The United States of America and Scientific Research

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Abstract

To gauge the current commitment to scientific research in the United States of America (US), we compared federal research funding (FRF) with the US gross domestic product (GDP) and industry research spending during the past six decades. In order to address the recent globalization of scientific research, we also focused on four key indicators of research activities: research and development (R&D) funding, total science and engineering doctoral degrees, patents, and scientific publications. We compared these indicators across three major population and economic regions: the US, the European Union (EU) and the People’s Republic of China (China) over the past decade. We discovered a number of interesting trends with direct relevance for science policy. The level of US FRF has varied between 0.2% and 0.6% of the GDP during the last six decades. Since the 1960s, the US FRF contribution has fallen from twice that of industrial research funding to roughly equal. Also, in the last two decades, the portion of the US government R&D spending devoted to research has increased. Although well below the US and the EU in overall funding, the current growth rate for R&D funding in China greatly exceeds that of both. Finally, the EU currently produces more science and engineering doctoral graduates and scientific publications than the US in absolute terms, but not per capita. This study’s aim is to facilitate a serious discussion of key questions by the research community and federal policy makers. In particular, our results raise two questions with respect to: a) the increasing globalization of science: “What role is the US playing now, and what role will it play in the future of international science?”; and b) the ability to produce beneficial innovations for society: “How will the US continue to foster its strengths?”

Introduction

Research in the US is widely believed to be essential to the country’s economic growth, and the innovations derived from basic and applied research provide enormous benefits to society [1]. For this reason, the federal government devotes a significant amount of funding towards research [1–10]. A number of economic studies are aimed at quantifying the benefit of federal research spending in terms of the return on investment [2,11–15] or the contribution to the growth of the economy [16]. These studies, among others, include some detailed estimates of the optimal amount of spending on research [16,17]. A large and ever growing number of projects developed with FRF have provided great benefits to society. Two notable and widely cited examples of applied and basic research, respectively, are the laser [18] and the PageRank algorithm [19]. The laser, developed with Federal support since the 1950s, was initially seen only as an academic “solution waiting for a problem” [18], but now it has a growing number of applications (for example, telecommunications and medical technologies) benefiting diverse aspects of our lives.
recently, the PageRank algorithm [19] was developed with support from the National Science Foundation (NSF) and the Department of Defense’s DARPA (Defense Advanced Research Projects Agency, www.darpa.mil) and, eventually, led to the formation of Google, the multi-billion dollar internet corporation, whose products are used throughout the world.

In this study, we seek to provide an objective analysis of the state of scientific research: a) in the US since the 1960s and b) in comparison with two other major population and economic regions, the EU (specifically, the EU-27, which consists of Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, and the United Kingdom) and China since 1996. This study focuses only on the comparison between these three population (over 300 million people each) and economic (over half of the US GDP each) regions since they are the only regions with both this level of population and economic output.

The task of evaluating scientific output using quantitative measures has been widely discussed [20–34]. The four indicators selected for our comparison are: 1. federal R&D spending; 2. the number of science and engineering doctorates awarded; 3. the number of patents issued; and 4. the number of papers published. The four metrics we chose for consideration have been utilized and evaluated in multiple studies [20–25]. These studies have also brought into discussion other important indicators such as citations, number of researchers, exports, and international prizes. While many of these metrics may have validity, we have attempted to simplify the comparisons by choosing the four most robust indicators having the most reliable and consistently available datasets. Our analysis relies purely on quantitative data because, though attempts have been made to develop a qualitative analysis, the low availability and inherent subjectivity of qualitative data make such an analysis exceptionally difficult [24]. Future analyses should address the more difficult problem of measuring research quality. However, our analysis is aimed at combining these four metrics in a unique manner which develops an understanding of the US’s current and future role in the scientific research community, a perspective which has not yet been discussed in the literature.

Work involving scientific and technical innovation is often divided into basic research, applied research and development. According to the NSF, basic research is the study of phenomena without specific applications in mind, while applied research is study to gain knowledge necessary to determine how a specific need may be met [3]. Development is the application of knowledge to produce useful devices to meet specific requirements [3]. In the present work, we do not distinguish between different types of research, and focus on research overall vs. R&D.

