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Research Article

The Relationship Between Scientific Production and Economic Growth Through R&D Investment: A Bibliometric Approach

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ABSTRACT

This quantitative bibliometric research measures the efficiency of investment in R&D for the 17 more relevant countries investing in R&D through a novel indicator based on the number of scientific articles (associated with stock markets), produced for every 1% of investment in R&D in terms of GDP. The study is justified by the need to deepen the relationship between investment in R&D and economic growth, and was conducted for developed and emerging countries separately, so that the understanding of which countries or regions' investment in R&D and its consequent scientific production has the greatest impact over the size of their economies through innovation. Our findings indicate clearly that R&D investment strongly correlates to the economy's size of the studied countries. In addition to finding our novel indicator statistically significant with respect to economic growth through a series of multiple linear regressions and proposing economic growth not statically, but as a dynamic cumulative effect over time, this becomes more relevant for emerging countries (represented in this study by China, Brazil, India, Russia and Turkey, or BRIC + Turkey) compared to developed ones, which decants into an opportunity for scholars and particularly governments to design or restructure their R&D policies towards innovation.

Keywords: Bibliometrics, Economic growth, Multiple linear regression, Research and development, Scientific production, SDG 8.

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INTRODUCTION

Economic growth is crucial and one of the three pillars of sustainable development today.[1] A flourishing economy is usually related to the size of its Gross Domestic Product (GDP), its GDP per capita or how agile its GDP growth is.[2] Nevertheless, it is less common among the literature to associate sustained economic growth to the efforts of research and development (R&D) conducted by each country, particularly related to its scientific production, and even more specifically to articles published. The United Nation's Sustainable Development Goals (SDGs) consider economic growth one of its priorities, precisely on SDG 8 "Decent work and economic growth", which at the same time contains, among its targets, achieving economic growth and productivity through innovation.[3] Herzer[4] studied how R&D spending as a percentage of GDP can influence economic growth, although the relation was established as R&D spending versus Total Factor Productivity (TFP) only in developing countries.[5] The author offered positive correlation between R&D spending and TFP, which could lead to the fact that in emerging countries the impact of R&D over economic growth could be higher. Soete *et al*.[6] studied OECD countries searching for the same as Herzer,[4] with the same findings regarding TFP. Also, there is a very relevant opportunity to narrow the research articles to those related to specific disciplines backed by evidence that state that their development promotes economic growth, such as stock markets and its close relation to economic development.[7] In spite of this, the literature associated to the relationship between scientific production, R&D spending and economic growth is incipient, particularly when including scientific production in the equation, and almost null if framed in stock markets which consider developed and emerging countries in the same study.

GDP remains to date as one of the most common ways to measure economic growth.[2] Even though it has some limitations, such as the fact that it is a measurement from today, but does not involve future sustainability or growth,[8] or even being proposed today some other ways of potentially measuring economic growth, such as lighting density in night images of planet Earth that

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reflect the concentration of lighting in urban areas and associated with economic activity,[9] GDP as traditionally stated permits a standardized and mainly comparable way of tracking economic growth at any country level.[10] In spite of the previous facts, GDP has been involved in bibliometric articles as a cause for different phenomena, or as a classification criterion. For example, Confraria and Godinho[11] used GDP to classify their bibliometric findings among the African countries studied, while De Moya-Anegón and Herrero-Solana[12] considered GDP as a factor for generating more publications, which is the most common scope.[13,14] GDP is also used for normalizing bibliometric results[15] and as an approximation of socio-economic development associated to the countries that publish articles.[16]

An important edge about the lack of studies that could consider GDP, or particularly GDP growth, not as an independent variable, but rather as a dependent one, is the fact that countries in general search for economic growth, which has been also reflected on the United Nations' SDGs.[3] In other words, countries should be looking for how to accelerate their economic growth. Furthermore, it is stated by the United Nations that innovation must participate towards achieving economic growth,[3] and indeed innovation has been stated to be one of the most important paths to achieve it.[17] According to Greenstone,[18] this can happen by investing in R&D, which coincides with the United Nations including innovation as a way towards economic growth. This would involve a different scope than that offered currently by the literature: R&D investment is needed to achieve innovation, and innovation is needed to reach economic growth.[19] Although R&D is not the only way to reach economic growth, being some other initiatives important, such as financial inclusion,[20] R&D remains highly relevant towards that objective,[21] particularly responsible research and innovation.[22] It is not only a matter of attracting investment towards emerging countries that need to boost their economic growths,[23] but also making sure that those companies that actually invest responsibly and efficiently in R&D get supported by their governments.[24]

