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## Article

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# Scientific research activity and GDP. An analysis of causality based on 144 countries from around the world

Wiesław Dębski<sup>1</sup>, Bartosz Świderski<sup>2</sup>, Jarosław Kurek<sup>2</sup>

## ABSTRACT

Using the Granger methodology, this paper presents the causal relationship between scientific research activity, expressed as the number of significant publications, and gross domestic product (GDP). With causality tests, this relationship is investigated from two points of view: for each individual country (144 were selected) and for each specific academic field (28 were selected). Considering annual data from 1996 to 2012, two hypotheses are tested. The first suggests that scientific research activity in a given country has a significant effect on GDP; the second verifies how much each specific field of scientific research activity affects this growth. Our research confirmed the existence of this relationship for a relatively large number of countries, especially highly developed countries and those with a high potential both in the fields of scientific research activity and in GDP. Moreover, this study identifies the most significant fields of this activity that affect GDP. Additionally, the article includes an empirical study regarding how information related to the number of significant scientific publications influenced the quality of Polish GDP forecasts for 2011-2012.

**KEY WORDS:** Granger causality, weighted least squares method, number of significant publications, GDP, forecast quality

**JEL Classification:** O10, O40

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## Introduction

GDP (gross domestic product) has been used in economic research for centuries and for various types of analyses, e.g., at the GDP level in economic development analysis in order to analyze the quality of life or wealth of society, at the GDP per capita level, and at the GDP growth rate level in economic cycle analysis. In macroeconomic analyses, especially in economic

growth models or econometric models of national economies, the GDP level is used most frequently. Researchers have always been interested in the cause-effect relationship between economic growth and the factors from which it results. The factors most commonly used in models describing how a country's economic growth is determined include 1) capital, which is usually measured as the value of fixed assets or the value of productive fixed assets, 2) employment, which is measured as the number of employed people or the amount of time worked, and 3) technological—or more generally, technological and organizational—progress. The problems of specifying and measuring

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these relationships have been considered in detail when developing and estimating econometric models of national economies (econometric macro-models). An extensive overview of these issues can be found in (Ashley, 1988; Bodkin, Klein, & Marwah, 1991; Welfe, 2013). The last factor, i.e., taking into account technological developments in research showing the development of GDP or production, was first considered by Solow (1957; 1962) in detail. In econometric models of national economies, the most difficult issue regarding this factor was always choosing the appropriate measure of technological development. In the most basic method, this development was expressed by the symptomatic variable  $t$  (e.g., the simple Cobb-Douglas function in which the set of exogenous variables was enlarged by the time variable  $t$ ), the value of the newest machines or devices, or the expenditure incurred to acquire them. In a somewhat later period (the 1980s and 1990s) this factor was also expressed as expenditure on research and development (R&D). Examples of such work include (Coe & Helpman, 1995; Eckstein, 1984). After the year 2000, this topic generated widespread discussion; participants included (Engelbrecht, 2002; Keller, 2004; Saggi, 2002; Welfe, 2004). There were also attempts to decompose this factor into tangible development (resulting from using the newest machines and devices) and intangible development (resulting from raising the qualifications of the employed, measured as the number of graduates from technical universities, the number of patents and licenses granted, expenditure on research and higher education, for example). Works by (Lee, 2005; Welfe, 2006; Xu & Wang, 1999; 2000) can be cited as examples of such attempts. Subsequently, intellectual—or even more widely, human—capital was taken into account when determining GDP. Nonetheless, the greatest problem encountered was selecting the appropriate measure of this intellectual capital. Real or cumulated expenditure on academic research activity was often used in empirical studies (Borensztein, De Gregorio, & Lee, 1998; Cincera & Van Pottelsberghe de la Potterie, 2001; Van Pottelsberghe de la Potterie & Lichtenberg, 2001; Welfe, 2006; 2009). Thus, as time passed, explaining the cause-effect relationship between the economic growth and scientific research activity of a given country, which illustrates human capital, became increasingly important in economic models, especially

econometric models of national economies describing the development of economic growth.

This fact is connected with the primary aim of the following article, which is focused on researching the degree of causality of academic research activity in a country to determine its economic growth, a phenomenon of interest to many economists. As mentioned above, the issue of defining the influence of scientific research activity on economic growth has been the subject of much investigation; however, no study has included as wide a range of countries as this paper. The main issue that arises here is to find a “good” measure of scientific R&D activity. Because our research includes cross-sectional time data and covers 144 countries, an important issue to be addressed was the wide availability of data (a statistical database for all the countries covered) and its comparability. Taking into account these two criteria, we decided to use the number of documents or the number of citable documents referring to a given country as a measure, which can be considered a symptomatic variable of human capital or technical-organizational development in a narrower sense, or possibly non-material technological development, which influences economic growth. The main aim of the article is not to elaborate a specific econometric model describing a given country's GDP but to verify if scientific research activity significantly, in the Granger sense (Engle & Granger, 1987), results in a country's economic growth. Another aim of this paper is to perform a comparative study, which results from the cross-sectional and temporal nature of the research. This study compares the significance of causality of individual research fields and for individual countries. Therefore, this paper verifies the main empirical hypothesis, which states that the scientific research activity of a given country, expressed by the number of published or cited academic papers, contributes significantly to determining the GDP of this country. In the second hypothesis, the degree to which chosen academic fields contribute to GDP growth in the given countries is tested.

Due to the availability of statistical data during our investigation, the following two measures have been adopted as the indicator of a given country's scientific research activity (“IoSA”):

- 1) Documents – the number of documents published during the selected year, usually called the country's scientific output.

**Table 1.** The result of correlation coefficients (Pearson's, Spearman's, Kendall's)

|                   | rho (lag(PKB,-1), lag(loSA,1)) |          |         |
|-------------------|--------------------------------|----------|---------|
|                   | Pearson                        | Spearman | Kendall |
| Documents         | 0.9345                         | 0.8759   | 0.7096  |
| Citable documents | 0.9348                         | 0.8766   | 0.7105  |

- 2) Citable documents – the number of citable documents for the selected year. Only articles, reviews and conference papers are considered.

Because two alternative indicators of academic research activity were adopted, their cause-effect relationship with GDP in the Granger sense was investigated. The tests were carried out for various orders of lag between these indicators and GDP. Statistical data (in an annual framework) related to the indicators for academic research activity were drawn from [www.scimagojr.com](http://www.scimagojr.com). The data concern various fields of publication and cover the 1996-2012 period. The information obtained includes the number of documents and citable documents by country and by academic field (28 different fields). Additionally, the data provide information on publications for each given country spanning all academic fields in the form of a summary “all” field.

Information regarding GDP in current prices originates from the World Bank service ([data.worldbank.org](http://data.worldbank.org)). These data were recalculated to 2011 prices in order to ensure comparability (the 2011 was taken as the base year). Because such data were incomplete, the research takes into consideration only those countries that had complete indicator numbers for scientific research activity, as well as GDP spanning the years 1996-2012. This sample was the longest possible sample that could be achieved, and 144 countries fulfilled the above conditions.

To begin, we decided to check the degree of general correlation between scientific research activity and GDP in the countries being investigated by combining two vectors [lag(PKB,-1), lag(loSA)] in one matrix with two columns, where lag(PKB,-1) indicates the GDP observation vector for a given country from the second to the last observation, and lag (loSA,1) indicates the loSA observation vector from the first to the penultimate observation. These vectors were then

placed into consecutive two-column matrices—one for each country—resulting in a matrix with the dimensions of  $144 \times (2012-1996) = 2304 \times 2$ . The correlation coefficients (Pearson's, Spearman's, Kendall's) between the first and second columns were then calculated. These coefficients are presented in table 1.

The values presented in the above table clearly show a high degree of correlation between the adopted scientific research activity indicators and GDP in the countries covered by the investigation. An analysis of the signs of the obtained correlation coefficients between lag(PKB,-1) and lag(loSA,1) for each country individually shows that the correlations according to Pearson, Spearman and Kendall are positive in over 80% of these cases.

## 1. Granger causality test

As shown in the article, the study analyzes causality in the Granger sense, where the cause is defined as scientific research activity (expressed as two indicators that signify the number of publications) in a given country, and the effect is defined as that country's GDP. The usefulness of this activity is also investigated in terms of its influence on the quality of Polish GDP forecasts compiled using a linear model for the years 2011-2012.

In the primary view of examining causality, the validity of following equation is considered

$$x_t = c_1 + \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + \dots + \alpha_p x_{t-p} + \beta_1 y_{t-1} + \beta_2 y_{t-2} + \dots + \beta_p y_{t-p} + \mu_t \quad (1)$$

against its alternative formulation

$$x_t = c_0 + \gamma_1 x_{t-1} + \gamma_2 x_{t-2} + \dots + \gamma_p x_{t-p} + e_t \quad (2)$$

estimated using the ordinary least squares (OLS) method.

**Table 2.** The rejection frequency for tests (1) and (2) in relation to the lag order  $p$

| $p$ | RF        |                   |           |                   |
|-----|-----------|-------------------|-----------|-------------------|
|     | Test 1    |                   | Test 2    |                   |
|     | Documents | Citable documents | Documents | Citable documents |
| 1   | 29.86%    | 29.86%            | 34.03%    | 34.72%            |
| 2   | 34.72%    | 34.03%            | 51.39%    | 52.08%            |
| 3   | 42.36%    | 43.75%            | 71.53%    | 69.44%            |
| 4   | 46.53%    | 47.22%            | 84.72%    | 84.72%            |
| 5   | 81.94%    | 83.33%            | 97.92%    | 97.22%            |

Examining causality is based on the general statement that variable  $y$  is the cause in relation to variable  $x$  if past values of  $x$  help explain future values  $y$  more accurately (Granger, 1969). Therefore, the following hypothesis is tested:

$$H_0 : \beta_1 = \beta_2 = \dots = \beta_p = 0$$

(3)

There are many varieties of Granger causality tests (Ashley, Granger, & Schmalensee, 1980; Amblard, 2012; Berndt, 1991; Can-Zhong & Qing-Wen, 2017; Ding, Chen, & Bressler, 2006; Geweke, 1982; Geweke, Meese, & Dent, 1983; Sims, 1972; Zhou & Sornette, 2006). In this paper, two are applied, and both are considered to be among the most popular varieties (Hamilton, 1994; Sims 1980). The statistics  $S_1$  for the first test and  $S_2$  for the second test are as follows (the results from these tests are denoted as *test 1* and *test 2*, respectively):

$$S_1 \equiv \frac{\frac{RSS_0 - RSS_1}{p}}{\frac{RSS_1}{T - 2p - 1}}$$

(4)

$$S_2 \equiv \frac{T(RSS_0 - RSS_1)}{RSS_1}$$

(5)

where

$$RSS_1 = \sum_{t=1}^T \hat{\mu}_t^2$$

(6)

$$RSS_0 = \sum_{t=1}^T e_t^2$$

(7)

It is assumed that statistics  $S_1$  and  $S_2$  have the corresponding distributions:  $F(p, T - 2p - 1)$  and  $\chi^2(p)$ , respectively, where  $T$  is the number of observations. In this study, a 5% significance level is applied as standard.

