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Forecasting scientific support for the advancement of the digital economy

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ABSTRACT

The aim of the study is to forecast scientific support for the advancement of the digital economy in the world and Ukraine. A methodological approach for forecasting scientific support for the advancement of the digital economy, based on bibliometric and patent analysis, is proposed. The main task of the analysis is to compare scientific developments which contribute to the advancement of the digital economy in Ukraine with those in other countries in the world. The forecast results indicate the upward trend in the volume of patents and scientific publications which ensure the advancement of the digital economy in the world in the coming years. It is revealed that, if the current situation persists, the share of Ukraine in the global number of patents and publications will remain extremely low. The forecast demonstrates that the inequality in the level of scientific support for the advancement of the digital economy between leading countries of the world and Ukraine will increase in the near future if immediate measures to stimulate own researches in the field of digital technologies are not taken at the state level.

Key words: forecasting, modeling, scientific support, digital economy

JEL classification: C23, C53, O10

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1. Introduction

The development of digital technologies and innovation form a new economic accounting in the world. Digital technologies cover most areas of modern society, creating new business models and changing the existing mechanisms of economic relations. In the majority of developed countries, the growth of digital data demonstrates an exponential trend. According to Digital Economy Report 2019 (UNCTAD, 2019), despite the difference in the pace of digital transformation in countries of the world, the processes of the digital economy affect the economic situation in all its regions. The digital economy both brings opportunities and poses new challenges for countries all around the world depending on their ability to adapt to new conditions *(*European Commission, 2014). On the one hand, advancement of the digital economy stimulates emergence of innovations and new professions (OECD, 2019), growth in labor productivity; while, on the other hand, it can lead to an increase in economic inequality among the world's countries, and their dependence on the leaders of the global digital market (USA and China) (Benčič S. et al. 2020). The digital economy introduces an additional factor in the formation of competitiveness – access to new technologies and data, which is becoming the driving force behind economic growth and is considered at the level of access to capital and investment (UNCTAD, 2019). Issues concerning the growing digital inequality among countries of the world are investigated by many scientists including R. Bukht, R. Heeks (Bukht & Heeks 2017), S. Benčič, Y. Kitsay, (Benčič et al. 2020), and others. However, the challenges associated with creating the digital economy in developing countries remain unresolved.

Therefore, studying factors which influence the formation and advancement of the digital economy is very relevant under modern conditions. Exploring these factors, many authors emphasize the importance of scientific and technological support for ensuring the advancement of the digital economy (Astakhova, Reshetnyak & Ilchenko, 2019; Grachev & Donichev, 2019; Kyzym et al. 2019; Malyarets et al. 2019; Kuznetsov et al. 2019). International rankings which deal with assessing the level of advancement of the digital economy in individual countries of the world consider scientific support to be one of the key components, e.g., the IMD World Digital Competitiveness Ranking includes the factor of scientific concentration (IMD, 2019). Therefore, more attention should be paid to assessing scientific support for the advancement of the digital economy.

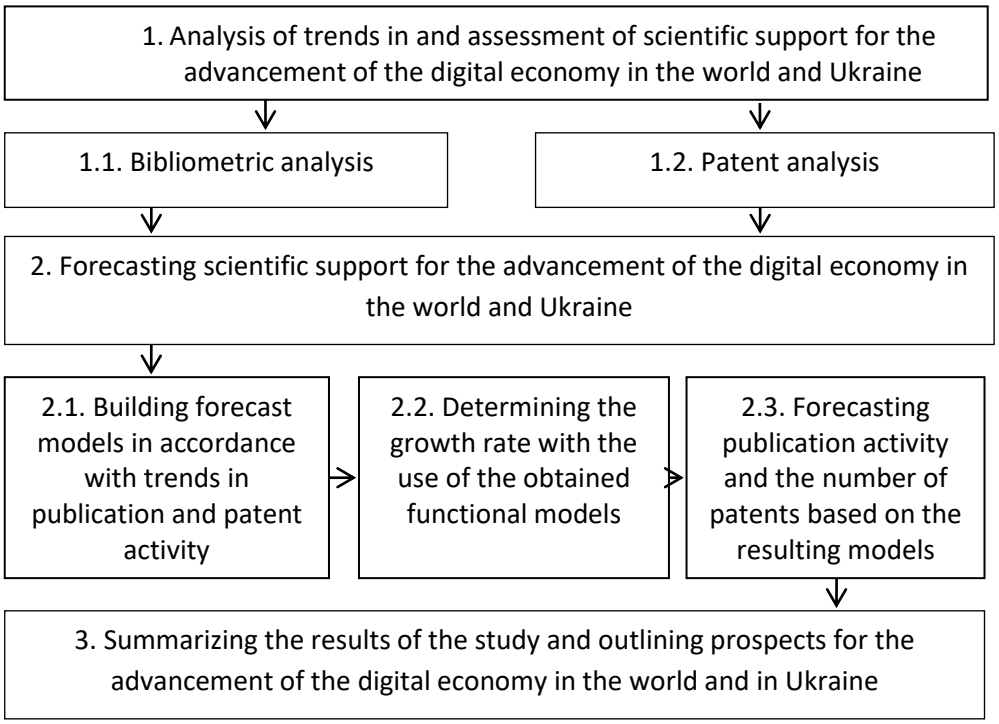
The aim of the study is to forecast scientific support for the advancement of the digital economy in the world and Ukraine.