Regarding bibliometric studies, although there are studies considering GDP as a variable to measure economic growth[2,10] or as a classification criterion,[11-14] studies associated with stock markets are scarce. Cicea and Marinescu[25] analyzed the relationship between foreign direct investment and economic growth, but did not include innovation or R&D as variables associated with the previously mentioned relationship. Other bibliometric studies only study the progress of publications made by specific financial journals,[26-29] so studying economic growth, in the way it has been delimited throughout the introduction, is an opportunity, along with delimiting it to stock markets. for which there is also a lack of literature.

Given the fact that there is a serious lack of literature associated with understanding how R&D, in terms of the number of articles published, achieves economic growth, the main objective of this research is to determine the impact of R&D spending in terms of scientific production related to stock markets, specifically number of articles published per each studied country, and its correlation with their economic growth, not only for emerging countries, but also for developed ones. The current bibliometric study becomes highly relevant for six reasons. First, it states the correlation between R&D spending as an independent variable and economic growth as a dependent variable, contrary to the traditional scope that considers economic growth as the independent variable.[12-14] Second, it encompasses not only the phenomena for emerging countries,[4] but for developed ones.[6] Third, the research fits within the United Nations' SDGs.[3] Fourth, it focuses on the number of articles published related to stock markets, topic that affects economic growth.[7] Fifth, the bibliometric type variable associated with the production of scientific articles ended up being statistically relevant, as will be shwon in the discussion section. Sixth, bibliometric studies are highly relevant to address the understanding of this type of problems.[30]

METHODOLOGY

The data search was conducted on February 7th, 2023, through the Web of Science Basic Search, targeting only stock market articles that could relate or promote economic growth. Narrowing the search to this kind of articles is important because the research does not pretend to establish a correlation between the publication of any kind of article with economic growth, but those articles resulting from the R&D effort and that could lead more probably to economic growth.[7] In order to capture all those relevant articles associated to stock markets, a standardized query was identified among relevant bibliometric literature.[31] Four criteria were prioritized for the search. First, following Khan *et al.*'s query configuration,[31] the keywords searched to target stock market articles were as per the query below:

"bank*" or "finance" or "financial market*" or "financial*" or "stock market*" or "stock indices" or "stock index" or "corporate finance" or "stability" or "liquidity" or "credit" or "asset pricing" or "bitcoin*" or "cryptocurrency*" or "risk*" or "governance" or "sukuk" or "takaful" or "islamic finance" or "islamic bank".

Although the previous search query has redundancies among its different terms, its configuration was respected, since the redundancy of terms, due to the "or" connector, should not influence the results considering that the data based used was the same (Web of Science),[32] in addition to representing a good start as a search criterion documented in the literature. Second, based on a previous test search, results associated to Web of Science Categories Business, Business Finance, Economics and Management go as far as 1985. In order to study the evolution of publications throughout time, the time horizon configured for the search was 1985 to 2022, being 2022 the last full year in order to preserve comparison among the full years analyzed. Third, since research articles are the main object of study, the document type for the search was configured as "Article". Fourth, the main Web of Science Categories associated in disciplinary terms with economic growth are Business, Business Finance, Economics and Management.[33] Therefore, the search was narrowed based on these specific categories.

Regarding the countries studied, the research was delimited to the main twenty countries associated with scientific production in terms of number of published articles. According to Abramo *et al*.,[34] these countries are United States, China, United Kingdom, Japan, Germany, Italy, France, Spain, Brazil, Canada, India, Australia, Russia, Netherlands, South Korea, Turkey, Poland, Iran, Sweden and Switzerland. According to the authors, 82.20% of the world's published articles in terms of clusters and 85.40% of the world's authorships are associated to those countries as the main country of origin.

The main research question is the following: to what extent the number of articles published per 1% of investment in R&D in terms of GDP correlates to the size of the economy of each country? The multiple linear regression named Model 1 shows the variables involved.

