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HEALTH SCIENCES

Global scientific production in the pre-Covid-19 Era: An analysis of 53 countries for 22 years

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Abstract: Based on an extensive analysis of public databases, we provide an overview of the global scientific output and describe the dynamics of the profound changes in the scientific enterprise during the last decades. The analysis included the scientific production of 53 countries over the 1996-2018 period. During this period, the production of articles per year has tripled. There was a strong correlation between the growth of the global gross domestic product and the increase in the number of articles (R^2 = 0.973, P<0.001). Six countries showed a robust increment of their scientific production and are currently among the top 20 in the ranking of world scientific production (China, India, South Korea, Brazil, Turkey, and Iran). The mean annual growth rate was about 12.7% for these six countries. The share of the global scientific production of these countries increased from 7% in 1996 to 27.8% in 2018. Conversely, the participation of the 10 most traditional countries has dropped from 73% to 45% during the same period. In conclusion, we believe that our findings may contribute to further studies aiming to evaluate the impact and changes of the scientific endeavor over the next years in light of the forthcoming new world framework.

Key words: research evaluation, scientific production, science policy, bibliometric indicators.

INTRODUCTION

Science can be described as a complex, self-organizing, and constantly evolving multiscale network. Scientific knowledge consists of concepts and relations embodied in research papers, books, patents, software, and other scholarly tools, organized into scientific disciplines and broader fields (May 1997, Evans & Foster 2011, Fortunato et al. 2018). Scientific discoveries, new technologies, and the intensive application of forefront knowledge are key factors for success in a competitive global economy. Therefore, the strength of a country's overall Research and Development (R&D) endeavor can be a relevant indicator of current and future national economic advantage (National Science Foundation 2018).

Quantifying the relative performance of individual scholars, institutions, and countries has become an integral part of decision-making in research policy and funding allocations (Browman & Stergiou 2008). The reasons for evaluation include the stimulation of research productivity, the proper selection for funding, and the reduction of asymmetry between suppliers and users of new knowledge (Abramo et al. 2011a, b). Quantifying the scientific performance for evaluation and comparison purposes has become an integral part of decision-making in research policy. Bibliometrics indicators are now considered important tools for science policy, thereby providing a basis for evaluating and orienting research funding agencies (Haeffner-Cavaillon & Graillot-Gak 2009).

Concurrently, the rise of Web technologies, accessible online databases and powerful reference tools, have greatly improved access to publication outputs (Allen et al. 2009, Evans & Foster 2011, Docampo & Bessoule 2019, Raban & Gordon 2020). In this regard, the SCImago Journal & Country Rank (SCI) is a unique publicly available portal developed from the information contained in the Scopus® database and provides access to several scientific indicators of journals and countries (SCImago 2019). These indicators can be used to assess and analyze several scientific domains, including country productivity and rankings. Citation data are drawn from over 34,100 titles from more than 5,000 international publishers and country performance metrics from 239 countries worldwide.

Based on a comprehensive analysis of the SCI database, this study aimed to provide an overview of the global scientific output from 1996 to 2018. The hypothesis was that the profound changes in scientific endeavor over the past two decades have changed the share of scientific output among traditional and emergent countries.

MATERIALS AND METHODS

We retrieved data regarding the scientific output of several countries from the SCImago website https://www.scimagojr.com/. SCImago is an online platform that ranks journals and countries in several fields of knowledge based on bibliometric indicators including, among others, the total number of documents per year, citable documents, citations per document, and the H-index. The ranking is based on the Scopus database, which includes a remarkably wide range and large number of scientific journals published not only in English but also in 50 other languages. The SCImago webpage is updated daily. It offers open access and is simple to use, thereby providing powerful tools for data analysis.

The inclusion criterion for this study was countries with more than 1000 documents at entry in 1996-1997. Thus, we retrieved data from a total of 53 countries, including 54,144,569 documents and 47,709,775 citable documents (about 96% of the total). We recorded the number of total documents and the number of citable (original articles, reviews and conference papers) documents comprising all fields of knowledge published throughout the 1996-2018 period, provided by the SCImago database.