The following part of the paper analyzes the hypothesis rejection frequency (RF)  $H_0$  at a significance level of 0.05:

$$RF = \frac{1}{K} \sum_{i=1}^K h_i$$

(8)

where:

$$h_i = \begin{cases} 1 & \text{if } p\text{-value}_i < 0.05 \\ 0 & \text{if } p\text{-value}_i \geq 0.05 \end{cases}$$

$p\text{-value}_i$  – denotes the significance level of the Granger test for a given country,

$k$  – number of countries (for all research areas = 144).

The table 2 shows the rejection frequency for tests (1) and (2) in relation to the lag order  $p$ .

The value of 42.36% (item [3,1]) indicates that for the lag order of 3 (years), out of 144 countries researched, the hypothesis was rejected in 42.36% of cases (at a significance level of 5%). It should be noted that assuming full (not asymptotic) congruity of tests, a rejection of hypothesis  $H_0$  should be observed at a

**Table 3.** The differences between RF and *RF rand*

| Lag | RF-RF <sub>random</sub> |                   |           |                   |
|-----|-------------------------|-------------------|-----------|-------------------|
|     | Test 1                  |                   | Test 2    |                   |
|     | Documents               | Citable documents | Documents | Citable documents |
| 1   | 23.92%                  | 23.93%            | 22.99%    | 23.72%            |
| 2   | 26.03%                  | 25.37%            | 28.86%    | 29.57%            |
| 3   | 27.89%                  | 29.25%            | 28.76%    | 26.65%            |
| 4   | 19.85%                  | 20.62%            | 14.37%    | 14.47%            |
| 5   | 13.30%                  | 14.68%            | 2.23%     | 1.52%             |

level of approximately 5% of cases for random indicators of scientific research activity.

## 2. Comparing causality tests with the random permutation version

Keeping in mind the asymptotic properties of the test adopted for this study and the fact that both of the above statistics have a tendency for an easier rejection of hypothesis  $H_0$  as the number of observations decreases or by increasing the order  $p$ , we decided to compare the test results with their alternative versions. Specifically, the results obtained from the statistics were compared with their versions for a random arrangement of the IoSA vector, i.e., the Granger test was repeated for every country analogically to the tests described above, with the one difference that instead of the original citation vector (IoSA), its random permutation was applied. The idea for this approach arises from the observation that if past scientific research activity remains unrelated to future values of GDP, one may expect a similar result for the Granger causality test for randomly selected values of the IoSA vector in the statistics of the applied test. However, to maintain the same IoSA distribution in the simulation, a permuted IoSA vector (in relation to the original) was applied.

This procedure was repeated 10,000 times. As a result, 10,000 different indicators of  $RF\_rand_i$  rejection were obtained. The results were averaged to obtain one value of  $RF\_rand$  for a given country. The differences

between RF and  $RF\_rand$  are presented in the table below. A positive difference between RF and  $RF\_rand$  indicates a more frequent rejection of hypothesis  $H_0$  for real IoSA values than for their random permutations (carried out independently for each of the countries studied).

For both of the above tests, higher values of  $RF - RF_{random}$  in the table 3 are an indication in favor of hypothesis  $H_1$  (the hypothesis of a lack of causality in comparison to randomly permuted IoSA values is more frequently rejected).

Interpreting the obtained results, one can state that the value of 27.89% (item [3.1]) suggests that if randomly permuted Documents values are applied, then the indicator for the rejection of hypothesis  $H_0$  would nominally be 27.89 percentage points lower than the same indicator obtained from non-random (i.e., original) Documents values. The indicators shown in the above table imply that scientific research activity, measured as the amount of published articles, results in an economic effect after approximately 2-3 years (i.e., considering lag orders from 1 to 4, the relatively highest values are lag orders 2 and 3).

## 3. Causality in individual scientific fields

The research presented so far tested the causality of scientific research activity, measured as the general number of publications in all fields, in determining the GDP for all countries. Let us study this causality

**Table 4.** The results of rejection frequency of the zero hypothesis

| test   | RF        |      |       |      |                   |      |       |      | RF - RFRandom |      |       |      |                   |      |       |       | NoC |
|--|-----------|------|-------|------|-------------------|------|-------|------|---------------|------|-------|------|-------------------|------|-------|-------|-----|
|  | Documents |      |       |      | Citable documents |      |       |      | Documents     |      |       |      | Citable documents |      |       |       |     |
|  | Lag 2     |      | Lag 3 |      | Lag 2             |      | Lag 3 |      | Lag 2         |      | Lag 3 |      | Lag 2             |      | Lag 3 |       |     |
|  | 1         | 2    | 1     | 2    | 1                 | 2    | 1     | 2    | 1             | 2    | 1     | 2    | 1                 | 2    | 1     | 2     |     |
| all  | 0.35      | 0.51 | 0.42  | 0.72 | 0.34              | 0.52 | 0.44  | 0.69 | 0.26          | 0.29 | 0.28  | 0.29 | 0.25              | 0.30 | 0.29  | 0.27  | 144 |
| Agricultural and Biological Sciences         | 0.28      | 0.43 | 0.31  | 0.60 | 0.26              | 0.44 | 0.32  | 0.59 | 0.19          | 0.20 | 0.16  | 0.17 | 0.17              | 0.22 | 0.18  | 0.16  | 124 |
| Arts and Humanities                          | 0.10      | 0.29 | 0.15  | 0.46 | 0.13              | 0.33 | 0.21  | 0.42 | 0.01          | 0.06 | -0.01 | 0.03 | 0.03              | 0.10 | 0.06  | -0.02 | 48  |
| Biochemistry, Genetics and Molecular Biology | 0.30      | 0.46 | 0.37  | 0.69 | 0.30              | 0.45 | 0.38  | 0.68 | 0.21          | 0.23 | 0.23  | 0.26 | 0.21              | 0.22 | 0.24  | 0.25  | 105 |
| Business, Management and Accounting          | 0.32      | 0.47 | 0.43  | 0.70 | 0.30              | 0.45 | 0.42  | 0.66 | 0.23          | 0.24 | 0.29  | 0.27 | 0.21              | 0.22 | 0.27  | 0.23  | 53  |
| Chemical Engineering                         | 0.19      | 0.44 | 0.30  | 0.59 | 0.22              | 0.44 | 0.29  | 0.56 | 0.11          | 0.21 | 0.16  | 0.16 | 0.13              | 0.21 | 0.14  | 0.13  | 73  |
| Chemistry                                    | 0.24      | 0.48 | 0.32  | 0.65 | 0.22              | 0.49 | 0.32  | 0.66 | 0.15          | 0.25 | 0.17  | 0.23 | 0.13              | 0.26 | 0.17  | 0.24  | 92  |
| Computer Science                             | 0.27      | 0.52 | 0.32  | 0.62 | 0.27              | 0.52 | 0.32  | 0.62 | 0.18          | 0.29 | 0.18  | 0.19 | 0.18              | 0.29 | 0.18  | 0.19  | 71  |
| Decision Sciences                            | 0.16      | 0.41 | 0.22  | 0.55 | 0.14              | 0.41 | 0.24  | 0.51 | 0.07          | 0.19 | 0.07  | 0.12 | 0.05              | 0.19 | 0.09  | 0.08  | 51  |
| Dentistry                                    | 0.15      | 0.37 | 0.34  | 0.63 | 0.15              | 0.34 | 0.34  | 0.59 | 0.06          | 0.14 | 0.20  | 0.21 | 0.06              | 0.12 | 0.20  | 0.16  | 41  |
| Earth and Planetary Sciences                 | 0.29      | 0.44 | 0.30  | 0.58 | 0.26              | 0.45 | 0.30  | 0.57 | 0.20          | 0.21 | 0.16  | 0.15 | 0.18              | 0.22 | 0.16  | 0.15  | 103 |
| Economics, Econometrics and Finance          | 0.35      | 0.41 | 0.29  | 0.63 | 0.35              | 0.41 | 0.31  | 0.59 | 0.26          | 0.18 | 0.15  | 0.20 | 0.26              | 0.18 | 0.17  | 0.16  | 51  |
| Energy                                       | 0.16      | 0.38 | 0.28  | 0.55 | 0.17              | 0.38 | 0.28  | 0.55 | 0.07          | 0.15 | 0.13  | 0.12 | 0.09              | 0.15 | 0.13  | 0.12  | 69  |
| Engineering                                  | 0.18      | 0.42 | 0.25  | 0.53 | 0.18              | 0.40 | 0.26  | 0.52 | 0.09          | 0.19 | 0.10  | 0.10 | 0.09              | 0.18 | 0.11  | 0.09  | 89  |
| Environmental Science                        | 0.25      | 0.51 | 0.35  | 0.63 | 0.25              | 0.48 | 0.34  | 0.63 | 0.16          | 0.28 | 0.20  | 0.21 | 0.16              | 0.26 | 0.19  | 0.20  | 104 |
| Health Professions                           | 0.19      | 0.38 | 0.21  | 0.57 | 0.14              | 0.38 | 0.19  | 0.60 | 0.10          | 0.15 | 0.07  | 0.14 | 0.06              | 0.15 | 0.05  | 0.17  | 42  |
| Immunology and Microbiology                  | 0.17      | 0.37 | 0.28  | 0.57 | 0.17              | 0.36 | 0.26  | 0.56 | 0.08          | 0.14 | 0.13  | 0.14 | 0.09              | 0.13 | 0.11  | 0.13  | 109 |
| Materials Science                            | 0.21      | 0.38 | 0.22  | 0.54 | 0.21              | 0.38 | 0.23  | 0.56 | 0.12          | 0.16 | 0.08  | 0.12 | 0.12              | 0.16 | 0.09  | 0.13  | 81  |
| Mathematics                                  | 0.29      | 0.49 | 0.33  | 0.67 | 0.27              | 0.48 | 0.34  | 0.67 | 0.20          | 0.27 | 0.18  | 0.24 | 0.18              | 0.26 | 0.20  | 0.24  | 79  |
| Medicine                                     | 0.23      | 0.38 | 0.39  | 0.62 | 0.23              | 0.38 | 0.37  | 0.67 | 0.15          | 0.15 | 0.25  | 0.19 | 0.14              | 0.15 | 0.22  | 0.24  | 128 |
| Multidisciplinary                            | 0.18      | 0.33 | 0.20  | 0.63 | 0.20              | 0.31 | 0.22  | 0.53 | 0.09          | 0.10 | 0.06  | 0.20 | 0.11              | 0.08 | 0.08  | 0.10  | 49  |
| Neuroscience                                 | 0.21      | 0.43 | 0.27  | 0.46 | 0.23              | 0.48 | 0.25  | 0.52 | 0.13          | 0.20 | 0.12  | 0.04 | 0.15              | 0.26 | 0.10  | 0.09  | 56  |
| Nursing                                      | 0.39      | 0.47 | 0.33  | 0.64 | 0.33              | 0.44 | 0.36  | 0.58 | 0.30          | 0.25 | 0.19  | 0.21 | 0.25              | 0.22 | 0.21  | 0.15  | 36  |
| Pharmacology, Toxicology and Pharmaceutics   | 0.20      | 0.33 | 0.24  | 0.53 | 0.19              | 0.28 | 0.25  | 0.49 | 0.12          | 0.10 | 0.10  | 0.10 | 0.10              | 0.05 | 0.11  | 0.07  | 79  |
| Physics and Astronomy                        | 0.20      | 0.45 | 0.30  | 0.61 | 0.20              | 0.46 | 0.31  | 0.60 | 0.11          | 0.23 | 0.15  | 0.18 | 0.11              | 0.24 | 0.16  | 0.17  | 84  |
| Psychology                                   | 0.26      | 0.47 | 0.25  | 0.45 | 0.28              | 0.47 | 0.23  | 0.47 | 0.17          | 0.24 | 0.09  | 0.03 | 0.19              | 0.25 | 0.08  | 0.05  | 53  |
| Social Sciences                              | 0.30      | 0.54 | 0.32  | 0.65 | 0.29              | 0.47 | 0.27  | 0.62 | 0.21          | 0.31 | 0.18  | 0.22 | 0.20              | 0.25 | 0.12  | 0.20  | 93  |
| Veterinary                                   | 0.22      | 0.54 | 0.25  | 0.58 | 0.24              | 0.51 | 0.24  | 0.61 | 0.13          | 0.32 | 0.10  | 0.16 | 0.15              | 0.29 | 0.09  | 0.18  | 72  |