Model 1

$$(\text{Economy size}_{n-1}) * (1 + \text{GDP growth rate}_n) = \frac{\text{Articles published}_n}{\text{R \& D spending (\% of GDP)}_n} + \text{Country type}$$

Economy size$_{n-1}$ represents the size of the economy of the country studied during the previous year, considering that for the most distant year (or initial year of study) the size of the economy is assumed to be 1, and subsequently it will be the percentage resulting from the compound growth of the economy through the gradual accumulation of GDP growth rates. The GDP growth rate$_n$ represents the percentage rate at which each economy grows or shrinks. The GDP growth rates for each year studied were extracted from the World Bank database.[35] Articles published$_n$ correspond to the number of articles published per year, and R&D spending (% of GDP)$_n$ reflects the effort of each country investing in R&D as a percentage of its GDP, for each year studied. The investments in R&D as a percentage of GDP were extracted from the OECD database.[36] Country type is the dummy variable that corresponds to 1 if the country studied is an emerging country, or 0 if the country studied is a developed one. In order to maintain comparability, since some countries did not have registered data related to GDP growth and/or R&D expense for every year, the study goes up to the year 2021.

Based on the fact that there are relevant differences in terms of scientific production and budgets destined specifically for research and development in developed versus emerging countries,[37] the second research question is the following: to what extent the number of articles published per 1% of investment in R&D in terms of GDP correlates to the size of the economy of developed countries comparatively to emerging countries? Therefore, not only a dummy variable was considered in Model 1, but two additional multiple linear regressions were conducted, one exclusively for developed countries and the other exclusively for emerging countries. This second multiple linear regression is shown below as Model 2, regression that was run twice, once for emerging countries and once for developed ones.

Model 2

$$(\text{Economy size}_{n-1}) * (1 + \text{GDP growth rate}_n) = \frac{\text{Articles published}_n}{\text{R \& D spending (\% of GDP)}_n}$$

It is expected that for the three regressions the adjusted R^2 will be relevant and that the coefficients will be statistically significant, although it is also expected that the impact of the investment in R&D will be higher for emerging countries than for the developed ones.[4,6] Among the listed countries, there are 14 developed countries and 6 emerging countries. Nevertheless, since the variable economy size n-1 requires data corresponding to continuous and uninterrupted years (in order to estimate the next year's economy size), three countries had to be discarded from the study due to intermittent availability of information: Australia, Iran and Switzerland. This adjustment left behind the 17 remaining countries classified as 12 developed countries and 5 emerging countries. The 17 countries remaining represent 77.60% of the world's published articles in terms of clusters and 80.70% of the world's published articles in terms of authorships.[34]

RESULTS

According to the delimitations described above, there were 524 entries remaining. Each entry represents one country in one year, with an economy size that corresponds to that year (dependent variable), and a specific number of articles published related to stock markets divided by the corresponding GDP growth for that year (independent variable). For each entry, the dummy variable was defined as 1 for emerging countries and 0 for developed ones. Although the total amount of articles is an input used to calculate one of the independent variables and not an independent variable for itself, it is also shown in Table 1 for reference matters.

Table 2 shows the results for the multiple linear regression that considered the 524 entries listed in Table 1. This regression points to understand the behavior of the variables for the entire time horizon from 1985 to 2021, whether the countries analyzed are developed or emerging. Independent variable 1 corresponds to Articles published$_n$/R&D spending (% of GDP)$_n$, while Independent variable 2 refers to the dummy variable, where 1 is emerging country and 0 is developed country. The adjusted R^2 for this regression is 0.2126. Table 3 shows the results for the multiple linear regression run only for developed countries (which correspond to those countries listed in Table 1 except for China, Turkey, Brazil, India and Russia), while Table 4 shows the results for the regression that corresponds to emerging countries only (China, Turkey, Brazil, India and Russia, or

Table 1: Number of entries for the panel data multiple linear regression.