Variables of interest

The following variables were retrieved from the SCImago website (https://www.scimagojr.com/countryrank.php): citable documents, number of citations, citations per documents, and h-index (in this particular case, the number of papers (h) published in a country that received at least h citations). Data retrieved from the SCImago website were also used to calculate the annual growth rate (the value at the end minus the value at the start of each year, divided by the starting value) and the average annual growth rate, using the following formula: growth rate during period A + growth rate during period B + growth rate during period C + ... + growth rate during period X) ÷ number of periods. In addition, we calculated the share of scientific output for each country and continent using the following formula: the number of citable documents from each specific country or region divided by the total number of citable documents.

Social, economic and demographic data were retrieved from various public databases: GDP (Gross domestic product, million current US$) – data from the United Nations website

- http://data.un.org/. World GDP (Gross domestic product, growth rate) – data from the World Bank website - https://data.worldbank.org/. GERD (Gross domestic expenditure on R&D, as percentage of GDP) – calculated as the total domestic expenditure on R&D during a given year divided by the GDP and multiplied by 100. Data from the Organization for Economic Co-operation and Development (OECD) website - https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB and also from the UNESCO website-http://uis.unesco.org/apps/visualisations/research-and-development-spending/.

Statistical analysis

We downloaded the spreadsheet with all variables of interest from the above-mentioned public databases and integrated all of them into a dedicated database on the SPSS (*Statistical Package for Social Science for Windows, Inc., USA*) version 18.0 for Windows. Continuous data were reported as medians and interquartile range (IQ) or means and standard deviation (SD), when appropriate. ANOVA was used to compare parametric variables of normal distribution. We performed a linear regression analysis to examine the correlation between world GDP and the increment of number of citable documents published over the 1996-2018 period.

RESULTS

Global increment of scientific production

Over the 1996-2018 period, there was a continuous increment of world scientific output as measured by the number of citable documents indexed in the SCImago database. Of note, this scientific output has expanded not only in terms of absolute number of papers published annually, but also regarding the number of countries with relevant scientific production. For instance, during the 1996-1997 period, 53 countries had an annual production of more than 1000 papers, while in 2018 this value had already been surpassed by 94 countries. However, the distribution of production is still heavily skewed. Only six countries accounted for about 50% of the world scientific output in 2018 (USA, China, UK, Germany, India, and Japan).

According to the inclusion criterion, our analysis encompassed 47,709,775 citable documents, corresponding to about 96% of the global output, originating from 53 countries over the 1996-2018 period. During this period, the production of citable documents per year tripled, increasing from 1,067,054 in 1996 to 3,340,092 in 2018. Over the same period, the global GDP increased by about 90% from 43,630 to 82,643 trillion US$. There was a strong correlation between the global GDP growth and the increment of the number of citable documents published over the 1996-2018 period ($R^2 = 0.973$, $P<0.001$, Figure 1). According to the linear regression equation, for each one US$ trillion increment in world GDP the number of papers increased by about 65,000. This also indicates that the increment of world GDP is responsible for a relevant proportion of the variation in the number of published papers.

Regarding the world regions, there has been a steady increment in production of scientific publications spread over all continents (Figure 2a). Of note, Asia surpassed the output of North America in 2007-2008 and, keeping its pace of growth, it will surpass Europe in about 13 years. Figure 2a also shows the slow but steady increment of scientific output in parallel with an increase of production of citable documents in less traditional regions.