**Table 5.** Sum of ranks (in descending order)

|   |  |
|---|--|
| 1 | All  |
| 2 | Biochemistry, Genetics and Molecular Biology |
| 3 | <i>Business, Management and Accounting</i>   |
| 4 | Mathematics                                  |

with respect to particular scientific fields. The table 4 shows the results (rejection frequency of the zero hypothesis) for these fields based on the previously mentioned tests, with the lag orders 2 and 3 for the original base data (RF). Differences compared to the results obtained for randomly permuted IoSA vectors (RF – RFRandom) are also listed.

Additionally, the table includes the indicator NoC (number of countries), defined as the number of countries for which combined data were available, i.e., both regarding GDP and the number of publications for each country for the 1996–2012 period. Thus, in further calculations, only those countries that had complete data were taken into account. Because some observations were missing from the database, different scientific fields of study had data from different numbers of countries. For example, data from the field of chemistry was available for only 92 countries (which could also be the result of natural inactivity of some countries in this field). A smaller number of countries results in a smaller number of observations used in the calculations. It also often leads to a change in the structure among the researched countries. Ultimately, it has a negative impact on the representativeness of the results. In the table below, where the number of countries used for calculations was less than half, i.e.,  $144 / 2 = 77$  (144 is the number of countries with full data used to study the relationship between GDP and the number of publications in any and all fields – all), the results are shown in italics.

The interpretation of the results shown in the table above is the same as for the previous study, e.g., for item [5, 3] the value 0.43 indicates that for the lag order of 3 (years) in the field of business, management and accounting, for 53 countries studied, hypothesis  $H_0$  was rejected in 43% of cases (at the significance level

of 5% for test 1, testing Documents). In turn, item [5, 11] with a value of 0.29 means that if, in the same test, randomly permuted IoSA values are used, the result would be 29 percentage points lower; therefore, the rejection frequency for hypothesis  $H_0$  would equal  $43\% - 29\% = 14\%$ . It should be emphasized that the above results are aggregate estimates, and the real effect of scientific research activity on economic growth may vary depending on the specifics of a given country.

If the sum of ranks (in descending order, meaning that the largest value would be given the rank of 1) is calculated for each column (except the last, which lists the indicators of the number of countries) and subsequently sorted in descending order, the following fields appear in positions 1 to 4:

The above scientific fields (shown in the table 5) can be seen (from the point of view of the approach applied above) as the areas that are most conducive to economic growth.

#### 4. Testing Granger causality for specific countries

The table 6 lists significance levels (p-value) for hypothesis  $H_0$ , verified for the total number of publications (divided into Documents and Citable documents) in all areas of scientific research activity (all) with reference to specific countries with lag orders 2 and 3. Lower values reflect easier rejection of hypothesis  $H_0$  in favor of an alternative hypothesis, and they are associated with a more significant causal relationship between the past number of publications in a given country and its subsequent GDP, i.e., that the number of publications from two years earlier influences the current level of GDP to a greater degree.

The rejection frequencies (RF) for hypothesis  $H_0$  (lack of causality) for particular groups of countries



**Table 6.** Significance levels (p-value) for hypothesis *H0*

| Test                     | p-value   |        |        |        |                   |        |        |        |
|--------------------------|-----------|--------|--------|--------|-------------------|--------|--------|--------|
|                          | Documents |        |        |        | Citable documents |        |        |        |
|                          | Lag 2     |        | Lag 3  |        | Lag 2             |        | Lag 3  |        |
|                          | Test 1    | Test 2 | Test 1 | Test 2 | Test 1            | Test 2 | Test 1 | Test 2 |
| Albania                  | 0.4815    | 0.3325 | 0.0158 | 0.0000 | 0.4529            | 0.3013 | 0.0205 | 0.0000 |
| Algeria                  | 0.4543    | 0.3028 | 0.0087 | 0.0000 | 0.4502            | 0.2984 | 0.0075 | 0.0000 |
| Angola                   | 0.4725    | 0.3226 | 0.0012 | 0.0000 | 0.5051            | 0.3589 | 0.0021 | 0.0000 |
| Armenia                  | 0.2154    | 0.0839 | 0.2662 | 0.0501 | 0.2486            | 0.1087 | 0.3399 | 0.0926 |
| Australia                | 0.0010    | 0.0000 | 0.0057 | 0.0000 | 0.0007            | 0.0000 | 0.0047 | 0.0000 |
| Austria                  | 0.4351    | 0.2824 | 0.4448 | 0.1758 | 0.4061            | 0.2523 | 0.4319 | 0.1642 |
| Azerbaijan               | 0.0063    | 0.0000 | 0.1093 | 0.0040 | 0.0077            | 0.0000 | 0.1239 | 0.0059 |
| Bahamas                  | 0.8299    | 0.7647 | 0.2392 | 0.0379 | 0.8853            | 0.8400 | 0.0836 | 0.0017 |
| Bangladesh               | 0.0029    | 0.0000 | 0.0100 | 0.0000 | 0.0030            | 0.0000 | 0.0057 | 0.0000 |
| Belarus                  | 0.1455    | 0.0400 | 0.3553 | 0.1032 | 0.0998            | 0.0187 | 0.5857 | 0.3269 |
| Belgium                  | 0.4937    | 0.3460 | 0.5059 | 0.2361 | 0.4691            | 0.3189 | 0.5193 | 0.2503 |
| Benin                    | 0.9876    | 0.9825 | 0.1333 | 0.0073 | 0.9955            | 0.9936 | 0.1476 | 0.0099 |
| Bhutan                   | 0.0264    | 0.0008 | 0.1539 | 0.0112 | 0.0263            | 0.0008 | 0.1371 | 0.0080 |
| Bolivia                  | 0.0173    | 0.0003 | 0.0065 | 0.0000 | 0.0169            | 0.0003 | 0.0069 | 0.0000 |
| Bosnia and Herzegovina   | 0.6256    | 0.5011 | 0.0291 | 0.0000 | 0.6334            | 0.5106 | 0.0297 | 0.0000 |
| Botswana                 | 0.5645    | 0.4274 | 0.8419 | 0.7045 | 0.5484            | 0.4086 | 0.8172 | 0.6627 |
| Brazil                   | 0.0868    | 0.0139 | 0.0016 | 0.0000 | 0.0879            | 0.0143 | 0.0020 | 0.0000 |
| Brunei Darussalam        | 0.2576    | 0.1158 | 0.9196 | 0.8434 | 0.3771            | 0.2230 | 0.5940 | 0.3372 |
| Bulgaria                 | 0.2153    | 0.0838 | 0.5342 | 0.2667 | 0.1986            | 0.0722 | 0.5057 | 0.2359 |
| Burkina Faso             | 0.8408    | 0.7793 | 0.6144 | 0.3628 | 0.9048            | 0.8668 | 0.4923 | 0.2219 |
| Burundi                  | 0.6766    | 0.5645 | 0.7845 | 0.6091 | 0.7108            | 0.6080 | 0.7852 | 0.6102 |
| Cambodia                 | 0.0051    | 0.0000 | 0.2228 | 0.0314 | 0.0041            | 0.0000 | 0.2450 | 0.0404 |
| Cameroon                 | 0.0821    | 0.0124 | 0.0101 | 0.0000 | 0.0748            | 0.0101 | 0.0142 | 0.0000 |
| Canada                   | 0.0018    | 0.0000 | 0.0028 | 0.0000 | 0.0031            | 0.0000 | 0.0036 | 0.0000 |
| Central African Republic | 0.9607    | 0.9446 | 0.9231 | 0.8498 | 0.9861            | 0.9804 | 0.7952 | 0.6265 |
| Chad                     | 0.1446    | 0.0395 | 0.0211 | 0.0000 | 0.1368            | 0.0354 | 0.0205 | 0.0000 |
| Chile                    | 0.0061    | 0.0000 | 0.0244 | 0.0000 | 0.0063            | 0.0000 | 0.0236 | 0.0000 |
| China                    | 0.0105    | 0.0001 | 0.0217 | 0.0000 | 0.0096            | 0.0000 | 0.0212 | 0.0000 |
| Colombia                 | 0.0045    | 0.0000 | 0.0170 | 0.0000 | 0.0042            | 0.0000 | 0.0132 | 0.0000 |