The relative research statuses of China, the EU, and the US in the world’s scientific research community are popular topics in literature. China’s increasing output is undeniable and its impact on the global landscape is widely discussed [25–33]. One fierce debate is between experts who believe China poses a serious threat to American scientific prowess and others who are more dismissive of the threat of Chinese scientific advance. The relative importance of European science is another contentious area in which scholars add to the debate ideas about the relative importance of different research fields [23,24]. The spread of globalization and increase in international collaborations has several researchers worried that the US is not receiving full credit for its research contributions [28,34]. Concern about US competitiveness in this changing research climate has been discussed in a number of notable reports issued by the Congressional Budget Office [2,4], the National Academies [3], the Battelle Memorial Institute [6], and the NSF [3,7–10]. Several authors evaluated trends in federal research spending [35], leading some of them to call for increases in either US federal or private R&D funding [21,36]. Many other nations have instituted policies designed to encourage innovation in all sectors [37]. Some analysts view the relative increase of scientific productivity in other countries as a threat to the US, but our view is that the exchange of scientific knowledge has the potential to benefit all countries involved [38]. From this wealth of opinions and fears about a US decline in scientific prowess we have attempted to draw rational conclusions to guide further discussion among scientists and policymakers. This study examines data from relevant sources and describes key research indicators for the US (over the past six decades), and the EU-27 and China (over the last decade).

### Table 1. Datasets used in the analysis.

| Dataset                              | Source organization and reference | Figures |
|--------------------------------------|-----------------------------------|---------|
| Federal funds for R & D              | NSF [3]                           | 1, 2, 3 |
| Gross domestic product               | Bureau of Economic Analysis [52]  | 1, 3    |
| Consumer price index                 | Bureau of Labor Statistics [53]   | 1, 2, 3 |
| Budget of the US government          | OMB [39]                          | 1, 3, 4 |
| National patterns of R&D resources   | NSF [8]                           | 5, 6    |
| Survey of industrial R&D             | NSF [10]                          |         |
| Science and technology tables        | OECD [40–43]                      | 7, 8    |
| Graduates by field of education      | OECD [46]                         | 9, 10   |
| Science and engineering indicators   | NSF [7]                           | 9, 10   |
| Triadic patents granted              | OECD [45]                         | 11, 12  |
| US population                        | US Census Bureau [54,55]          | 2, 8, 10, 12, 14 |
| EU-15 population                     | European Central Bank [56]        | 8, 10, 12, 14 |

doi:10.1371/journal.pone.0012203.t001
Methods

Data and Analysis

Research spending. Table 1 lists the datasets analyzed in this paper from numerous reliable sources, including several NSF surveys. The first [3] was a survey of all federal agencies that funded basic and applied research. The second [8] was a sample survey of organizations that perform research, and it requested the outlays for basic and applied research, and for the origin(s) of the funding to be specified. For example, an institution could spend money on a research project, but funding for the project could come from a contract with the federal government [8]. The companies included in this survey were categorized by the type of industry to which they belonged [10].

From the Office of Management and Budget (OMB) [39], we obtained a historical record of the US federal budget that contains the total outlays since 1956 (see Table 1). In addition, since 1962, OMB recorded mandatory and discretionary outlays for each federal program. Discretionary spending is set by the US government each fiscal year and includes, for example, defense, education and research spending [39]. In contrast, mandatory spending is not set by an annual spending bill; it includes Social Security and Medicare.

We used multiple datasets made available from the Organization for Economic Co-operation and Development (OECD) from 1996–2006 for China, the EU-27, and the US. These datasets included: R&D spending, R&D spending divided by GDP, R&D spending divided by population, and percent of R&D financed by government [40–43].

Patents. To rule out the potential bias in domestic patents discussed at length in [44], we utilized triadic patent data. Triadic patents are patents which are valid with the United States Patent and Trademark Office, the Japan Patent Office, and the European Patent Office. These patents will theoretically represent higher value discoveries. Though these patents are not valid in China and many other countries, they present the closest reality to an international patent. The triadic patent data from 1996–2006 was accessed through OECD for China, the EU-27, and the US [45].

Doctoral degrees. For our analysis of doctoral degrees, we found the number of science and engineering doctorates awarded by institutions in China, the EU, and the US [7]. (Due to data constraints, analysis for doctoral degrees was limited to the EU-15 rather than the EU-27.) We obtained the number of science and engineering doctorates awarded by the EU countries from the OECD [46]. To standardize these datasets as much as possible (Table 1), we selected the degrees classified with the UNESCO International Standard Classification of Education 1997 [47] (field codes 31, 42, 44, 46, 48, 52, 54, 58, and 62) as representing science and engineering degrees. (Missing values were set to 0.)