Figure 2b shows the increment in citable documents from 1996 to 2018 for the six top ranked countries that together accounted for about 50% of the world scientific output. China has shown a robust steady increment

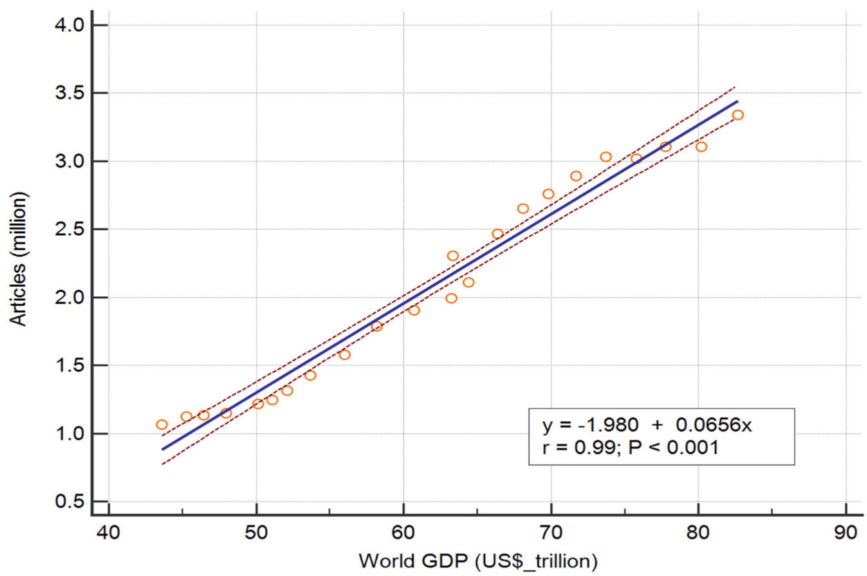

Figure 1. Correlation between annual production of scientific articles and the annual increment of world GDP.

in scientific output and has recently tied with the US. India has also exhibited an impressive growth in the absolute number of papers, surpassing Japan in 2015 and has recently tied with Germany´s output. From 1996 to 2018, China multiplied its production of papers by 20 times, India increased it 7.5 times, while the increase of Japan was of only 1.3 times.

Growth rate of world scientific output

Over the 22-year period (1996-2018), the growth pace of global scientific output averaged 7.4% annually, more than double the respective GDP growth rate pace, which was f about 3% for the 53 countries included in the analysis. Figure 3 graphically juxtaposes the annual growth pace of citable documents over the corresponding average global GDP growth rate over this period. The graph also illustrates the period labelled as "great recession of 2008" roughly between 2007 and 2009, when the mean GDP growth rate dropped to 1.4%, with its nadir in 2009 with a fall to -2.5%. This figure accounts for a loss of about three trillion dollars of global GDP in 2009. Of particular interest, Figure 3 also highlights that the growth pace of scientific production has been declining since this recession period. From 1996 to 2010, the overall average annual growth pace was of 9%, while, over the period 2011-2017, this parameter has plunged to about 4%. Concomitantly, the corresponding figures for the GDP growth rate were 3.4% and 2.5%, respectively.

Emergent regions and countries on the scientific output scenario

As expected, the increment of scientific output in less traditional regions had an impact on the share of global scientific production. For instance, the three main regions (Europe, Asia, and North America) had contributed 93.5% of all publications in 1996, but their share in global scientific output was reduced to about 86% in 2018. Of note, there was a shift in scientific production even within these regions. There has been a relative decline in the share of North America (from 34.5% to 19.5%) and in Europe (40.8% to 32.8%), and a noticeable increment in the participation of Asia (from 16.3% to 30.3%). Figure 4 illustrates longitudinally the dynamics of the changes in the share of scientific output by region over this period. Of note, it can be observed that the increment of Asia's share