**Table 6.** Significance levels (p-value) for hypothesis  $H_0$  (Continued)

| Test               | p-value   |        |        |        |                   |        |        |        |
|--------------------|-----------|--------|--------|--------|-------------------|--------|--------|--------|
|                    | Documents |        |        |        | Citable documents |        |        |        |
|                    | Lag 2     |        | Lag 3  |        | Lag 2             |        | Lag 3  |        |
|                    | Test 1    | Test 2 | Test 1 | Test 2 | Test 1            | Test 2 | Test 1 | Test 2 |
| Congo              | 0.6914    | 0.5832 | 0.6277 | 0.3801 | 0.5045            | 0.3582 | 0.6860 | 0.4597 |
| Costa Rica         | 0.0240    | 0.0007 | 0.0087 | 0.0000 | 0.0339            | 0.0016 | 0.0099 | 0.0000 |
| Croatia            | 0.9053    | 0.8676 | 0.9617 | 0.9236 | 0.8985            | 0.8581 | 0.9599 | 0.9200 |
| Cyprus             | 0.5936    | 0.4621 | 0.0517 | 0.0003 | 0.5695            | 0.4334 | 0.0552 | 0.0004 |
| Czech Republic     | 0.3704    | 0.2165 | 0.1049 | 0.0035 | 0.2802            | 0.1343 | 0.1043 | 0.0035 |
| Denmark            | 0.6608    | 0.5446 | 0.5248 | 0.2564 | 0.5983            | 0.4678 | 0.3370 | 0.0907 |
| Dominican Republic | 0.6528    | 0.5346 | 0.6470 | 0.4057 | 0.5904            | 0.4583 | 0.6082 | 0.3549 |
| Ecuador            | 0.7544    | 0.6645 | 0.6149 | 0.3635 | 0.6831            | 0.5727 | 0.5200 | 0.2511 |
| Egypt              | 0.6333    | 0.5104 | 0.8447 | 0.7093 | 0.6271            | 0.5029 | 0.8468 | 0.7129 |
| El Salvador        | 0.1801    | 0.0601 | 0.6813 | 0.4530 | 0.1701            | 0.0540 | 0.6521 | 0.4125 |
| Eritrea            | 0.4264    | 0.2732 | 0.1156 | 0.0048 | 0.3892            | 0.2351 | 0.0838 | 0.0017 |
| Estonia            | 0.1343    | 0.0341 | 0.3525 | 0.1012 | 0.1055            | 0.0210 | 0.3598 | 0.1064 |
| Ethiopia           | 0.0048    | 0.0000 | 0.0190 | 0.0000 | 0.0043            | 0.0000 | 0.0154 | 0.0000 |
| Fiji               | 0.0032    | 0.0000 | 0.0483 | 0.0003 | 0.0037            | 0.0000 | 0.0499 | 0.0003 |
| Finland            | 0.2119    | 0.0814 | 0.2310 | 0.0346 | 0.1932            | 0.0686 | 0.2218 | 0.0310 |
| France             | 0.2810    | 0.1350 | 0.1441 | 0.0092 | 0.2249            | 0.0907 | 0.1453 | 0.0095 |
| Gabon              | 0.1139    | 0.0245 | 0.0329 | 0.0001 | 0.1466            | 0.0405 | 0.0845 | 0.0018 |
| Gambia             | 0.9943    | 0.9919 | 0.6282 | 0.3807 | 0.8893            | 0.8454 | 0.2251 | 0.0322 |
| Georgia            | 0.0032    | 0.0000 | 0.0035 | 0.0000 | 0.0031            | 0.0000 | 0.0031 | 0.0000 |
| Germany            | 0.1397    | 0.0369 | 0.2031 | 0.0244 | 0.1418            | 0.0380 | 0.2139 | 0.0281 |
| Ghana              | 0.9575    | 0.9401 | 0.7421 | 0.5426 | 0.9212            | 0.8896 | 0.7445 | 0.5462 |
| Greece             | 0.2443    | 0.1054 | 0.0017 | 0.0000 | 0.1844            | 0.0629 | 0.0015 | 0.0000 |
| Grenada            | 0.1612    | 0.0487 | 0.1875 | 0.0196 | 0.1238            | 0.0290 | 0.1831 | 0.0183 |
| Guatemala          | 0.0074    | 0.0000 | 0.0147 | 0.0000 | 0.0101            | 0.0001 | 0.0200 | 0.0000 |
| Guinea             | 0.4739    | 0.3241 | 0.6871 | 0.4613 | 0.4749            | 0.3252 | 0.6949 | 0.4724 |
| Guinea-Bissau      | 0.8152    | 0.7449 | 0.8653 | 0.7452 | 0.9208            | 0.8889 | 0.8760 | 0.7641 |
| Guyana             | 0.1445    | 0.0394 | 0.0957 | 0.0026 | 0.0844            | 0.0131 | 0.0481 | 0.0002 |
| Honduras           | 0.0958    | 0.0171 | 0.0067 | 0.0000 | 0.1229            | 0.0286 | 0.0071 | 0.0000 |
| Hong Kong          | 0.0042    | 0.0000 | 0.0020 | 0.0000 | 0.0057            | 0.0000 | 0.0027 | 0.0000 |

**Table 6.** Significance levels (p-value) for hypothesis  $H_0$  (Continued)

| Test       | p-value   |        |        |        |                   |        |        |        |
|------------|-----------|--------|--------|--------|-------------------|--------|--------|--------|
|            | Documents |        |        |        | Citable documents |        |        |        |
|            | Lag 2     |        | Lag 3  |        | Lag 2             |        | Lag 3  |        |
|            | Test 1    | Test 2 | Test 1 | Test 2 | Test 1            | Test 2 | Test 1 | Test 2 |
| Hungary    | 0.3506    | 0.1974 | 0.5126 | 0.2432 | 0.4107            | 0.2569 | 0.5622 | 0.2988 |
| Iceland    | 0.7437    | 0.6506 | 0.3235 | 0.0820 | 0.7495            | 0.6581 | 0.3851 | 0.1253 |
| India      | 0.8963    | 0.8551 | 0.1707 | 0.0151 | 0.7895            | 0.7108 | 0.0980 | 0.0028 |
| Indonesia  | 0.0000    | 0.0000 | 0.3494 | 0.0991 | 0.0000            | 0.0000 | 0.3443 | 0.0956 |
| Italy      | 0.1411    | 0.0376 | 0.0024 | 0.0000 | 0.1062            | 0.0213 | 0.0025 | 0.0000 |
| Japan      | 0.2131    | 0.0822 | 0.7568 | 0.5653 | 0.2110            | 0.0807 | 0.7876 | 0.6141 |
| Jordan     | 0.7967    | 0.7203 | 0.2561 | 0.0453 | 0.8206            | 0.7522 | 0.3858 | 0.1259 |
| Kazakhstan | 0.0276    | 0.0009 | 0.0368 | 0.0001 | 0.0281            | 0.0010 | 0.0313 | 0.0000 |
| Kenya      | 0.3866    | 0.2325 | 0.0926 | 0.0024 | 0.4045            | 0.2506 | 0.1929 | 0.0212 |
| Kyrgyzstan | 0.1264    | 0.0302 | 0.0094 | 0.0000 | 0.1171            | 0.0259 | 0.0091 | 0.0000 |
| Laos       | 0.0000    | 0.0000 | 0.0004 | 0.0000 | 0.0000            | 0.0000 | 0.0003 | 0.0000 |
| Latvia     | 0.1141    | 0.0246 | 0.1299 | 0.0068 | 0.1315            | 0.0327 | 0.1364 | 0.0078 |
| Lebanon    | 0.0162    | 0.0002 | 0.0064 | 0.0000 | 0.0160            | 0.0002 | 0.0023 | 0.0000 |
| Lesotho    | 0.0657    | 0.0076 | 0.1967 | 0.0224 | 0.0872            | 0.0140 | 0.2161 | 0.0289 |
| Lithuania  | 0.0616    | 0.0066 | 0.0077 | 0.0000 | 0.0621            | 0.0067 | 0.0083 | 0.0000 |
| Luxembourg | 0.8931    | 0.8507 | 0.0535 | 0.0004 | 0.8873            | 0.8427 | 0.0678 | 0.0008 |
| Macedonia  | 0.0334    | 0.0015 | 0.0141 | 0.0000 | 0.0415            | 0.0026 | 0.0195 | 0.0000 |
| Madagascar | 0.7443    | 0.6513 | 0.6766 | 0.4465 | 0.7991            | 0.7235 | 0.7522 | 0.5582 |
| Malawi     | 0.6713    | 0.5578 | 0.6068 | 0.3532 | 0.6428            | 0.5222 | 0.7835 | 0.6076 |
| Malaysia   | 0.1652    | 0.0510 | 0.0198 | 0.0000 | 0.1572            | 0.0464 | 0.0256 | 0.0000 |
| Mali       | 0.4313    | 0.2783 | 0.0071 | 0.0000 | 0.5002            | 0.3533 | 0.0047 | 0.0000 |
| Malta      | 0.8098    | 0.7378 | 0.0787 | 0.0014 | 0.8162            | 0.7463 | 0.0615 | 0.0006 |
| Mauritania | 0.0205    | 0.0004 | 0.2158 | 0.0288 | 0.0189            | 0.0003 | 0.2190 | 0.0299 |
| Mauritius  | 0.0333    | 0.0015 | 0.0503 | 0.0003 | 0.0206            | 0.0004 | 0.0357 | 0.0001 |
| Mexico     | 0.1487    | 0.0417 | 0.0224 | 0.0000 | 0.1592            | 0.0476 | 0.0189 | 0.0000 |
| Moldova    | 0.0585    | 0.0058 | 0.0005 | 0.0000 | 0.0562            | 0.0053 | 0.0004 | 0.0000 |
| Mongolia   | 0.0396    | 0.0023 | 0.0003 | 0.0000 | 0.0495            | 0.0040 | 0.0004 | 0.0000 |
| Morocco    | 0.0157    | 0.0002 | 0.0070 | 0.0000 | 0.0082            | 0.0000 | 0.0030 | 0.0000 |
| Mozambique | 0.1345    | 0.0342 | 0.1283 | 0.0065 | 0.1537            | 0.0445 | 0.1281 | 0.0065 |

