## 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: 010, 040

<sup>1</sup> University of Finance and Management in Warsaw - Management and Finance, Poland; <sup>2</sup> Warsaw University of Life Sciences - Faculty of Applied Informatics and Mathematics, Department of Applied Informatics, Poland

### 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

Correspondence concerning this article should be addressed to: Wiesław Dębski, University of Finance and Management in Warsaw - Management and Finance, 55 Pawia Str., Warsaw 01-030, Poland. E-mail: wdebski@vizja.pl growth models or econometric models of national economies, the GDP level is used most frequently. Researchers have always been interested in the causeeffect 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 316

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"):

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

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						

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

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. 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). 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(IoSA)] 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 (IoSA,1) indicates the IoSA 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(IoSA,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 complied using a linear model for the years 2011-2012.

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

$$\begin{aligned} x_t &= c_1 + \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + \ldots + \alpha_p x_{t-p} + \beta_1 y_{t-1} + \beta_2 y_{t-2} + \\ &+ \ldots + \beta_p y_{t-p} + \mu_t \end{aligned} \tag{1}$$

against its alternative formulation

$$x_{t} = c_{0} + \gamma_{1} x_{t-1} + \gamma_{2} x_{t-2} + \ldots + \gamma_{p} x_{t-p} + e_{t}$$
(2)

estimated using the ordinary least squares (OLS) method.

		RF					
	1	Test 1	Test 2				
p	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%			

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

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:

$$H_0: \beta_1 = \beta_2 = \dots = \beta_p = 0 \tag{3}$$

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):

$$S_{1} \equiv \frac{RSS_{0} - RSS_{1}}{\frac{P}{T - 2p - 1}}$$
(4)

$$S_2 \equiv \frac{T\left(RSS_0 - RSS_1\right)}{RSS_1} \tag{5}$$

where

$$RSS_1 = \sum_{t=1}^T \hat{\mu}_t^2 \tag{6}$$

$$RSS_0 = \sum_{t=1}^T \hat{e}_t^2 \tag{7}$$

It is assumed that statistics  $S_1$  and  $S_2$  have the corresponding distributions: F(p, T-2p-1) and  $x^2(p)$ , 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:

$$RF = \frac{1}{K} \sum_{i=1}^{K} h_i \tag{8}$$

where:

$$\boldsymbol{h}_i = \left\{ \begin{array}{l} \boldsymbol{1} \ \textit{if } p\textit{-value}_i < 0.05 \\ \\ \boldsymbol{0} \ \textit{if } p\textit{-value}_i \geq 0.05 \end{array} \right.$$

*p-value*<sub>i</sub> – 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

		RF-RFrand	om				
	١	Test 1	Test 2				
Lag	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%			

Table 3. The differences between RF and RF rand

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<sub>0</sub> 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 permutated 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, 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  $\rm H_{0}$  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<sub>random</sub> in the table 3 are an indication in favor of hypothesis  $H_1$  (the hypothesis of a lack of causality in comparison to randomly permutated 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 permutated 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

				_													
		RF						RF - RFrandom						_			
		Docu	ments		Cit	able d	ocume	ents		Docu	ments		Citable documents				- NoC
	La	g 2	La	g 3	La	g 2	La	g 3	La	g 2	La	g 3	La	g 2	La	g 3	NUC
test	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 4. The results of rejection frequency of the zero hypothesis

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

1	All
2	Biochemistry, Genetics and Molecular Biology
3	Business, Management and Accounting
4	Mathematics

Table 5. Sum of ranks (in descending order)

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 permutated 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 permutated 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  $H_{0^{2}}$  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<sub>0</sub> (lack of causality) for particular groups of countries

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

	p-value										
		Docu	ments		Citable documents						
lest	La	g 2	La	g 3	La	g 2	La	g 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			

I.

	p-value											
Test		Docu	ments			Citable documents						
	La	g 2	La	g 3	La	g 2	La	g 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				

	p-value											
		Docu	ments		Citable documents							
Test	La	g 2	La	g 3	La	g 2	La	g 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				

I.

	p-value										
Test		Docu	ments			Citable documents					
	La	g 2	La	g 3	La	g 2	La	g 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			

	p-value											
		Docu	ments			Citable documents						
Test	La	g 2	La	g 3	La	g 2	La	g 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				
Тодо	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 H0 (lack of causality) for particular groups of countries and significance level 0.01

				RF (p-val	ue = 0.01)				_
		Docu	ments			Citable d	ocuments	;	_
	La	g 2	La	g 3	La	g 2	Lag 3		_
Group	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Number of countries
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 H0 (lack of causality) for particular groups of countries and significance level 0.05

				RF (p-val	ue = 0.05)				_
		Docu	ments			Citable d	ocuments	;	_
	Lag 2		La	g 3	La	g 2	La	Lag 3	
Group	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Number of countries
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 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

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
All	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
Biochemistry, Genetics and Molecular Biology	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
Chemistry	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
Immunology and Microbiology	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
Medicine	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
Physics and Astronomy	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.