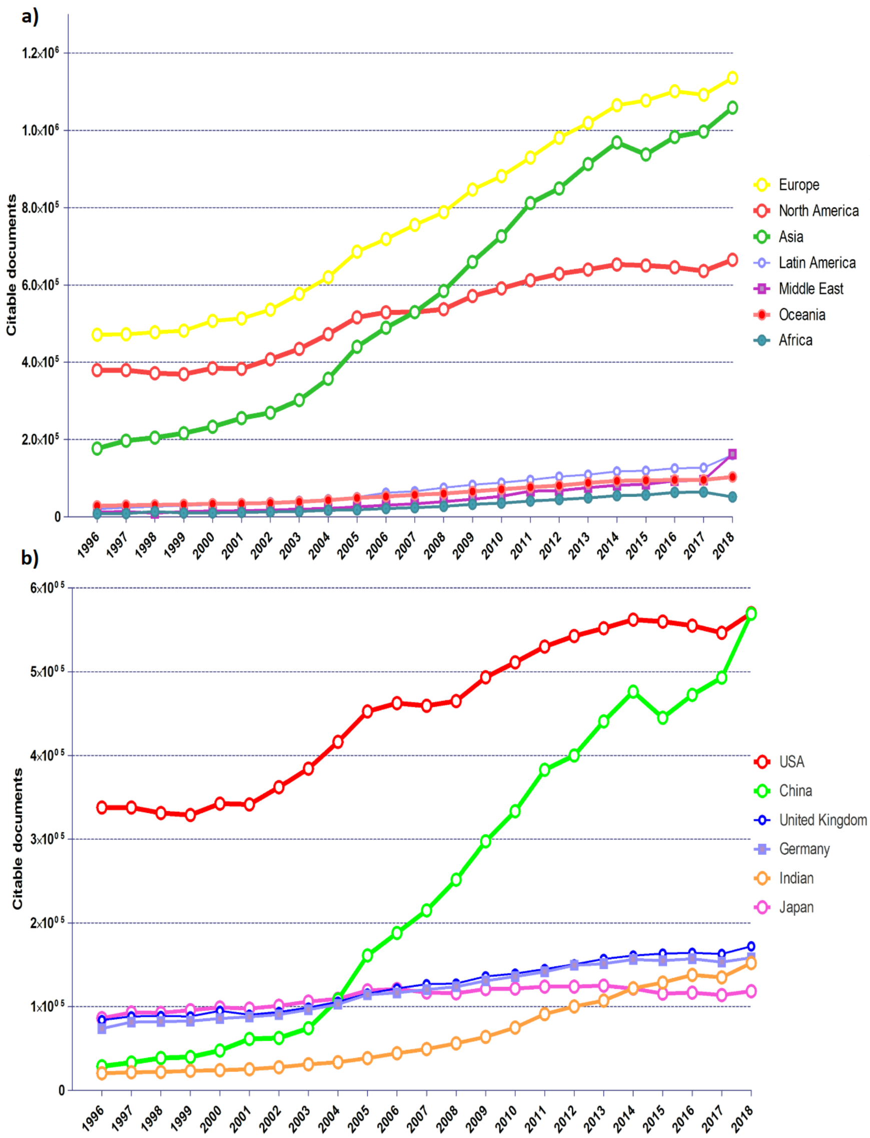

Figure 2. a) Annual production of scientific articles indexed in the SCImago database by seven continents; **b)** Annual production of scientific articles indexed in the SCImago database by the six most productive countries.

was almost exactly symmetrical to the relative decline of North America's participation.

Of particular interest, some countries have shown a stronger increment in their scientific production. Of 53 countries included in the analysis, 20 (37.7%) had a mean growth greater than the average increment of 7.4% observed for the entire global scientific production during the last 20 years. Nevertheless, most of these countries still had a small output, with an average of < 20 000 papers annually. On the other hand, six countries had a steady robust increment in scientific production during the last 20 years and are currently among the top 20 in the ranking of world scientific production (China, India, South Korea, Brazil, Turkey, and Iran). The mean growth rate during the study period was about 12.7% for these six countries. Figure 5 illustrates the mean growth rate per year of the emergent countries as compared to the world increment during the same period. All emergent countries had a mean growth rate above the word average.