Country	First year	Last year	Entries	Total papers	Country	First year	Last year	Entries	Total papers
USA	1985	2020	36	80,949	South Korea	1991	2020	30	4,463
United Kingdom	1985	2019	35	22,915	Japan	1985	2020	36	3,941
China	1991	2020	30	16,616	Sweden	2003	2020	18	3,152
Germany	1985	2020	36	14,450	Turkey	1990	2020	31	3,142
Canada	1998	2021	24	11,829	Brazil	2000	2019	20	2,334
France	1985	2020	36	10,547	Poland	1991	2020	30	2,030
Italy	1985	2020	36	8,850	India	1996	2018	23	2,018
Spain	1985	2020	36	8,486	Russia	1990	2020	31	1,637
Netherlands	1985	2020	36	8,089	TOTAL			524	205,448

Table 2: Results of the first multiple linear regression (524 entries).

Variable type	Variable name	Coeff.	*p*-value	Lower limit	Upper limit
Constant	Intercept	1.2402	0.000*	1.0811	1.3993
Independent 1	Articles published$_n$/R&D spending (% of GDP)$_n$	0.0019	0.000*	0.0015	0.0023
Independent 2	Country type (dummy variable)	1.1292	0.000*	0.8600	1.3984

*Statistically significant at a 99% confidence level.

Table 3: Results of the second multiple linear regression (developed countries, 389 entries).

Variable type	Variable name	Coeff.	*p*-value	Lower limit	Upper limit
Constant	Intercept	1.5318	**0.000***	1.4725	1.5910
Independent 1	Articles published$_n$/R&D spending (% of GDP)$_n$	0.0005	**0.000***	0.0004	0.0007

*Statistically significant at a 99% confidence level.

BRIC + Turkey). The total entries analyzed per regression were 389 and 135 respectively (totaling 524). Independent variable 1 is Articles published$_n$/R&D spending (% of GDP)$_n$. For these particular cases, the dummy variable was no longer needed since developed (Table 3) and emerging (Table 4) countries were treated separately. The adjusted R^2 for each regression is 0.1006 and 0.6164 respectively. Regarding the three regressions, all of the independente variables plus the constants were statistically significant at a 99% confidence level.

The two research questions stated were the following:

Question 1: to what extent the number of articles published per 1% of investment in R&D in terms of GDP correlates to the size of the economy of each country?

Question 2: to what extent the number of articles published per 1% of investment in R&D in terms of GDP correlates to the size of the economy of developed countries comparatively to emerging countries?

It was expected that, for all cases, the adjusted R^2s would be statistically relevant. According to Hair *et al.*,[38] this can be assumed starting on an adjusted R^2 of 0.60. Therefore, only the regression shown in Table 4 would have a statistically significant adjusted R^2. Nevertheless, it is important also to highlight that, in all cases, coefficients were statistically significant at a 99% confidence level. Considering the previous facts, the results for the first regression (524 entries) and the first research question, the coefficient of the number of articles published per 1% of investment in R&D in terms of GDP show a statistically relevant correlation to the size of the economy of each country, although the strength of the model is not as high as expected, with an adjusted R^2 of 0.2126. It is also relevant to point out that, since the coefficients were statistically relevant, then the model can be considered as highly dispersed, although valid in terms of the relationship between the variables in a highly dispersed environment. That is, landed in the context that the model intends to explain, the range of possibilities in terms of the size of the economy (dependent variable) versus the productivity of investment in R&D expressed per 1% of investment in GDP (independent variable 1) and the fact that the country is a developed or emerging one (independente variable 2) is wide, but there is still a relationship between the variables with coefficients that aim to explain said relationship.

Table 4: Results of the third multiple linear regression (emerging countries, 135 entries).

Variable type	Variable name	Coeff.	*p*-value	Lower limit	Upper limit
Constant	Intercept	1.3598	**0.000***	1.0213	0.5570
Independent 1	Articles published$_n$/R&D spending (% of GDP)$_n$	0.0093	**0.000***	0.0081	0.5800

*Statistically significant at a 99% confidence level.

Regarding the second question, the interpretation of the results is almost the same as for the first question for the multiple linear regression of developed countries (389 entries). Nevertheless, in the case of the multiple linear regression of emerging countries (135 entries), not only coefficients are statistically significant, but the adjusted R^2 can be considered as statistically valid as well. Therefore, emerging countries not only show relevant correlation between the articles published per 1% of investment in R&D in terms of GDP and the size of the economy than that shown by developed countries, but the strength of the model is high as previously expected.