I.

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:

$$GDP_{t} = c_{1} + \alpha_{1}GDP_{t-1} + \alpha_{2}GDP_{t-2} + \dots + \alpha_{p}GDP_{t-p} + \beta_{1}A_{t-1} + \beta_{2}A_{t-2} + \dots + \beta_{p}A_{t-p} + \mu_{t}$$
(9)

and

$$GDP_{t} = c_{0} + \gamma_{1}GDP_{t-1} + \gamma_{2}GDP_{t-2} + \ldots + \gamma_{p}GDP_{t-p} + e_{t}$$
(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:

$$\begin{aligned} GDP_{2012} &= c_{2012}^{1} + \alpha_{2011}^{\prime} GDP_{2011} + \ldots + \alpha_{1996}^{\prime} GDP_{1996} + \\ &+ \beta_{2011}^{\prime} A_{2011} + \ldots + \beta_{1996}^{\prime} A_{1996} + \mu_{2012} \end{aligned} \tag{11}$$

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

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

$$GDP_{2011} = c_{2011}^0 + \gamma_{2010} GDP_{2010} + \ldots + \gamma_{2009} GDP_{2009} + \\ + \ldots + \gamma_{1996} GDP_{1996} + e_{2011}$$
(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.,  $\mu_{2011}$ ,  $e_{2012}$ ), the procedure is analogical. Assuming



$$\boldsymbol{X_{2}} = \begin{bmatrix} A_{2011-p\_Poland} & \cdots & A_{2011-p\_Poland} \\ A_{2009\_Poland} & \cdots & A_{2010-p\_Poland} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_Poland} & \cdots & A_{1996\_Poland} \\ A_{2010\_Country1} & \cdots & A_{2011-p\_Country1} \\ A_{2009\_Country1} & \vdots & A_{2010-p\_Country1} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_Country1} & \cdots & A_{1996\_Country1} \\ A_{2010\_Country2} & \cdots & A_{2011-p\_Country2} \\ A_{2009\_Country2} & \vdots & A_{2010-p\_Country2} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_Country2} & \cdots & A_{1996\_Country2} \\ \vdots & \vdots & \vdots \\ A_{2010\_CountryN} & \cdots & A_{2011-p\_CountryN} \\ A_{2000\_CountryN} & \cdots & A_{2010-p\_CountryN} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_CountryN} & \cdots & A_{1996\_CountryN} \\ \vdots & \vdots & \vdots \\ A_{1996+p-1\_CountryN} & \cdots & A_{1996\_CountryN} \end{bmatrix}$$
(15)

where country<sub>i</sub> 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).



May W denote the matrix with diagonal elements  $\boldsymbol{\Theta}$  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  

$$X=[1, X_1, X_2]$$
 (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,

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

For the model parameters estimated in this way, the forecast errors  $PK\overline{B}_{2011}$  and  $PK\overline{B}_{2012}$  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 =

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

MAPE =

$$= \frac{1}{2} \left( \left| \frac{\widetilde{GDP}_{2012} - GDP_{2012}}{GDP_{2012}} \right| + \left| \frac{\widetilde{GDP}_{2011} - GDP_{2011}}{GDP_{2011}} \right| \right)$$
(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  $\boldsymbol{\Theta}$  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  $\boldsymbol{\Theta}$ .

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.

#### References

- Amblard, P.O., & Michel, O. J. J. (2012). The Relation between Granger Causality and Directed Information Theory: A Review. *Entropy*, 15(1), 113– 143. https://doi.org/10.3390/e15010113
- Ashley, R. (1988). On the Relative Worth of Recent Macroeconomic Forecasts. *International Journal* of Forecasting, 4(3), 363-376.