Figure 6 illustrates the relative decline in the share of scientific production by the traditional countries (considered as the 10 most productive countries, USA, UK, Germany, Japan France,

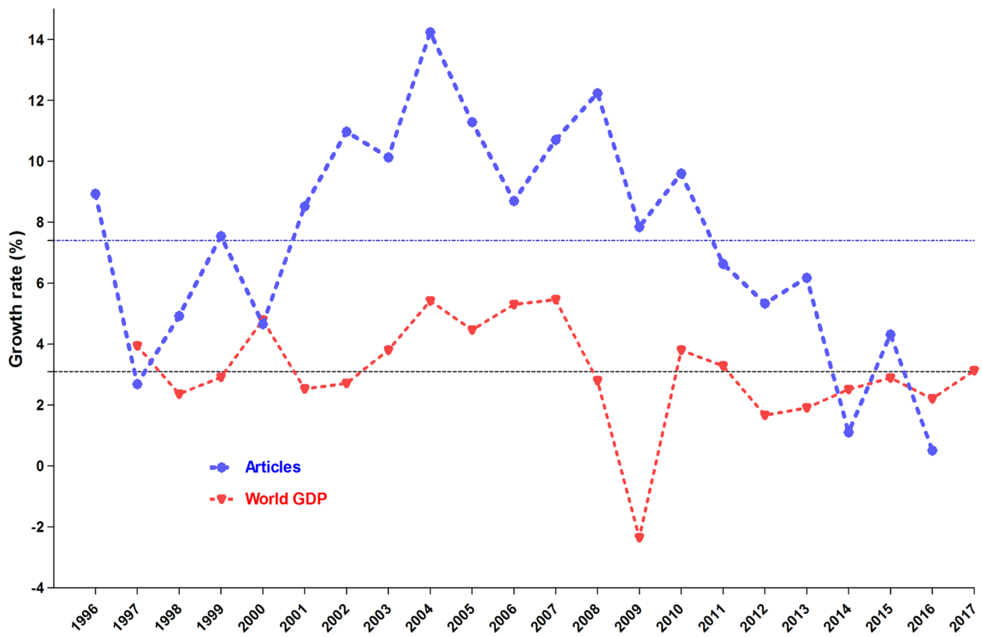

Figure 3. Annual growth pace of scientific papers compared to the corresponding growth pace of world GDP. The horizontal lines represent the mean growth rate of articles and world GDP over the period.

Italy, Canada, Australia, Spain, and Russia) and the substantial increment of the share for the six emergent countries. The share of the global scientific production of these six countries increased from about 7% in 1996 to 27.8% in 2018. Conversely, the participation of the 10 most traditional countries dropped from 73% in 1996 to about 45% in 2018. In relative terms, Iran had the highest increment in its scientific production with an annual mean growth rate of 21.5%, increasing from about 1000 papers in 1996 to 54915 papers in 2018. Its share of world scientific production expanded from 0.09% to 1.54%. However, among these countries, China and India stand out and both are among the top 5 in the ranking of world scientific production.

DISCUSSION

In this study, our findings highlight the profound transformations experienced by science endeavor for the past two decades and the remarkable impact of GDP on scientific production. The overall increment of the global scientific output has been auspicious during the last decades. First, our analysis shows that, from 1996 to 2018, the growth pace of global scientific output averaged 7.4% annually. This growth pace is exactly double that of the 1981-1994 period, when the world's output of scientific papers increased by 3.7% per year (May 1997). Of note, these rates correspond to a doubling time over 9.5 and 19 years, respectively. In addition, over this period, the distribution of science output has been shifting from regions and countries with the emergence of new important players and a parallel decline of some traditional countries. Therefore, there has been a remarkable redistribution of scientific output among the countries included in our analysis.

During the last decades, several indexes have shown a steady increment in global scientific research output. According to the 2015 UNESCO Report, between 2008 and 2014, the number of scientific articles catalogued in the WoS (Web of Science) grew by 23%. Growth was strongest among the middle-income economies (94%), primarily driven by the growth in Chinese publications (151%). Moreover, global gross