**Table 6.** Significance levels (p-value) for hypothesis  $H_0$  (Continued)

| Test                  | p-value   |        |        |        |                   |        |        |        |
|-----------------------|-----------|--------|--------|--------|-------------------|--------|--------|--------|
|                       | Documents |        |        |        | Citable documents |        |        |        |
|                       | Lag 2     |        | Lag 3  |        | Lag 2             |        | Lag 3  |        |
|                       | Test 1    | Test 2 | Test 1 | Test 2 | Test 1            | Test 2 | Test 1 | Test 2 |
| Namibia               | 0.0477    | 0.0037 | 0.0938 | 0.0025 | 0.0515            | 0.0044 | 0.1096 | 0.0040 |
| Nepal                 | 0.0001    | 0.0000 | 0.0002 | 0.0000 | 0.0002            | 0.0000 | 0.0004 | 0.0000 |
| Netherlands           | 0.2472    | 0.1076 | 0.1353 | 0.0077 | 0.2068            | 0.0778 | 0.1361 | 0.0078 |
| Nicaragua             | 0.6506    | 0.5319 | 0.0341 | 0.0001 | 0.6130            | 0.4857 | 0.0550 | 0.0004 |
| Niger                 | 0.9509    | 0.9308 | 0.0850 | 0.0018 | 0.9349            | 0.9085 | 0.0837 | 0.0017 |
| Nigeria               | 0.0019    | 0.0000 | 0.0021 | 0.0000 | 0.0017            | 0.0000 | 0.0018 | 0.0000 |
| Norway                | 0.0045    | 0.0000 | 0.0050 | 0.0000 | 0.0090            | 0.0000 | 0.0075 | 0.0000 |
| Pakistan              | 0.1993    | 0.0727 | 0.0226 | 0.0000 | 0.2100            | 0.0801 | 0.0220 | 0.0000 |
| Panama                | 0.6655    | 0.5505 | 0.0993 | 0.0030 | 0.7233            | 0.6241 | 0.1004 | 0.0031 |
| Papua New Guinea      | 0.5914    | 0.4594 | 0.8085 | 0.6483 | 0.6533            | 0.5352 | 0.8529 | 0.7236 |
| Paraguay              | 0.0335    | 0.0015 | 0.1024 | 0.0033 | 0.0230            | 0.0006 | 0.0691 | 0.0009 |
| Peru                  | 0.0000    | 0.0000 | 0.0002 | 0.0000 | 0.0001            | 0.0000 | 0.0002 | 0.0000 |
| Philippines           | 0.0000    | 0.0000 | 0.0066 | 0.0000 | 0.0000            | 0.0000 | 0.0067 | 0.0000 |
| Poland                | 0.0021    | 0.0000 | 0.0000 | 0.0000 | 0.0017            | 0.0000 | 0.0000 | 0.0000 |
| Portugal              | 0.9835    | 0.9766 | 0.4365 | 0.1683 | 0.9937            | 0.9910 | 0.3862 | 0.1262 |
| Puerto Rico           | 0.0400    | 0.0024 | 0.1999 | 0.0234 | 0.0371            | 0.0020 | 0.1867 | 0.0193 |
| Romania               | 0.5174    | 0.3728 | 0.9791 | 0.9578 | 0.5161            | 0.3714 | 0.9787 | 0.9570 |
| Russian Federation    | 0.0357    | 0.0018 | 0.0001 | 0.0000 | 0.0435            | 0.0029 | 0.0001 | 0.0000 |
| Rwanda                | 0.0119    | 0.0001 | 0.0293 | 0.0000 | 0.0268            | 0.0009 | 0.0548 | 0.0004 |
| Saint Kitts and Nevis | 0.3914    | 0.2373 | 0.4761 | 0.2057 | 0.4459            | 0.2938 | 0.3443 | 0.0956 |
| Samoa                 | 0.0702    | 0.0088 | 0.0232 | 0.0000 | 0.0835            | 0.0128 | 0.0324 | 0.0001 |
| Senegal               | 0.4988    | 0.3518 | 0.5000 | 0.2299 | 0.4321            | 0.2792 | 0.4210 | 0.1547 |
| Seychelles            | 0.0007    | 0.0000 | 0.0092 | 0.0000 | 0.0005            | 0.0000 | 0.0064 | 0.0000 |
| Sierra Leone          | 0.0290    | 0.0011 | 0.0508 | 0.0003 | 0.0378            | 0.0021 | 0.0423 | 0.0002 |
| Singapore             | 0.0009    | 0.0000 | 0.0029 | 0.0000 | 0.0010            | 0.0000 | 0.0035 | 0.0000 |
| Slovakia              | 0.7077    | 0.6040 | 0.1328 | 0.0072 | 0.6673            | 0.5528 | 0.2027 | 0.0243 |
| Slovenia              | 0.4949    | 0.3474 | 0.6142 | 0.3626 | 0.4830            | 0.3342 | 0.5976 | 0.3416 |
| Solomon Islands       | 0.0114    | 0.0001 | 0.0112 | 0.0000 | 0.0235            | 0.0006 | 0.0053 | 0.0000 |
| South Africa          | 0.0372    | 0.0020 | 0.0001 | 0.0000 | 0.0290            | 0.0011 | 0.0001 | 0.0000 |

**Table 6.** Significance levels (p-value) for hypothesis  $H_0$  (Continued)

| Test                | p-value   |        |        |        |                   |        |        |        |
|---------------------|-----------|--------|--------|--------|-------------------|--------|--------|--------|
|                     | Documents |        |        |        | Citable documents |        |        |        |
|                     | Lag 2     |        | Lag 3  |        | Lag 2             |        | Lag 3  |        |
|                     | Test 1    | Test 2 | Test 1 | Test 2 | Test 1            | Test 2 | Test 1 | Test 2 |
| South Korea         | 0.0137    | 0.0001 | 0.0128 | 0.0000 | 0.0132            | 0.0001 | 0.0195 | 0.0000 |
| Spain               | 0.5469    | 0.4068 | 0.0728 | 0.0011 | 0.4641            | 0.3135 | 0.0266 | 0.0000 |
| Sri Lanka           | 0.0996    | 0.0186 | 0.1342 | 0.0075 | 0.0952            | 0.0169 | 0.1263 | 0.0062 |
| Sudan               | 0.4591    | 0.3080 | 0.3332 | 0.0882 | 0.4594            | 0.3083 | 0.3501 | 0.0996 |
| Suriname            | 0.8657    | 0.8132 | 0.0321 | 0.0001 | 0.8491            | 0.7906 | 0.0527 | 0.0003 |
| Swaziland           | 0.2651    | 0.1218 | 0.2927 | 0.0638 | 0.2648            | 0.1216 | 0.3397 | 0.0925 |
| Sweden              | 0.0065    | 0.0000 | 0.0521 | 0.0003 | 0.0042            | 0.0000 | 0.0341 | 0.0001 |
| Switzerland         | 0.0503    | 0.0041 | 0.0204 | 0.0000 | 0.0720            | 0.0093 | 0.0279 | 0.0000 |
| Tajikistan          | 0.4754    | 0.3258 | 0.4768 | 0.2063 | 0.4781            | 0.3288 | 0.4816 | 0.2111 |
| Tanzania            | 0.0321    | 0.0014 | 0.0277 | 0.0000 | 0.0311            | 0.0013 | 0.0265 | 0.0000 |
| Thailand            | 0.0001    | 0.0000 | 0.0009 | 0.0000 | 0.0001            | 0.0000 | 0.0012 | 0.0000 |
| Togo                | 0.6341    | 0.5114 | 0.0609 | 0.0006 | 0.4985            | 0.3514 | 0.0699 | 0.0009 |
| Trinidad and Tobago | 0.0265    | 0.0009 | 0.0133 | 0.0000 | 0.0249            | 0.0007 | 0.0246 | 0.0000 |
| Tunisia             | 0.9833    | 0.9764 | 0.0475 | 0.0002 | 0.6559            | 0.5385 | 0.0099 | 0.0000 |
| Turkey              | 0.0012    | 0.0000 | 0.0069 | 0.0000 | 0.0014            | 0.0000 | 0.0075 | 0.0000 |
| Turkmenistan        | 0.4661    | 0.3157 | 0.0701 | 0.0009 | 0.4233            | 0.2700 | 0.0477 | 0.0002 |
| Uganda              | 0.0322    | 0.0014 | 0.0665 | 0.0008 | 0.0461            | 0.0034 | 0.0655 | 0.0007 |
| Ukraine             | 0.4539    | 0.3024 | 0.4993 | 0.2292 | 0.4920            | 0.3442 | 0.5767 | 0.3160 |
| United Kingdom      | 0.0168    | 0.0003 | 0.0081 | 0.0000 | 0.0325            | 0.0014 | 0.0121 | 0.0000 |
| United States       | 0.0181    | 0.0003 | 0.0048 | 0.0000 | 0.0315            | 0.0013 | 0.0104 | 0.0000 |
| Uruguay             | 0.6434    | 0.5229 | 0.2647 | 0.0494 | 0.6357            | 0.5134 | 0.3187 | 0.0790 |
| Uzbekistan          | 0.4317    | 0.2787 | 0.4330 | 0.1652 | 0.4196            | 0.2661 | 0.4206 | 0.1543 |
| Vanuatu             | 0.4848    | 0.3362 | 0.7913 | 0.6202 | 0.5873            | 0.4545 | 0.8273 | 0.6796 |
| Venezuela           | 0.7894    | 0.7106 | 0.9794 | 0.9584 | 0.7805            | 0.6988 | 0.9800 | 0.9595 |
| Vietnam             | 0.1779    | 0.0587 | 0.2655 | 0.0498 | 0.1792            | 0.0596 | 0.2668 | 0.0504 |
| Yemen               | 0.1335    | 0.0337 | 0.2521 | 0.0435 | 0.1136            | 0.0244 | 0.1964 | 0.0223 |
| Zambia              | 0.0921    | 0.0158 | 0.2276 | 0.0332 | 0.1037            | 0.0202 | 0.3733 | 0.1163 |
| Zimbabwe            | 0.1035    | 0.0201 | 0.1250 | 0.0060 | 0.1343            | 0.0341 | 0.1609 | 0.0127 |