Papers. We also analyzed the number of papers produced by authors in the US, the EU-27 and China [7] from journals covered in the Thomson Reuters Science Citation Index or the Social Sciences Citation Index. Each region received a fractional count based on the fraction of the institutions in the region.

Limitations of the data and analysis. Datasets have been acquired from the best and most reliable sources available.
However, there are some issues with regard to comparability across regions. In particular, the data do not measure the skill level of the doctoral graduates, the value of the patents granted or the originality of the papers published. These qualities may vary between the regions. Despite these potential limitations, the comparisons are illustrative in the present context.

Most of the datasets were directly amenable to statistical analysis, including, for example, the annual absolute and relative differentials. The OECD data had missing values for the fraction of R&D funded by the government in China for 2001 and 2002 therefore we estimated this using linear interpolation.

Results

State of the research support in the US

Adjusted for inflation and divided by the population, growth in the US FRF has been uneven, with large increases during some years and gradual reductions during other years (Figures 1A and 2). Figure 1 also shows FRF as a percentage of GDP (B), total
federal spending (C) and federal discretionary spending (D). Each plot shows two peaks, one during the mid 1960s, and the other during the early 2000s. Year to year differences for the above quantities are shown in Figure 3.

The two peaks can be explained mainly by the trends in the National Aeronautics and Space Administration (NASA) and National Institutes of Health (NIH) budgets. The first peak is attributable to the burst of funding that NASA received during the space race, and the second peak to the period of regularly increased NIH funding on the “doubling curve” (Figure 4). Which of these peaks is higher depends on whether one considers total or discretionary spending. The curves have different shapes in part because discretionary spending has declined from two-thirds of the federal budget in 1965 to one-third in 2001. Therefore, the FRF surges had different impacts on the two budgets. In either case, the fraction of spending devoted to research has declined since 2001.

Figure 5A compares US FRF with research funding from other sources since 1956. At present, industry and the federal government contribute approximately equally towards research (the FRF is 106% that of industry). However, 45 years ago, FRF was more than twice (221%) that of industry. Although contributions from nonprofits, universities and state governments have increased slowly, these contributions still account for less than 16% of total research spending in the US. As shown in Figure 5B, when R&D spending is considered (i.e., development spending is added), industry’s spending has grown from half (49.6% in 1965) to more than two times (249% in 2007) that of the government. This change is in part the result of a shift from development spending to research spending by the US government (Figure 6). US FRF has risen from 33.7% in 1965 of the total US R&D spending to 64.6% in 2007 (Figure 6).

Table 2 summarizes the distribution of funds spent by industry on R&D in 2007, while Table 3 does the same for the federal government R&D. It is interesting to note that among manufacturing industries, which capture 69.8% of the overall industry spending on R&D, pharmaceuticals and medicines account for 19.6% of the overall spending. This reflects both the importance of Healthcare to the overall US economy and the research intensive nature of this industry (only the category of Computers and electronic parts ranked higher in spending). Among nonmanufacturing industries (36.2% of the spending), scientific R&D services capture only 5% of the overall R&D spending (Table 2).

In contrast, 75.5% of federal R&D spending is captured by two categories: the Department of Defense (49.9%) and the NIH (24.5%) within the Department of Health and Human Services (Table 3). Surprisingly, DARPA receives only 3.1% of the federal R&D budget yet has generated a great number of high impact science and technology advances. Also surprisingly, the NSF, a pivotal funding agency for the scientific community charged with promoting the progress of basic and applied science, receives only 3.6%. Finally, the Department of Education, which is responsible for the advancement of teaching methods for the future workforce, receives only 0.3% of the federal R&D budget.