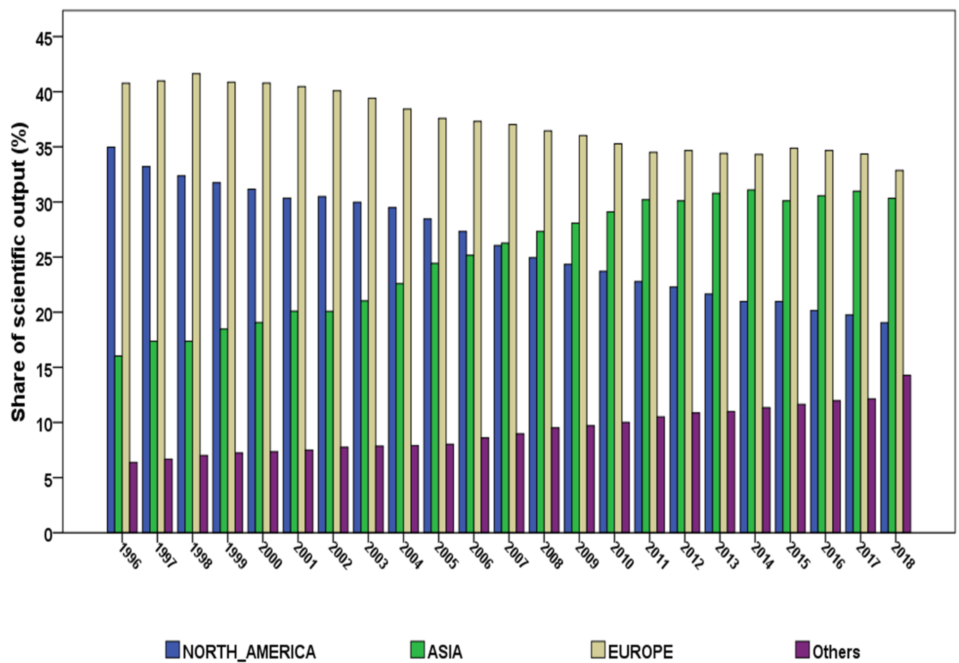

Figure 4. Share of world scientific output by main region, 1996-2018.

expenditure on R&D reached a total of 1.48 trillion PPP (purchasing power parity) dollars in 2013 and grew faster (30.5%) than the global economy (20.1%) between 2007 and 2013 (United Nations Educational 2015). Our findings showed that there was a remarkably positive correlation between the increment of the world GDP and the increase of scientific output over the period 1996-2018. Nevertheless, the growth pace of scientific production is even more accelerated than the growth pace of global GDP. In a period of 22 years, when the global GDP almost doubled, the scientific production roughly tripled.

In this changing scenario, we were able to identify some patterns regarding the diversity of scientific production among countries. First, concerning the number of papers published, there is a group of countries that remain constant among the top 10 ranked with minimal variation over the 1996-2018 period. Only India was able to join this select group during the last two decades, rising from 13th position in 1996 to the current 5th position. Another major player is China, which had a remarkable increment in its scientific output during the last decades. Over 1996-2018, the mean growth rate of China's output was about 15%, reaching an astonishing average of about 26% from 2000 to 2005. At this pace of 15% annually, China has doubled its scientific output every five years. India also had an impressive growth rate of about 9% over 1996-2018, and especially during the 2005-2010 period, when the average annual growth rate was 15.3%. By contrast, during the same period, the US and Japan had a mean growth rate of only 2.3% and 1.5%, respectively. At these paces, the doubling time for the US and Japan is about 31 and 48 years, respectively.

Another group of countries can be labelled as emergent players in this scenario of scientific production. We identified six countries with an impressive annual mean growth rate of about 12.5%. These countries had a substantial increment in their scientific output and two (China and India) are currently ranked among the top 10 countries and the remaining four among the top 20 in the ranking of scientific production (South Korea, Brazil, Turkey and Iran). However,