**Table 7.** The rejection frequencies (RF) for hypothesis  $H_0$  (lack of causality) for particular groups of countries and significance level 0.01

| Group                       | RF (p-value = 0.01) |        |        |        |                   |        |        |        | Number<br>of<br>countries |
|-----------------------------|---------------------|--------|--------|--------|-------------------|--------|--------|--------|---------------------------|
|                             | Documents           |        |        |        | Citable documents |        |        |        |                           |
|                             | Lag 2               |        | Lag 3  |        | Lag 2             |        | Lag 3  |        |                           |
|                             | Test 1              | Test 2 | Test 1 | Test 2 | Test 1            | Test 2 | Test 1 | Test 2 |                           |
| All                         | 0.174               | 0.382  | 0.236  | 0.611  | 0.181             | 0.368  | 0.243  | 0.611  | 144                       |
| G20                         | 0.308               | 0.692  | 0.538  | 0.769  | 0.385             | 0.692  | 0.462  | 0.846  | 13                        |
| European Union              | 0.080               | 0.160  | 0.200  | 0.600  | 0.080             | 0.160  | 0.160  | 0.560  | 25                        |
| Very high human development | 0.237               | 0.368  | 0.316  | 0.658  | 0.237             | 0.368  | 0.263  | 0.632  | 38                        |
| High human development      | 0.156               | 0.375  | 0.250  | 0.656  | 0.156             | 0.375  | 0.281  | 0.688  | 32                        |
| Medium human development    | 0.194               | 0.472  | 0.278  | 0.583  | 0.222             | 0.444  | 0.278  | 0.639  | 36                        |
| Low human development       | 0.108               | 0.297  | 0.108  | 0.568  | 0.108             | 0.270  | 0.162  | 0.514  | 37                        |
| Asia                        | 0.333               | 0.545  | 0.333  | 0.636  | 0.364             | 0.545  | 0.364  | 0.697  | 33                        |
| Africa                      | 0.070               | 0.302  | 0.163  | 0.581  | 0.093             | 0.279  | 0.186  | 0.535  | 43                        |
| North America               | 0.133               | 0.400  | 0.267  | 0.600  | 0.067             | 0.400  | 0.200  | 0.667  | 15                        |
| South America               | 0.250               | 0.500  | 0.250  | 0.750  | 0.250             | 0.500  | 0.250  | 0.750  | 12                        |
| Europe                      | 0.146               | 0.317  | 0.244  | 0.634  | 0.146             | 0.317  | 0.220  | 0.610  | 41                        |
| Australia and Oceania       | 0.286               | 0.571  | 0.286  | 0.714  | 0.286             | 0.429  | 0.429  | 0.714  | 7                         |

and significance levels 0.01 and 0.05 are listed in Tables 7 and 8, respectively.

Generally, higher values are seen than may have been expected to result from the respective significance levels (1% and 5%). The presence of relatively low values for the European Union is striking (except for two cases in test 2). This situation may be explained by a longer period of relative economic stagnation in which the development of scientific research activity has a lesser impact on GDP. The situation is different in the remaining G20 countries, where this relationship is most visible among the researched countries. When comparing continents, a relatively strong relationship between scientific research and GDP exists in Asia and South and North

America. The cause-effect relationship between scientific research activity and GDP is visibly weaker in Europe than in Australia and Oceania. This relation is especially evident in the USA, United Kingdom, Canada, Australia, and Sweden, as well as Far Eastern countries such as China (including Hong Kong), South Korea, the Philippines, Thailand, Singapore, Russia, Turkey and Poland. The table also shows the weakest relationship in the 37 countries that constitute the “low human development” group. Generally, it seems that the scientific activity is not a (significant) driver of economic development in all countries. For example, there are countries where the economy is based mainly on the mining industry or tourism, where science plays a secondary role.

**Table 8.** The rejection frequencies (RF) for hypothesis  $H_0$  (lack of causality) for particular groups of countries and significance level 0.05

| Group                          | RF (p-value = 0.05) |        |        |        |                   |        |        |        | Number<br>of<br>countries |
|--------------------------------|---------------------|--------|--------|--------|-------------------|--------|--------|--------|---------------------------|
|                                | Documents           |        |        |        | Citable documents |        |        |        |                           |
|                                | Lag 2               |        | Lag 3  |        | Lag 2             |        | Lag 3  |        |                           |
|                                | Test 1              | Test 2 | Test 1 | Test 2 | Test 1            | Test 2 | Test 1 | Test 2 |                           |
| All                            | 0.347               | 0.514  | 0.424  | 0.715  | 0.340             | 0.521  | 0.438  | 0.694  | 144                       |
| G20                            | 0.692               | 0.846  | 0.769  | 0.846  | 0.692             | 0.846  | 0.769  | 0.846  | 13                        |
| European Union                 | 0.120               | 0.280  | 0.200  | 0.680  | 0.120             | 0.280  | 0.280  | 0.680  | 25                        |
| Very high human<br>development | 0.316               | 0.474  | 0.395  | 0.711  | 0.316             | 0.474  | 0.447  | 0.711  | 38                        |
| High human development         | 0.375               | 0.531  | 0.531  | 0.750  | 0.375             | 0.563  | 0.563  | 0.719  | 32                        |
| Medium human development       | 0.417               | 0.583  | 0.472  | 0.722  | 0.389             | 0.583  | 0.444  | 0.667  | 36                        |
| Low human development          | 0.270               | 0.459  | 0.324  | 0.676  | 0.270             | 0.459  | 0.324  | 0.676  | 37                        |
| Asia                           | 0.545               | 0.636  | 0.515  | 0.818  | 0.545             | 0.667  | 0.545  | 0.758  | 33                        |
| Africa                         | 0.279               | 0.442  | 0.326  | 0.651  | 0.256             | 0.442  | 0.326  | 0.651  | 43                        |
| North America                  | 0.400               | 0.600  | 0.533  | 0.800  | 0.400             | 0.600  | 0.467  | 0.800  | 15                        |
| South America                  | 0.500               | 0.667  | 0.583  | 0.833  | 0.500             | 0.667  | 0.583  | 0.750  | 12                        |
| Europe                         | 0.244               | 0.439  | 0.366  | 0.683  | 0.244             | 0.439  | 0.415  | 0.683  | 41                        |
| Australia and Oceania          | 0.429               | 0.571  | 0.714  | 0.714  | 0.429             | 0.571  | 0.714  | 0.714  | 7                         |

5. Testing the influence of IoSA on GDP forecasts using the example of Poland

This chapter first examines, based on the previous two tests, the level of Granger causality between the number of publications in given fields of scientific research and GDP for Poland. We chose Poland (our home country) as an example for a detailed analysis. Additionally, we chose one country due to the volume of the article. The study was carried out for lag orders 2 and 3. The table 9 lists the p-values resulting from this testing. Next, the direct influence of information contained in the IoSA vector on the quality of Polish GDP forecasts for 2011-2012 is tested using the adopted linear model (described later in this chapter).

It is clear from the results presented in the above table that the total number of publications (all) resulting from scientific research activity in Poland has a significant effect (p-value less than 0.01) in the Granger sense on Polish GDP growth. This conclusion is drawn based on both scientific research activity indicators used in the tests, as well as both tested lag orders. The same conclusions can be formulated in relation to the following fields of scientific research activities in Poland: biochemistry, genetics and molecular biology, chemistry, immunology and microbiology, medicine, and physics and astronomy. Moreover, test 2 shows that the same conclusion can be drawn for other fields of scientific research. Generalizing these results, it can be claimed that publications related to scientific research associated with highly innovative

**Table 9.** The result of p-values for lag orders 2 and 3

| Area  | p-value   |        |        |        |                   |        |        |        |
|---|-----------|--------|--------|--------|-------------------|--------|--------|--------|
|   | Documents |        |        |        | Citable documents |        |        |        |
|   | Lag 2     |        | Lag 3  |        | Lag 2             |        | Lag 3  |        |
|   | Test 1    | Test 2 | Test 1 | Test 2 | Test 1            | Test 2 | Test 1 | Test 2 |
| <b>All</b>  | 0.0021    | 0      | 0      | 0      | 0.0017            | 0      | 0      | 0      |
| Agricultural and Biological Sciences                | 0.5423    | 0.4014 | 0.7037 | 0.4853 | 0.5517            | 0.4124 | 0.7117 | 0.4969 |
| Arts and Humanities                                 | 0.9384    | 0.9134 | 0.7852 | 0.6102 | 0.9288            | 0.9    | 0.7231 | 0.5139 |
| <b>Biochemistry, Genetics and Molecular Biology</b> | 0.0051    | 0      | 0.0002 | 0      | 0.0042            | 0      | 0.0001 | 0      |
| Business, Management and Accounting                 | 0.9409    | 0.9169 | 0.9428 | 0.8871 | 0.954             | 0.9352 | 0.9694 | 0.9386 |
| Chemical Engineering                                | 0.0558    | 0.0052 | 0.1147 | 0.0047 | 0.0499            | 0.004  | 0.1048 | 0.0035 |
| <b>Chemistry</b>                                    | 0.0011    | 0      | 0.0004 | 0      | 0.0011            | 0      | 0.0005 | 0      |
| Computer Science                                    | 0.0848    | 0.0132 | 0.2136 | 0.028  | 0.0687            | 0.0084 | 0.1822 | 0.0181 |
| Decision Sciences                                   | 0.0587    | 0.0059 | 0.0435 | 0.0002 | 0.0508            | 0.0042 | 0.0371 | 0.0001 |
| Dentistry   | 0.83      | 0.7648 | 0.058  | 0.0005 | 0.825             | 0.7581 | 0.0845 | 0.0018 |
| Earth and Planetary Sciences                        | 0.0085    | 0      | 0.028  | 0      | 0.0111            | 0.0001 | 0.0357 | 0.0001 |
| Economics, Econometrics and Finance                 | 0.7108    | 0.608  | 0.114  | 0.0046 | 0.725             | 0.6263 | 0.162  | 0.013  |
| Energy  | 0.5472    | 0.4071 | 0.4486 | 0.1794 | 0.5147            | 0.3698 | 0.4646 | 0.1945 |
| Engineering   | 0.1031    | 0.02   | 0.1633 | 0.0133 | 0.0879            | 0.0143 | 0.1523 | 0.0109 |
| Environmental Science                               | 0.2178    | 0.0856 | 0.0102 | 0      | 0.2203            | 0.0874 | 0.0126 | 0      |
| Health Professions                                  | 0.0125    | 0.0001 | 0.0554 | 0.0004 | 0.0157            | 0.0002 | 0.0656 | 0.0008 |
| <b>Immunology and Microbiology</b>                  | 0.0006    | 0      | 0.0005 | 0      | 0.0004            | 0      | 0.0005 | 0      |
| Materials Science                                   | 0.0463    | 0.0034 | 0.1078 | 0.0038 | 0.0498            | 0.004  | 0.1114 | 0.0043 |
| Mathematics   | 0.2078    | 0.0785 | 0.4117 | 0.1468 | 0.2034            | 0.0755 | 0.4108 | 0.1461 |
| <b>Medicine</b>                                     | 0.0006    | 0      | 0.0006 | 0      | 0.0004            | 0      | 0.0005 | 0      |
| Multidisciplinary                                   | 0.6011    | 0.4712 | 0.3312 | 0.0869 | 0.4434            | 0.2911 | 0.4998 | 0.2297 |
| Neuroscience  | 0.0896    | 0.0149 | 0.2501 | 0.0426 | 0.1021            | 0.0196 | 0.28   | 0.057  |
| Nursing   | 0.0489    | 0.0039 | 0.1423 | 0.0089 | 0.096             | 0.0172 | 0.2313 | 0.0346 |
| Pharmacology, Toxicology and Pharmaceutics          | 0.7455    | 0.6529 | 0.8929 | 0.7944 | 0.7583            | 0.6696 | 0.935  | 0.8723 |
| <b>Physics and Astronomy</b>                        | 0.002     | 0      | 0.0071 | 0      | 0.0019            | 0      | 0.0067 | 0      |
| Psychology  | 0.0197    | 0.0004 | 0.019  | 0      | 0.0114            | 0.0001 | 0.0138 | 0      |
| Social Sciences                                     | 0.3404    | 0.1878 | 0.1178 | 0.005  | 0.3073            | 0.1576 | 0.1089 | 0.004  |
| Veterinary  | 0.0875    | 0.0141 | 0.0589 | 0.0005 | 0.0859            | 0.0136 | 0.0582 | 0.0005 |

Note: Scientific fields characterized by all p-values below 0.01 are emphasized in bold.



technological development have the largest impact on GDP growth in Poland (with a lag of 2 and 3 years).

