2,782	27,446
Adj. R-squared	0.11	0.08	0.10	0.00	0.03
Journal Fixed Effects	Yes	Yes	Yes	Yes	Yes

Table A.5

Distribution of Chinese Authors Across Fields and Abroad

The table summarizes the presence of Chinese authors in Top-3 journals over the period 1980-2022, based on 140,376 published articles. Panel A reports field-level statistics for chemistry, medicine, physics, mathematics, and other disciplines, including the total number of papers, the share with at least one Chinese author, the share with a Chinese first author, the average percentage of Chinese authors per paper, and their geographic distribution across Europe, the USA, China, and foreign talent working domestically (Imports). Panel B documents the distribution of Chinese authors abroad using 810,741 author observations who have published at least one paper in the elite journals. The columns report the total number of authors, the number and share with Chinese surnames, and the comparison to non-Chinese authors across the USA, Europe, and other countries. Method and analysis are further explained in "Appendix G: Measuring China's Scientific Influence Factoring in the Diaspora."

Panel A: Distribution of Chinese Authors by Field

	Total Papers	≥1 Chinese (%)	Chinese 1st author (%)	Avg % Chinese	Europe (%)	USA (%)	China (%)	Imports (%)
Chemistry	8,092	28.3	16.3	13.3	4.6	15.8	8.7	2.3
Medicine	35,473	12.8	2.9	2.8	1.7	7.9	1.5	0.8
Physics	3,350	25.1	13.6	11.2	4.3	13.6	7.0	2.6
Mathemati	10,942	34.1	26.1	22.8	3.0	18.2	13.5	3.6
Other	82,519	24.0	9.6	7.3	2.9	18.0	3.6	1.4
Total	140,376							

Panel B: Distribution of Chinese Authors Abroad

	Total Authors	Chinese Authors	% Chinese	Non-Chinese	% Non-Chinese
USA	401,465	41,584	10.4%	359,881	89.6%
Other	124,562	8,454	6.8%	116,108	93.2%
Europe	284,714	5,076	1.8%	279,638	98.2%
Total	810,741	55,114	6.8%	755,627	93.2%

Table A.6

Ranking of Countries by Scientific Output in Top-3 Journals

The table reports country- and region-level fractional publication counts in the Top-3 journals. Panel A presents rankings of the top 25 countries, based on fractional publication of authors based on their location aggregated across disciplines (chemistry, medicine, physics, mathematics, and other) for the periods 2015-2022 and 2020-2022. Scores are equal-weighted across disciplines, with the top-ranked country normalized to 100. Panel B compares regional shares of Top-3 publications between 2000 and 2022, reporting the distribution across the USA, Europe, China, and Rest of World. Panel C reports the aggregate and per-capita publication counts of the leading countries in the period 2020-2022, along with an innovation index combining total output and per-capita efficiency. Method and analysis are further explained in "Appendix H: Ranking of Scientific Innovation in Top-3 Journals."

Panel A: Countries by Mean Scientific Output in Top-3 Journals

	Country	Ø Fractional Publications (2020-	Trend	Country	Ø Fractional Publications (2015-2022)
1	United States	1,539.1	-	United States	1,507.4
2	United Kingdom	**413.9**	↑	**China**	274.0
3	**China**	277.7	↓	United Kingdom	**272.6**
4	Germany	211.2	-	Germany	204.3
5	France	114.3	-	France	117.8
6	Switzerland	93.9	↑	Japan	88.3
7	Japan	90.2	↓	Switzerland	87.4
8	Canada	86.7	↑	Australia	84.5
9	Australia	84.2	↓	Canada	79.2
1	Netherlands	58.4	-	Netherlands	57.5
11	Spain	52.2	↑	Korea, Rep.	46.8
12	Italy	47.2	-	Italy	45.0
1	Israel	44.8	-	Israel	40.3
1	Korea, Rep.	42.6	↓	Spain	39.2
1	Sweden	30.5	↑	Singapore	29.4
1	Singapore	28.8	↑	Austria	27.8
17	Austria	27.0	↓	Sweden	26.2
1	Denmark	24.6	↑	Belgium	23.5
1	Belgium	24.0	↓	Denmark	23.2
2	India	14.5	↑	Brazil	14.0
21	Brazil	14.4	↓	India	12.0
2	Norway	11.7	↑	Finland	11.0
2	Finland	10.5	↑	South Africa	10.9
2	Russian Federation	10.1	↓	Norway	9.7
2	Poland	9.1	↓	Russian Federation	8.9