![Figure 6. The US FRF as a percent of federal R&D spending.](image)

**Table 2. Breakdown of industry spending on R&D in 2007.**

| Category                | Subcategory                        | Further subcategory             | Percent |
|-------------------------|------------------------------------|---------------------------------|---------|
| Manufacturing           |                                    |                                 | 69.8    |
|                         | Chemicals                          |                                 | 22.8    |
|                         | Computer and electronic products   | Pharmaceuticals and medicines   | 19.6    |
|                         |                                    | Semiconductor and other electronic components | 7.5 |
|                         | Transportation equipment           | Navigational, measuring, electromedical, and control instruments | 5.1 |
| Nonmanufacturing        | Information                        |                                 | 30.2    |
|                         | Publishing, including software     |                                 | 11.9    |
|                         | Professional, scientific, and technical services | Computer systems design and related services | 8.6 |
|                         |                                    | Scientific R&D services        | 5.0     |

Only categories and subcategories that received at least 5% of the overall industry R&D spending are listed.

doi:10.1371/journal.pone.0012203.t002
Research indicators in the US, the EU and China

Figure 7A shows absolute government R&D spending in the US, the EU-27 and China from 1996 to 2007. Currently, the US still has a higher level of R&D spending than the EU-27 and China. The same holds at a per capita level, as shown in Figure 8. Although R&D spending is much lower in China than in the US and the EU-27, their growth rate of spending relative to 2000 is much higher than the US or the EU-27 (Figure 7B). Figure 7C shows government R&D spending as a percent of GDP. Both the US and the EU-27 R&D budgets as fractions of their respective GDPs have been declining in recent years, while China’s has held steady; however, China’s recent GDP growth has been much greater than that of the US or the EU-27. Therefore, in absolute numbers, a constant fraction of the Chinese GDP is a substantial increase, in absolute terms, for China’s FRF.

Figure 9 shows the number of science and engineering doctorates awarded in the US, the EU and China. Figure 10 displays these quantities per capita. Over the range for which data are available, the EU-27 produced the most science and engineering doctorates in absolute terms, followed by the US and China. However, the US still produces the most science and engineering doctorates per capita. Figure 9 also shows the number of science and engineering doctoral degrees awarded in the US to its citizens and permanent residents. All of the curves, except the one for China, show a dip in 2002 and steady growth thereafter.

We make three key observations from Figures 9 and 10. First, the EU-15 produces the highest number of science and engineering doctorate degrees. Second, although the number of graduates in China started at a very low level, it increased by a factor of five from 1996 to 2006. This number does not include the number of Chinese who obtain their doctorates overseas and return home (this number was not available). However, an estimated 4,500 Chinese students obtained science and engineering doctoral degrees from the US in 2007 [7]. Third, the number of US degrees awarded to US citizens and permanent residents (solid and dashed lines, respectively) has consistently been about two-thirds of the total number of degrees awarded in the US. The rest are awarded to students with temporary visas. A recent study [48] estimated that 40% of these students return home within five years of graduation.

The triadic patent data in Figure 11 shows a close competition between the US and the EU in terms of absolute number of triadic patents. The number of triadic patents for China is far lower than both the US and EU. When normalized per capita, the US has a substantial lead over the EU in terms of triadic patents, and both still greatly lead China (see Figure 12). As triadic patents are not recognized and promoted in China, this metric is likely an uneven comparison, but analysis using domestic patent data showed similar trends. Figure 13 shows the number of papers published by authors in three compared regions between 1996 and 2007. The number of papers published per year is slowly increasing in the US. For the EU-27, the rate of increase is somewhat larger. The number of publications in China is the lowest among the three, but is increasing at the highest rate. Finally, while the EU-27 has more publications than the US in absolute number, the EU-27 has fewer publications per capita (see Figure 14).

Discussion

Our findings can be summarized into eight key results. 1. The level of US federal research funding (FRF) has varied between 0.2% and 0.6% of the GDP during the last six decades. 2. Since the 1960s, the US FRF contribution has gone from twice that of industrial research funding to roughly equal. 3. Similarly, since the 1960s, research and development (R&D) funding by the US government changed from almost twice that of industry to less than half of industry funding levels. 4. The US FRF spending has also shifted in focus; approximately 65% of the total US R&D spending now goes to research support whereas in the 1960s ~30% was directed to research support. 5. There has been a decline in the fraction of spending devoted to research since 2001. 6. Although well below the US and the EU in overall R&D funding, FRF in China has had a sustainable and high growth rate as stagnation in the US and the EU. 7. The EU currently produces more science and engineering doctoral graduates and scientific publications than the US in absolute terms, but not per capita. 8. One third of all the doctorate degrees in the US are obtained by the students on the temporary visas, and ~40% of those return home within 5 years of their graduation [48].