The second part of the study, as stated earlier, comprises an analysis of the influence of information contained in the IoSA vector on the forecast quality of Polish GDP. In other words, an attempt is made to examine how past knowledge contained in publications (Documents, Citable documents) influences the forecast quality of future GDP. A test was carried out for the GDP forecasts for 2011-2012. Such forecasts of Polish GDP were made for these years based the model described below and subsequently checked for quality by calculating the errors, expressed as root mean square error (RMSE) and mean absolute percentage error (MAPE). The forecasts were created by first estimating the model parameters based on data from the IoSA vector for the years 1996-2010, then calculating the GDP forecast for 2011 using the estimated model parameters, and, finally, repeating the procedure for 2012 but with the model estimated based on data for 1996-2011. For both forecast years, the average forecast error was calculated as RMSA and MAPE.

An additional phenomenon was analyzed during the above test. When forecasting Polish GDP for a given year, it is possible to apply a model estimated from data pertaining solely to Poland or one estimated from data pertaining solely to other countries. One may imagine suitably formulated time series in both cases to estimate, e.g., the parameters of an autoregressive model with the appropriate lag order. It is also possible to use data pertaining to all countries except Poland to estimate the model. The first approach (estimating the model parameters using only data pertaining to Poland) corresponds to the case where all the observations are used; however, a non-zero weight (in the weighted OLS method) equal to a certain positive constant is assigned only to observations for Poland, while the remaining observations have weights equal to zero. The other approach, where a GDP model for Poland is estimated using data from 1996-2010/2011 for other countries, matches the case where all the observations are used (pertaining to Poland and other countries); however, the observation weight for Poland would assume the value of zero, and all observations relating to other countries would have a certain non-negative weight. An interesting situation arises if these weights are defined as variables. Such a case is examined below.

It is assumed that observation weights pertaining to Poland in proportion to other countries are related as  $\Theta$  to  $(1 - \Theta)$ , where  $\Theta$  denotes a number in the range  $[0,1]$ . Therefore, if  $\Theta$  is equal to 1, only observations pertaining to Poland are used to estimate the parameters of the regression equation. On the other hand, if  $\Theta$  is equal to zero, only observations from other countries are used to estimate the model. If, in turn,  $\Theta$  is equal to 0.5, all the observations have the same weight, and if  $\Theta = 0.75$ , the weight of observations for Poland is 3 times  $(0.75 / (1 - 0.75) = 3)$  greater (this corresponds to the situation in which observations pertaining to Poland would be repeated 3 times).

Two alternative model descriptions were used in this test:

$$GDP_t = c_1 + \alpha_1 GDP_{t-1} + \alpha_2 GDP_{t-2} + \dots + \alpha_p GDP_{t-p} + \beta_1 A_{t-1} + \beta_2 A_{t-2} + \dots + \beta_p A_{t-p} + \mu_t \quad (9)$$

and

$$GDP_t = c_0 + \gamma_1 GDP_{t-1} + \gamma_2 GDP_{t-2} + \dots + \gamma_p GDP_{t-p} + e_t \quad (10)$$

where  $A$  denotes Documents or Citable documents and  $p$  denotes the lag order.

The quality of the GDP forecasts for 2011 and 2012 was tested by applying random terms  $\mu_{2012}$ ,  $\mu_{2011}$ ,  $e_{2012}$ , and  $e_{2011}$  in the following models:

$$GDP_{2012} = c_{2012}^1 + \alpha_{2011}' GDP_{2011} + \dots + \alpha_{1996}' GDP_{1996} + \beta_{2011}' A_{2011} + \dots + \beta_{1996}' A_{1996} + \mu_{2012} \quad (11)$$

$$GDP_{2011} = c_{2011}^1 + \alpha_{2010}' GDP_{2010} + \dots + \alpha_{1996}' GDP_{1996} + \beta_{2010}' A_{2010} + \dots + \beta_{1996}' A_{1996} + \mu_{2011} \quad (12)$$

$$GDP_{2012} = c_{2012}^0 + \gamma_{2011}' GDP_{2011} + \dots + \gamma_{2010}' GDP_{2010} + \dots + \gamma_{1996}' GDP_{1996} + e_{2012} \quad (13)$$

$$GDP_{2011} = c_{2011}^0 + \gamma_{2010}' GDP_{2010} + \dots + \gamma_{2009}' GDP_{2009} + \dots + \gamma_{1996}' GDP_{1996} + e_{2011} \quad (14)$$

From a technical estimation point of view, information used to prepare the forecast based on the above equations can be divided into the following two types:

a) Information obtained from past relationships between past GDP and future GDP (optionally taking

into account IoSA) only for observations pertaining to Poland,

- b) Information obtained from past relationships between past GDP and future GDP (optionally taking into account IoSA) only for observations pertaining to countries other than Poland (i.e., for  $144 - 1 = 143$  countries).

To eliminate the natural difference in the countries' size, GDP and IoSA data were divided by their average values for the period 1996–2010, calculated for each country. This information can be used to estimate the parameters of the tested equations with different weights, as mentioned earlier. A more accurate specification is made below on the example of estimating the error in  $\mu_{2012}$ , i.e., for 2012. In the case of estimating the remaining errors (i.e.,  $\mu_{2011}$ ,  $e_{2011}$ ,  $e_{2012}$ ), the procedure is analogical. Assuming

$$X_1 = \begin{bmatrix} GDP_{2010\_Poland} & \cdots & GDP_{2011-p\_Poland} \\ GDP_{2009\_Poland} & \cdots & GDP_{2010-p\_Poland} \\ \vdots & \vdots & \vdots \\ GDP_{1996+p-1\_Poland} & \cdots & GDP_{1996\_Poland} \\ GDP_{2010\_Country1} & \cdots & GDP_{2011-p\_Country1} \\ GDP_{2009\_Country1} & \vdots & GDP_{2010-p\_Country1} \\ \vdots & \vdots & \vdots \\ GDP_{1996+p-1\_Country1} & \cdots & GDP_{1996\_Country1} \\ GDP_{2010\_Country2} & \cdots & GDP_{2011-p\_Country2} \\ GDP_{2009\_Country2} & \vdots & GDP_{2010-p\_Country2} \\ \vdots & \vdots & \vdots \\ GDP_{1996+p-1\_Country2} & \cdots & GDP_{1996\_Country2} \\ \vdots & \vdots & \vdots \\ GDP_{2010\_CountryN} & \cdots & GDP_{2011-p\_CountryN} \\ GDP_{2009\_CountryN} & \cdots & GDP_{2010-p\_CountryN} \\ \vdots & \vdots & \vdots \\ GDP_{1996+p-1\_CountryN} & \cdots & GDP_{1996\_CountryN} \end{bmatrix}$$

$$X_2 = \begin{bmatrix} A_{2011-p\_Poland} & \cdots & A_{2011-p\_Poland} \\ A_{2009\_Poland} & \cdots & A_{2010-p\_Poland} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_Poland} & \cdots & A_{1996\_Poland} \\ A_{2010\_Country1} & \cdots & A_{2011-p\_Country1} \\ A_{2009\_Country1} & \vdots & A_{2010-p\_Country1} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_Country1} & \cdots & A_{1996\_Country1} \\ A_{2010\_Country2} & \cdots & A_{2011-p\_Country2} \\ A_{2009\_Country2} & \vdots & A_{2010-p\_Country2} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_Country2} & \cdots & A_{1996\_Country2} \\ \vdots & \vdots & \vdots \\ A_{2010\_CountryN} & \cdots & A_{2011-p\_CountryN} \\ A_{2009\_CountryN} & \cdots & A_{2010-p\_CountryN} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_CountryN} & \cdots & A_{1996\_CountryN} \end{bmatrix} \quad (15)$$

where  $country_i$  denotes the  $i$ -th country out of the researched countries other than Poland,  $N=143$ ,  $m=16$  (for 2012; however,  $m=15$  in the forecast for 2011).

$$\Theta = \begin{bmatrix} \Theta \\ \Theta \\ \vdots \\ \Theta \\ 1-\Theta \\ 1-\Theta \\ \vdots \\ 1-\Theta \\ 1-\Theta \\ \vdots \\ 1-\Theta \\ 1-\Theta \\ \vdots \\ 1-\Theta \\ 1-\Theta \\ \vdots \\ 1-\Theta \end{bmatrix} \quad (16)$$

May  $W$  denote the matrix with diagonal elements  $\Theta$  on the main diagonal. For the discussed case, this matrix will constitute the weighting matrix, where observations pertaining to Poland are weighted with respect to observations pertaining to the remaining countries.