Panel B: China's Global Share & Displacement (2000-2022)

	2000 Fractional Publications	2022 Fractional Publications	CAGR %	% Share (2000)	% Share (2022)	Δ Share
China	24	614	15.8%	0.7%	15.2%	+14.5 pp
USA	1,547	1,697	0.4%	47.2%	42.0%	-5.2 pp
Europe	1,249	1,131	-0.4%	38.1%	28.0%	-10.1 pp
Rest of the World	458	596	1.2%	14.0%	14.8%	+0.8 pp
Total	3,277	4,038	1.0%			

Panel C: Countries' Average Innovation Performance From 2020 to 2022

	Total Fractional Publications	Fractional Publications / M Population	Innovation Index
United States	1539.1	4.5	71.8
China	413.9	0.3	14.8
United Kingdom	277.7	4.1	28.8
Germany	211.2	2.5	19.0
France	114.3	1.7	12.1
Japan	93.9	0.7	6.7
Switzerland	90.2	10.4	52.9
Australia	86.7	3.3	18.9
Canada	84.2	2.2	13.3
Netherlands	58.4	3.3	17.8
Korea, Rep.	52.2	1.0	6.6
Italy	47.2	0.8	5.3
Israel	44.8	5.0	25.6
Spain	42.6	0.9	5.7
Singapore	30.5	5.4	27.3
Austria	28.8	3.2	16.4
Sweden	27.0	2.6	13.4
Belgium	24.6	2.1	11.0
Denmark	24.0	4.1	20.6
Brazil	14.5	0.1	0.8
India	14.4	0.0	0.5
Finland	11.7	2.1	10.6
South Africa	10.5	0.2	1.2
Norway	10.1	1.9	9.4
Russian Federation	9.1	0.1	0.6

Table A.7

Estimation of Country-Level Scientific Productivity

The table presents regression results estimating the structural determinants of scientific productivity. Panel A reports coefficients from Models (1) and (2), excluding China from the estimation sample. The dependent variable is the annual count of Top-3 journal publications (*Articles_Top3*). Independent variables include the logarithm of total population (*LogPopulation*), GDP per capita (*GDP/Capita*), perceived corruption (*Corruption*), average country temperature (*Temperature*), the square root of globalization (*Globalization*$^{1/2}$), the participation of elites in politics (*Elite Participation*), and political rights (*Political Rights*). Model (1) is estimated without year fixed effects, while Model (2) includes year fixed effects, using a sample of 2,242 country-year observations over from 2000 to 2022. Panel B compares China's actual versus model-predicted publication counts, showing residuals and percentage differences for each year. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. *t*-statistics in brackets. Analysis is further explained in "Appendix I: Performance of China in Relation to its Fundamentals."

Panel A: Model Estimation Using All Countries Excluding China

	(1) ***Articles_Top3***	**(2)** ***Articles_Top3***
LogPopulation	0.762***	0.757***
	[33.28]	[32.61]
Corruption	-0.699***	-0.697***
	[-20.83]	[-20.56]
GDP/Capita	0.372***	0.364***
	[13.25]	[12.82]
Temperature	-0.239***	-0.242***
	[-10.04]	[-10.05]
Globalization$^{1/2}$	-0.190***	-0.187***
	[-8.19]	[-8.01]
Elite Participation	0.133***	0.134***
	[4.75]	[4.73]
Political Rights	0.053*	0.056*
	[1.75]	[1.83]
Constant	1.408***	
	[75.99]	
Observations	2,242	2,242
Adj. R-squared	0.69	0.69
Year Fixed Effects	No	Yes

Panel B: China's Performance, Model vs Reality

Year	Actual Pubs	Expected Pubs	Residual	% Difference
2000	24	26	-2	-8.2%
2001	34	27	7	+24.0%
2002	40	27	13	+49.2%
2003	47	26	21	+80.8%
2004	56	26	30	+118.8%
2005	43	29	14	+49.8%
2006	41	29	12	+39.5%
2007	56	30	25	+82.6%
2008	59	32	27	+82.5%
2009	84	36	49	+137.6%
2010	110	36	74	+205.6%
2011	129	37	91	+245.9%
2012	159	40	119	+298.6%
2013	189	46	144	+315.7%
2014	110	48	63	+131.3%
2015	177	50	127	+251.9%
2016	137	52	85	+162.7%
2017	169	53	116	+220.1%
2018	205	55	150	+275.4%
2019	251	58	193	+330.6%
2020	286	60	226	+378.0%
2021	341	58	283	+483.0%
2022	614	53	561	+1,065.1%