DISCUSSION

Although GDP as a measurement of economic growth has limitations,[8] it still remains as the most common and appropriate way to measure it.[2,9] The methodology of this research considered GDP as part of the regression models in two specific locations: one of them as a dependent variable, specifically in terms of accumulated economic growth; and on the other hand as part of the main independent variable, constituted by the number of articles published divided by the percentage of GDP invested in R&D. Beyond the results obtained in the regressions, by itself considering cumulative economic growth as an approximation to the size of an economy is an innovative perspective compared to the existing literature. In addition, the main independent variable, being posed in the way it is, invites us to interpret it as a novel indicator of efficiency in terms of R&D effort. The investment made in R&D should yield results, and these should be reflected in the scientific production generated and measured as the number of publications, since epistemologically speaking knowledge would not exist if it is not published.[39] Therefore, Articles published$_n$/R&D spending (% of GDP)$_n$ represents an important addition to the understanding of the efficiency of the investment in R&D.

Herzer[4] anticipated that R&D spending had a positive effect over TFP, but being R&D expressed as a percentage of GDP as it usually is in the current literature.[5] Through the regressions run as part of this research, there is now complementary evidence that states that not only higher investment in R&D promotes a higher economic growth, but also a higher number of scientific articles produced in relative terms with the R&D spending as a percentage of GDP also leads to a higher economic growth. Specifically, scientific articles produced about stock markets, which is a discipline whose results, if implemented, promote economic growth.[40] However, since the correlated dependent variable corresponds to the size of the economy expressed as the accumulation of GDP growth rates, this means that the relationship no longer revolves only around annualized growth, but rather the cumulative effect over the years and reflected in the whole size of the economy. The fact that this is relevant in terms of the coefficients only confirms that the productivity of investment in R&D remains not only relevant, but for both developed and emerging countries. This can be evidenced also through China, whose scientific production has grown rapidly,[41] as well as its economy.[35] However, the consistency of the regression in terms of the adjusted R^2 for emerging countries suggests that the effect over economic growth in these countries is much more relevant, and therefore it would be reasonable to think that emerging countries will benefit marginally more from the investment in R&D, that developed countries, considering the size of their economies nowadays.

Investment in R&D remains relevant today, not only supported by the fact that it leads to the innovation that the United Nations[3] associates with economic growth (SDG 8), but there is now specific evidence that investment in R&D, and particularly that measured in terms of its productivity over the generation and publication of more scientific articles, correlates with the size of the economy and its future progressive growth. As the main finding of the research, the scientific articles generated and published per each 1% of the investment in R&D in terms of GDP offer a statistically strong enough correlation in order to be used as an indicator of R&D investment efficiency towards economic growth. This is particularly important for emerging countries, where there is a greater opportunity to see the benefits of R&D investment in terms of the size of their economies. Considering that the coefficient of the independent variable for the regression of developed countries is much lower than the coefficient of the independent variable for the regression of emerging countries (0.0005 versus 0.0093 respectively), the effect on economic growth is greater due to greater investment in R&D and greater scientific production. This makes it more attractive for emerging countries to invest in research and development due to the greater impact that said investment would have on the growth of their economies, which suggests that the governments of these countries should undertake policies aimed at supporting R&D through attraction of companies, or supporting efficient companies in terms of R&D.[23,24]

CONCLUSION AND RECOMMENDATIONS

According to the results and the discussion, it can be concluded that R&D is essential for the economic growth of countries. This correlation turns out to be particularly important so that emerging countries, through an increase in scientific production as a result of investment in R&D, can achieve higher levels of economic development. Scientific production, measured through the number of articles published for every 1% investment in R&D, turned out to be an indicator strongly correlated with accumulated economic growth, so it makes sense that emerging countries, which would benefit the most from measure of this relationship, dedicate greater efforts to R&D, with the objective that their economies accelerate their growth. It is highly recommended that the scientific community delve into the use of this new indicator of efficiency of investment in R&D to measure the productivity of said investment, in the framework of responsible research and innovation.[22] It is also recommended that governments and different corresponding institutions in emerging countries begin to measure their productivity in the generation of scientific articles in order to appropriately allocate their investment in R&D.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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