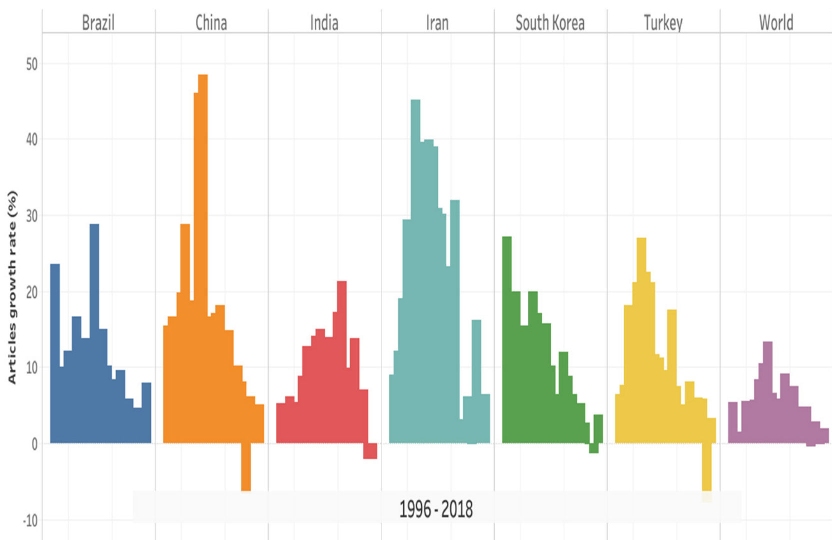

Figure 5. Annual growth rate of article production by the emergent countries compared to the overall growth rate of world production.

emerging countries remain lagging behind in terms of effectiveness in providing scientific capability to their populations (Wong 2019). In addition, we should stress that, despite the relevant increment of scientific output in these emergent countries, the question of the impact of this production still needs to be thoroughly addressed. One of the many tangible measures of scientific impact, the number of citations, stands out in its frequency of use (Abramo 2018, Abramo & D'Angelo 2018). In spite of heated debates, the citation-based measures are thought to provide, by proxy, a reasonable quantitative index of the importance or a scientist's standing in the research community (Wang et al. 2013, Sinatra et al. 2016, Ioannidis et al. 2019). In this regard, citations of publications from these emergent countries still fall beneath the average. For instance, data from China's Ministry of Science and Technology suggest that, despite the rapid growth in articles authored by Chinese scholars, the average number of citations per article was of only 9.4. This is lower than the global average of 11.8, putting China in 15th place by this measure (Huang 2018). The relatively low impact of the scientific papers from emergent countries may be due to the fact that, to some extent, many of their articles are still published in the native language and in journals of limited circulation, thereby passing under the international radar (United Nations Educational 2015).

In spite of this optimistic scenario regarding the scientific world output, our analysis has shown a dual pattern of increment in scientific output over two quite distinct periods. The growth pace slowed down to a half after 2011 and therefore is currently similar to the pace of the 1981-1994 period. The smaller average annual growth rate for the 2011–2017 period may partly reflect the effect of the recession years (notably, 2008-2010) at the outset of this period. Nevertheless, we believe that the deceleration in the growth pace of the world GDP alone does not account for the fall in the growth rate of scientific production. Our data have shown indeed that the global GDP recovered relatively fast its former growth pace, while the growth rate of scientific production continued to be reduced after 2011. After the so called "Great recession of 2008" characterized by a deep financial crisis that had spread all over the world, public commitment to R&D funding declined in many countries in the context of austere budgets (Nordling 2009, Abbott 2013, Trachana 2013, Escobar 2017, Science News Staff 2017, Editorial 2018, Nogrady 2018, Angelo 2019, Ojeda 2019, Wessel 2019). Therefore,