Table A.8

Explaining the Rise of Chinese Scientific Productivity

The table presents trend-robust analyses examining the rise of Chinese scientific output in elite journals from 2002-2022. We use top-3 publications from Scopus in our analyses (*Articles_Top3*). Panel A reports error correction models (ECM) estimated separately for each country. The ECM decomposes dynamics into a speed-of-adjustment term toward long-run equilibrium and short-run effects of year-over-year changes in the explanatory variables on changes in publications. . ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels. *t*-statistics in brackets. Method is further explained in "Appendix J: Explaining China's Performance."

Panel A: Error Correction Models	**(1)** **China** ***Articles_Top***	**(2)** **USA** ***Articles_Top***	**(3)** **Germany** ***Articles_Top***	**(4)** **Japan** ***Articles_Top***	**(5)** **Netherlands** ***Articles_Top***	**(6)** **Spain** ***Articles_Top***	**(7)** **Sweden** ***Articles_Top***
ΔResearch Spending	2.0710**	-0.0450	-0.0347	-0.1122	-0.0270	-1.8098*	-0.3163
	[2.68]	[-0.47]	[-0.16]	[-0.35]	[-0.07]	[-2.02]	[-1.07]
ΔEducation Spending/GDP	0.1179	0.0124	0.1030***	0.8018**	-0.1766	0.1682	0.0569
	[0.33]	[0.44]	[3.35]	[2.52]	[-1.21]	[1.38]	[0.61]
Error Correction	-1.165***	-0.941***	-1.142***	-0.415*	-0.927***	-0.572***	-0.901***
	[-3.84]	[-3.78]	[-4.48]	[-1.87]	[-3.67]	[-3.98]	[-3.89]
Observations	17	20	20	20	20	20	19
Adj. R-squared	0.37	0.38	0.48	0.26	0.39	0.31	0.46
Augmented Dickey-Fuller (5%)	Yes	Yes	Yes	No	No	No	Yes

Panel B: Panel Regression with China Interactions

This Panel B reports a regression pooling all seven countries with country fixed effects, a cubic time trend, and China interaction terms. The interaction coefficient tests whether the effect of each variable is significantly different for China relative to other countries. *Research Spending* is the total dollar value of governmental research expenditures. *Education Spending/GDP* is the government's yearly education budget normalized by GDP. Standard errors are clustered by country. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels. *t*-statistics in brackets. Method is further explained in "Appendix J: Explaining China's Performance."

	Articles_Top3
Research Spending	0.1292
	[1.40]
Education Spending/GDP	0.0775
	[1.12]
*China*Research Spending*	1.9149***
	[20.18]
*China*Education Spending/GDP*	-0.1049
	[-1.52]
Observations	143
Adj. R-squared	0.98

Panel C: Further Explanations on the Rise of Chinese Scientific Productivity

The table presents analyses examining the rise of Chinese scientific output in elite journals from 2002-2022. We use Top-3 publications from Scopus in our analyses (*Articles_Top3*). *Research Spending* is the total dollar value of governmental research expenditures. *Doctoral Graduates* is the total number of yearly Ph.D. graduates scaled by 1,000. *Education Spending / GDP* is the government's yearly education budget normalized by GDP. Column (1) presents results for China, while Columns (2) - (7) present separate regressions for each of USA, Germany, Japan, the Netherlands, Spain, and Sweden. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels. *t*-statistics in brackets. Method is further explained in "Appendix J: Explaining China's Performance"