To shorten the notation, let us assume

$$X = [1, X_1, X_2] \quad (17)$$

where  $1$  denotes the vector of ones related to the free term,  $X_1$  represents GDP, and  $X_2$  represents the IoSA vector (in the case of the model with a random term denoted as  $e$ ,  $X_2$  is an empty vector). Consequently, the WOLS (weighted OLS) estimator may be used; thus,

$$\begin{bmatrix} \tilde{\alpha} \\ \beta \end{bmatrix} = [X^T W X]^{-1} X^T W y \quad (18)$$

For the model parameters estimated in this way, the forecast errors  $PK\widehat{B}_{2011}$  and  $PK\widehat{B}_{2012}$  can be calculated (in other words, the realizations of random terms:  $\mu_{2012}$ ,  $\mu_{2011}$ ,  $e_{2012}$ , and  $e_{2011}$ ). RMSE and MAPE

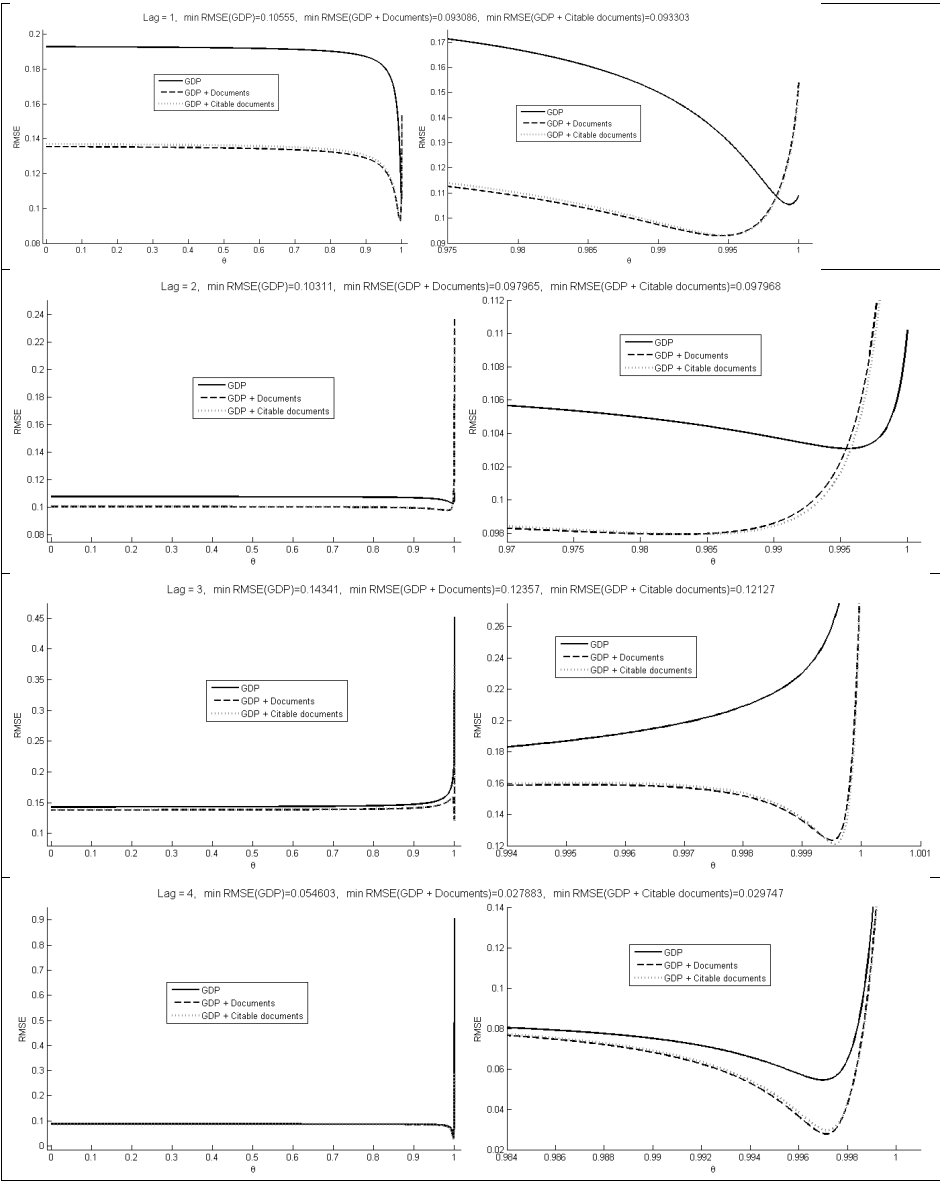


Figure 1. RMSE for "Documents" and "Citable documents" with function \_ and lag=1,2,3,4

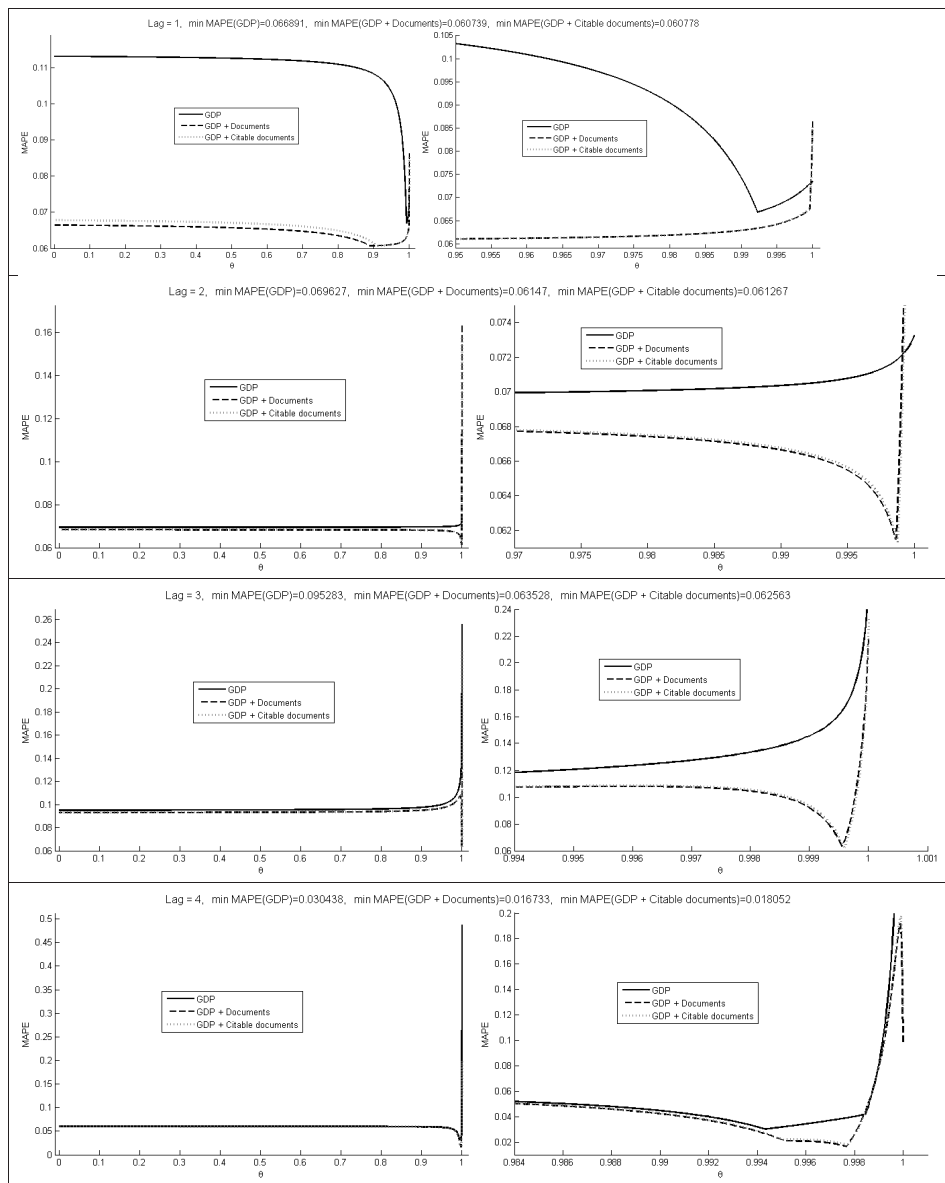


Figure 2. MAPE for "Documents" and "Citable documents" with function \_ and lag=1,2,3,4

shall be used as measures of error. These are defined as follows:

$$RMSE = \sqrt{\frac{\left(\widehat{GDP}_{2012} - GDP_{2012}\right)^2 + \left(\widehat{GDP}_{2011} - GDP_{2011}\right)^2}{2}} \quad (19)$$

$$MAPE = \frac{1}{2} \left( \left| \frac{\widehat{GDP}_{2012} - GDP_{2012}}{GDP_{2012}} \right| + \left| \frac{\widehat{GDP}_{2011} - GDP_{2011}}{GDP_{2011}} \right| \right) \quad (20)$$

As explained earlier, parameter  $\Theta$  reflects the relationship between the share of observations for Poland and observations for other countries. Therefore, both types of errors are functions of  $\Theta$ . The model error figure with and without indicators of scientific research activity (number of publications) are presented in figure 1 for various lag orders. RMSE graphs for “Documents” and “Citable documents” as a function  $\Theta$  are shown for two forecast variants, i.e., with and without the adopted indicators of scientific research activity. For most cases, an interesting phenomenon is visible near the value  $\Theta = 0.99$ . The error curve falls to a certain minimum value, after which it rises again. Thus, information from other countries (or, more precisely, using observations pertaining to other countries in the process of estimating the parameters for the equation applied to forecast Polish GDP) improves the forecast of Polish GDP. However, this information should be balanced by an appropriately small weight. The graphs on the right side show an enlargement of the same error graph for the upper range of  $\Theta$ .

Graphs representing MAPE for “Documents” and “Citable documents” with function  $\Theta$  are presented in figure 2, analogically to RMSE above. The graphs on the right show an enlargement of the left error graph for the upper range of  $\Theta$ .

It is worth noting that for all of the above graphs, the lowest forecast error is observed for the predictive equation variant taking into account the characteristics of scientific research activity (i.e., GDP + Documents or GDP + Citable documents). For each lag in the range of 1-4, the lowest RMSE and MAPE appear when applying a non-zero weight for countries other

than Poland. In both cases, i.e., Documents and Citable documents, the lowest RMSE appears in the model with a lag order equal to 4). In all cases, it is evident that scientific research activity indicators help better explain GDP.

## Conclusions

The subject of research described in this paper was the causality, in the Granger sense, between scientific research activity and GDP. The research was carried out using annual data pertaining to 144 countries around the world and 28 distinct areas of scientific research activity. Generally, the study confirmed the main proposed hypothesis, which claims that in many countries and fields of study, a causal relationship exists between scientific research activity, measured as the number of significant publications, and GDP. This relationship is very pronounced in many countries, including the USA, United Kingdom, Canada, Australia, Russia, and China. Generally, this relationship is most visible in the G20 group of countries (which have a large potential for both scientific research activity and GDP), with the exclusion of European Union countries. The relatively less visible relationship between scientific research activity and GDP in the European Union is striking, especially in countries such as Germany, France and Italy (which may be caused by an extended period of economic stagnation). Conversely, this relationship is clearly visible on the Asian and American continents. The weakest relationship is found in countries belonging to the low human development group.

The second hypothesis, which claims a varied influence of distinct scientific research activities on GDP, proved that fields of study such as (1) biochemistry, genetics and molecular biology; (2) business, management and accounting; and (3) mathematics are most conducive to fostering economic growth.

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