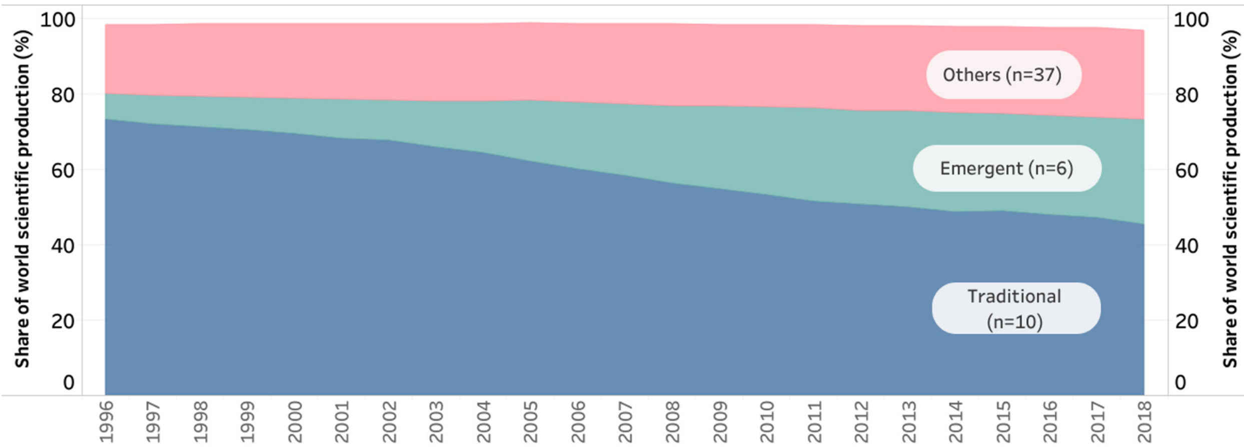

Figure 6. Share of world scientific output by country, 1996-2018.

one might speculate that the decline of world scientific production was triggered by a severe economic crisis that has taken a heavy toll on the R&D budget around the world. Nevertheless, we are aware that other pivotal variables would need to be included in the analysis in order to obtain a more complete view of this issue. For instance, data regarding GERD (Gross domestic expenditure on R&D), and data on innovation and technological transfer (e.g., patent registrations) might also be correlated with the rate of scientific output. Such a comprehensive analysis may provide a more informative view about the decline of scientific output. However, these data are not promptly available or are fragmented in the World Bank and UNESCO databases.

The most obvious limitation of this study was the uncertainty about the causal and even temporal relationship between economic issues and the question of the world scientific productivity. First, the effects of a financial crisis and consequent public funding cuts may take a while to fully take place. Second, it is a complex task to discern with certainty the different impact of public and private funding on scientific endeavor around the world. On the other hand, we used a comprehensive updated database covering a span of more than 22 years of global scientific output. In addition, we correlated the data with robust social and economic indicators provided by reliable world multinational organisms such as the United Nations and UNESCO.

In conclusion, our data have shown a mixed scenario for the scientific endeavor during the last two decades. On one hand, the growth pace of scientific production has exhibited an accelerated increase all over the word, especially in middle-income countries. Consequently, there was an emergence of new important players on the scene of the global scientific community, stimulating collaborative efforts and even a healthy competition between traditional and new players. On the other hand, our data have also shown a worrisome scenario for the scientific community. The great recession of 2008 produced a substantial slowdown of the growth pace of scientific output that persists today. In addition, the novel corona virus disease (COVID-19) pandemic starting in early 2020 has been threatening the entire world health systems and a severe economic recession is expected for the next years (Fauci et al. 2020, Kickbusch et al. 2020). Consequently, we are facing today a much more complex scenario. Our findings suggest that the scientific endeavor is strongly dependent on the economic strength of the nations. Paradoxically, when the entire world is looking forward to an immediate response by the scientific community, the scientific endeavor seems to be threatened by the dire consequences of the pandemic. For instance, we have recently shown that Brazil had a median annual growth rate of articles of about 13% from 1996 to 2009. However, from 2010 to 2017, in parallel with a systematic decrease in the budget if the Ministry of Science, Technology, Innovations and Communications (MCTIC), the median annual growth rate of research papers has plunged to only about 6% (Oliveira et al. 2020). As COVID-19 continues to spread throughout the world, we may expect an even more difficult path towards the recovery of the former vigorous growth pace of the world scientific output (Bolaños-Villegas et al. 2020). Hopefully, this may be an opportunity for the governments and general population to definitively understand the importance of science in their daily lives (Editorial 2020). We believe that our findings may contribute to further studies aiming to evaluate the impact and changes in the scientific endeavor for the next years in light of the forthcoming new world framework.

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