	(1) **China** ***Articles_Top3***	**(2)** **USA** ***Articles_Top3***	**(3)** **Germany** ***Articles_Top3***	**(4)** **Japan** ***Articles_Top3***	**(5)** **Netherlands** ***Articles_Top3***	**(6)** **Spain** ***Articles_Top3***	**(7)** **Sweden** ***Articles_Top3***
Research Spending	1.2751***	-0.1214***	-0.0805	-1.0402**	-0.0325	1.3410**	0.1000
	[4.21]	[-3.92]	[-1.12]	[-2.36]	[-0.14]	[2.44]	[0.30]
Doctoral Graduates	0.0167*	0.0012	0.0108	0.0528	-0.1560**	-0.0358**	0.3819
	[1.94]	[0.57]	[1.38]	[0.73]	[-2.31]	[-2.29]	[1.05]
Education Spending / GDP	0.0006	0.0025	0.0756*	0.7500***	0.0155	-0.0553	0.0755
	[0.01]	[0.17]	[1.94]	[3.04]	[0.11]	[-0.24]	[1.05]
Constant	-1.9373***	4.1343***	1.4132***	1.1990	1.3158*	-0.6695	-2.0450
	[-8.15]	[24.11]	[8.60]	[0.85]	[1.76]	[-0.95]	[-1.20]
Observations	18	21	21	21	21	21	20
F-statistic	142.5***	8.76***	3.58**	8.18***	11.05***	3.14*	0.68
Adj. R-squared	0.97	0.61	0.39	0.59	0.66	0.36	0.11

Appendix References

Abritis, A., & McCook, A. (2017). Cash bonuses for peer-reviewed papers go global. *Science*, *357*(6351), 541. https://doi.org/10.1126/science.357.6351.541

Aghion, P., Dewatripont, M., & Stein, J. C. (2008). Academic freedom, private-sector focus, and the process of innovation. *The RAND Journal of Economics*, *39*(3), 617–635. https://doi.org/10.1111/j.1756-2171.2008.00031.x

Association of American Medical Colleges. (2026). *Applications accepted information: Medical School Admission Requirements (MSAR) report for applicants and advisors*. Retrieved October 28, 2026, from https://students-residents.aamc.org/system/files/2026-01/MSAR012%20-%20Applications%20Accepted%20Information-1.pdf

Ben-David, J. (1984). *The scientist's role in society*. University of Chicago Press.

Boulet, J. R., Norcini, J. J., Whelan, G. P., Hallock, J. A., & Seeling, S. S. (2006). The international medical graduate pipeline: Recent trends in certification and residency training. *Health Affairs*, *25*(2), 469–477. https://doi.org/10.1377/hlthaff.25.2.469

Bound, J., Turner, S., & Walsh, P. (2009). *Internationalization of U.S. doctorate education* (NBER Working Paper No. 14792). National Bureau of Economic Research. https://doi.org/10.3386/w14792

Card, D., DellaVigna, S., Funk, P., & Iriberri, N. (2022). Gender differences in peer recognition by economists. *Econometrica*, *90*(5), 1937–1971. https://doi.org/10.3982/ECTA18027

Center for Security and Emerging Technology. (2019, November 27). Outline of the national plan for medium- and long-term education reform and development [English translation]. Retrieved October 28, 2026, from https://cset.georgetown.edu/publication/outline-of-the-national-plan-for-medium-and-long-term-education-reform-and-development/

Crespi, G. A., & Geuna, A. (2008). An empirical study of scientific production: A cross country analysis, 1981–2002. *Research Policy*, *37*(4), 565–579. https://doi.org/10.1016/j.respol.2007.12.007

Cyranoski, D., Gilbert, N., Ledford, H., Nayar, A., & Yahia, M. (2011). Education: The PhD factory. *Nature*, *472*(7343), 276–279. https://doi.org/10.1038/472276a

Einstein, A. (1905). *Eine neue Bestimmung der Moleküldimensionen* [Doctoral dissertation]. ETH Zurich. https://doi.org/10.3929/ethz-a-000565688

Einstein, A., Podolsky, B., & Rosen, N. (1935). Can quantum-mechanical description of physical reality be considered complete? *Physical Review*, *47*(10), 777–780. https://doi.org/10.1103/PhysRev.47.777

Franzoni, C., Scellato, G., & Stephan, P. (2012). Foreign-born scientists: Mobility patterns for 16 countries. *Nature Biotechnology*, *30*(12), 1250–1253. https://doi.org/10.1038/nbt.2449

Furman, J. L., Porter, M. E., & Stern, S. (2002). The determinants of national innovative capacity. *Research Policy*, *31*(6), 899–933. https://doi.org/10.1016/S0048-7333(01)00152-4

Garfield, E. (1955). Citation indexes for science: A new dimension in documentation through association of ideas. *Science*, *122*(3159), 108–111. https://doi.org/10.1126/science.122.3159.108

Garfield, E. (1972). Citation analysis as a tool in journal evaluation: Journals can be ranked by frequency and impact of citations for science policy studies. *Science*, *178*(4060), 471–479. https://doi.org/10.1126/science.178.4060.471

Hofstede, G. (2001). *Culture's consequences: Comparing values, behaviors, institutions and organizations across nations* (2nd ed.). Sage.