Our world is an ever-changing environment, and it is naive to think that any country can conduct business as it has been and...
expect that to be adequate for the future. While the US can pride itself on a legacy of remarkable advancements, it is time once again to reexamine what policies and resources are available for the future. We must examine the question: “What role is the US playing now, and what role will it play in the future of international science?” The US is facing increasing global competition in research and research related areas. Although our current comparisons are limited to China and the EU, it is clear that many regions throughout the world are investing in science and should be studied as well. These include other parts of
Asia (specifically, India, Israel, Japan, South Korea, and South-West Asia), non-EU Europe (specifically, Russian Federation, Switzerland and Ukraine) and the Americas (specifically, Argentina, Brazil, Canada, and Mexico).

In addition, given the results of our analysis, we must consider “How will the US continue to foster its scientific strengths?” These results illustrate that the US financial commitment to research has plateaued in recent years, although the federal government has shifted more of its funding towards basic and applied research, while industry continues to concentrate on development. As science is founded on rigor and quality, it will be a mistake to be distracted by sheer quantity. A point in its favor is that the US currently has a very strong system of university research. In fact, in the 2009 Academic Ranking of World Universities, 17 of the top 20 universities were in the US [49]. However, at the same time, students in US K-to-12 schools are lagging behind students from many countries [50]. It is crucial that the US focus ever more diligently not only on the quality of the science it produces, but also on the quality of its scientific workforce. Therefore, focusing on K-12 education in general and, specifically, on STEM (Science-Technology-Engineering-Mathematics) becomes vitally important for the US [50].

Research (both basic and applied) translates into technological innovations that, in turn, transform into benefits for society and improvements in people’s lives. Given that a substantial increase in funding is unlikely, the US government will have to find new innovative ways to increase the effectiveness of current funding. Similarly to post World War II, when Vannevar Bush helped to formulate new federal policy towards science [51], we argue that now is the best time to do the same. As the 21st century moves ahead, it is vital that the federal government continues and strengthens its support of research and formulates a thoughtful and competitive science policy for this new century. This work calls for a serious discussion by the research communities within the government, academia and industry as well as among historians and administrators of science, policy analysts and makers (see, for example, [57]).

Figure 11. Recent triadic patents granted in the US, the EU-27 and China. Triadic patents are patents which are valid with the United States Patent and Trademark Office, the Japan Patent Office, and the European Patent Office. The blue, green, and red lines show the number of triadic patents granted to American (US), European (within the EU-27), and Chinese inventors, respectively.

doi:10.1371/journal.pone.0012203.g011

Figure 12. Per capita triadic patents granted in the US, the EU-27 and China. The blue, green, and red lines show the number of triadic patents granted per capita to American (US), European (within the EU-27), and Chinese inventors, respectively. Per capita figures were divided by the population of the region.

doi:10.1371/journal.pone.0012203.g012

Figure 13. Recently published papers by researchers in the US, the EU-27 and China. Papers from journals included in the Science Citation Index and the Social Sciences Citation Index were enumerated. Each region received a fractional count based on the fraction of the institutions in the region.

doi:10.1371/journal.pone.0012203.g013

Figure 14. Published papers per capita by researchers in the US, the EU-27 and China. Papers from journals included in the Science Citation Index and the Social Sciences Citation Index were enumerated. Each region received a fractional count based on the fraction of the institutions in the region. The number of papers was divided by the size of the population of each region.

doi:10.1371/journal.pone.0012203.g014
Acknowledgments

We would like to thank Andrew Bauman, Vicki Cohn, James Crawford, David Cullen, Kevin Finneran, Thomas Hansen, James Hendricks, Ronald Johnson, Evelyn Koller, David Lipman, Brenton Louie, Andrew Lowe, Courtney MacNealy, Michael Portman, Peter Richardson, Richard Roberts, Richard Satava, Alex Shneider, Margaret Sedensky, Arnold Smith, and William Smith for their critical reading and insightful discussions.

Author Contributions

Analyzed the data: GJH WAH RH NK EAS PA PC DF BRF BL FM VO CVS GvB JCW EK. Wrote the paper: GJH WAH RH EAS EK. Made significant contributions to the interpretation of the results: NK PA PC DF BRF BL FM VO CVS GvB JCW. Helped decide the scope of the paper: NK PA PC DF BRF BL FM VO CVS GvB JCW. Suggested analysis to include: NK PA PC DF BRF FM CVS GvB JCW. Conceived of the analysis and directed the project: EK.

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