- Ashley, R., Granger, C. W. J., & Schmalensee, R. (1980). Advertising and Aggregate Consumption: An Analysis of Causality. *Econometrica*, 48(5), 1149-1168.
- Bodkin, R. G., Klein, L. R., & Marwah K. (1991). A History of Macroeconometric Model-Building. Northampton, UK: Edward Elgar Publishing.
- Berndt, E. (1991). The Practice of Econometrics: Classic and Contemporary. New York, NY: Addison-Wesley.
- Borensztein, E., De Gregorio, J., & Lee, J. W. (1998). How does foreign direct investment affect economic growth. *Journal of International Economics*, 45(1), 115-135.
- Can-Zhong, Y., & Qing-Wen, L. (2017). The mutual causality analysis between the stock and futures markets. *Physica A: Statistical Mechanics* and its Applications, 478, 188-204. https://doi. org/10.1016/j.physa.2017.02.071
- Cincera, M., & Van Pottelsberghe de la Potterie, B. (2001). International R&D spillovers: A survey. *Cahiers Economiques de Bruxelles*, 169(1), 1-20.
- Coe, D.T., Helpman, E. (1995). International R&D spillovers. *European Economic Review*, 39(5), 859-887. https://doi.org/10.1016/0014-2921(94)00100-E
- Ding, M., Chen, Y., & Bressler, S. (2006). Granger causality: Basic theory and application to Neuroscience. In S. Schelter, M. Winterhalder, & Timmer J. (Eds.), Handbook of Time Series Analysis (pp. 437-460). Wienheim: Wiley. https://doi. org/10.1002/9783527609970.ch17
- Eckstein, O. (1984). The Dri Model of the U.S. Manufacturing Industries. New York, NY: Mcgraw-Hill.
- Engelbrecht, H. J. (2002). Human capital and international knowledge spillovers in TFP growth of a sample of developing countries: an exploration of alternative approaches. *Applied Economics*, 34(7), 832-841. https://doi. org/10.1080/00036840110061947
- Engle, R. F., & Granger, C. N. J. (1987). Co-integration and error correction: representation, estimation and testing. *Econometrica*, 55(2), 251-276.
- Geweke, J. (1982). Measurement of linear dependence and feedback between multiple time series. *Journal of the American Statistical Association*, 77(378), 304-313.
- Geweke, J., Meese R., & Dent, W. (1983). Comparing Alternative Tests of Causality in Temporal

Systems: Analytic Results and Experimental Evidence. *Journal of Econometrics*, 21(2), 161-194. https://doi.org/10.1016/0304-4076(83)90012-X

- Granger, C. W. J. (1969). Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica*, 37(3), 424-438.
- Hamilton, J. D. (1994). Time Series Analysis. 1-1. New Jersey, NJ: Princeton University Press.
- Keller, W. (2004). International technology diffusion. *Journal of Economic Literature*, 42(3), 752-782.
- Lee, G. (2005). Direct versus indirect international R&D spillovers. *Information Economics and Policy*, 17(3), 334-348.
- Saggi, K. (2002). Trade, Foreign direct investment and international technology transfer: a survey. *The World Bank Observer*, 17(2), 191-235. Retrieved from https://openknowledge.worldbank.org/handle/10986/19843
- Sims, C. (1972). Money, income and causality. American Economic Review, 62(4), 540-552.
- Sims, C. (1980). Macroeconomics and reality. *Econo*metrica, 48(1), 1-48.
- Solow, R. (1957). Technical change and aggregate production function. *Review of Economics and Statistics*, 39(3), 312-320.
- Solow, R. (1962). Technical progress, capital formation and economic growth. *American Economic Review*, 52(2), 76-86.
- Van Pottelsberghe de la Potterie, B., & Lichtenberg, F. R. (2001). Does foreign direct investment transfer technology across borders? *Review of Economics and Statistics*, 83(3), 490-497. https://doi. org/10.1162/00346530152480135
- Welfe, W. (Ed.). (2004). Długookresowy, makroekonometryczny model W8D gospodarki polskiej [Long-term macroeconometric model W8D of the Polish economy]. Lódź: Wydawnictwo Uniwersytetu Łódzkiego.
- Welfe, W. (2006, July). Towards modelling knowledgebased economies. Paper presented at Second international symposium in management, engineering and informatics, Orlando, FL.
- Welfe, W. (Ed.). (2009). Knowledge-based economies. Models and methods. Frankfurt/Main: Peter Lang.
- Welfe, W. (2013). Macroeconometric models. Berlin: Springer Verlag.

- Xu, B., & Wang, J. (1999). Capital goods trade and R&D spillovers in OECD. Canadian Journal of Economics, 32(5), 1258-1274.
- Xu, B., & Wang, J. (2000). Trade, FDI and international technology diffusion. *Journal of Economic Integration*, 15(1), 585-601.
- Zhou, W. X., & Sornette, D. (2006). Non-parametric determinants of real-time lag structure between two time series: The optimal thermal causal path method. *Journal of Macroeconomics*, 28(1), 195-224. https://doi.org/10.1080/14697680500383763