Jia, H. (2020). Chinese academics who work abroad are slower to win honour. *Nature*, *577*(7790), 302–303. https://doi.org/10.1038/d41586-019-03772-1

Leydesdorff, L., & Wagner, C. (2009). Is the United States losing ground in science? A global perspective on the world science system. *Scientometrics*, *78*(1), 23–36. https://doi.org/10.1007/s11192-008-1830-4

MacLeod, W. B., & Urquiola, M. (2021). Why does the United States have the best research universities? Incentives, resources, and virtuous circles. *Journal of Economic Perspectives*, *35*(1), 185–206. https://doi.org/10.1257/jep.35.1.185

Mallapaty, S. (2020). China bans cash rewards for publishing papers. *Nature*, *579*(7797), 18–19. https://doi.org/10.1038/d41586-020-00574-8

Marginson, S. (2022). 'All things are in flux': China in global science. *Higher Education*, *83*(4), 881–910. https://doi.org/10.1007/s10734-021-00712-9

May, R. M. (1997). The scientific wealth of nations. *Science*, *275*(5301), 793–796. https://doi.org/10.1126/science.275.5301.793

Mayer, M. (2012). Exploring China's rise as knowledge power. In E. Fels, J.-F. Kremer, & K. Kronenberg (Eds.), *Power in the 21st century: International security and international political economy in a changing world* (pp. 287–311). Springer. https://doi.org/10.1007/978-3-642-25082-8_15

National Center for Science and Engineering Statistics. (2025). *Nearly half of 2023 U.S. doctorate recipients with temporary visas were from China or India* (NSF 25-336). U.S. National Science Foundation. https://ncses.nsf.gov/pubs/nsf25336

Price, D. J. de S. (1963). *Little science, big science*. Columbia University Press.

Quan, W., Chen, B., & Shu, F. (2017). Publish or impoverish: An investigation of the monetary reward system of science in China (1999–2016). *Aslib Journal of Information Management*, *69*(5), 486–502. https://doi.org/10.1108/AJIM-01-2017-0014

Sun, Y., & Cao, C. (2014). Demystifying central government R&D spending in China. *Science*, *345*(6200), 1006–1008. https://doi.org/10.1126/science.1253479

Tollefson, J. (2018). China declared world's largest producer of scientific articles. *Nature*, *553*(7689), 390–391. https://doi.org/10.1038/d41586-018-00927-4

Van Noorden, R. (2023). How big is science's fake-paper problem? *Nature*, *623*(7987), 466–467. https://doi.org/10.1038/d41586-023-03464-x

Wade, N. (1975). Citation analysis: A new tool for science administrators. *Science*, *188*(4187), 429–432. https://doi.org/10.1126/science.188.4187.429.a

Watson, J. D., & Crick, F. H. C. (1953). Molecular structure of nucleic acids: A structure for deoxyribose nucleic acid. *Nature*, *171*(4356), 737–738. https://doi.org/10.1038/171737a0

Xu, X., & Huang, H. (2024). Understanding government-funded doctoral students' non-degree international exchange experiences: Evidence from China. *Journal of Studies in International Education*, *28*(2), 185–203. https://doi.org/10.1177/10283153231178129

Yang, R. (2012). Up and coming? Doctoral education in China. *Australian Universities' Review*, *54*, 64–71.

Zhu, J., & Liu, W. (2020). Comparing like with like: China ranks first in SCI-indexed research articles since 2018. *Scientometrics*, *124*(2), 1691–1700. https://doi.org/10.1007/s11192-020-03525-2

Zweig, D., Chen, C., & Rosen, S. (2004). Globalization and transnational human capital: Overseas and returnee scholars to China. *The China Quarterly*, *179*, 735–757. https://doi.org/10.1017/S0305741004000566