2. Materials and methods

Results of research activity are evaluated with the help of scientometric analysis, in particular, through estimating the number of scientific publications and patents in the relevant sectors of the economy. The relationship between research and patent activity is noticed by many authors, including M. Meyer (Meyer, 2006). The need for using bibliometric indicators to assess research performance is justified by A. F. Raan (Raan, 1999) and E. A. Korzhavykh (Korzhavykh, 2012). The importance of bibliometric and patent analysis for evaluating research and development activity is emphasized in works of A. Hullmann (Hullmann & Meyer, 2003), S. Hinze, H. Grupp (Hinze & Grupp, 1996). Thus, the leading tools for identifying promising areas of scientific research are bibliometric and patent analysis.

The methodological approach proposed for forecasting scientific support for the advancement of the digital economy is based on bibliometric and patent analysis. The main task of this type of analysis is to compare scientific developments which contribute to the advancement of the digital economy in Ukraine with those in other countries of the world. The main stages of the study are shown in Figure 1.

Fig. 1. Methodological approach to forecasting scientific support for the advancement of the digital economy



Source: own modelling

At the first stage, the level of scientific support for the advancement of the digital economy is analyzed based on comparing publication and patent activity of researchers in the world and Ukraine. The main goal of this stage is to compile a list of the most promising areas of scientific and technical research and determine the degree of scientific development of those related to advancement of the digital economy. The study of publication activity of scientists from countries of the world is carried out using the database of bibliometric indicators of the SCImago Journal & Country Rank portal – Shape of Science – an information visualization project whose aim is to reveal the structure of science (SCImago Journal & Country Rank, 2019). This will allow identifying the most popular subject categories related to advancement of the digital economy in the area of Computer Science. The study of patent activity of scientists is carried out using the data of the World Intellectual Property Organization (WIPO, 2019). At this stage, trends in the number of scientific publications (patents) is analyzed, and the share of the three leading countries, other countries of the world, and Ukraine in the total number of publications (patents) in subject areas related to scientific support for the advancement of the digital economy is calculated by the following formula:

$$\alpha_{ij} = \frac{\sum_{t=2010}^{2018} k_{ij}^{t}}{\sum_{i=1}^{l} \sum_{t=2010}^{2018} k_{ij}^{t}} \quad (1)$$

where α_{ij} is the share of the i^{th} country or group of countries in the global number of scientific publications (patents) in the j^{th} field; k_{ij}^{t} is the number of scientific publications (patents) of the i^{th} country in the global number of scientific publications (patents) in the j^{th} field in the t^{th} year.

The results obtained in the course of the analysis of bibliometric indicators and the number of patents related to advancement of the digital economy will allow to determine the place of Ukraine in the world in terms of scientific achievements and formulate recommendations as to priority

support for R & D by the state and business in various areas associated with scientific support for the digital economy. A comparison of the significance of scientific support for the advancement of the digital economy in the global and Ukrainian scientific field allows identifying the future research priorities for Ukrainian scientists.

The second stage of the methodological approach involves forecasting scientific support for the advancement of the digital economy in the world and Ukraine, based on the construction of approximation functions. The tools for the approximation of dynamic flows of information on publication and patent activity are trend models. As shown by previous studies, the most appropriate are those which are described by polynomial trendlines:

$$f(x) = a_0 + \sum_{n=1}^{m} a_n x^n \tag{2}$$

where $a_0, a_1, \ldots, a_m$ are trendline coefficients, which are calculated using the least squares method. The essence of the least squares polynomial approximation is to find the coefficients at which the model function passes through the points corresponding to the minimum sum of squared deviations of values from the parameters studied, which is described by the formula:

$$\sum_{t=1}^{m} (y_t - f(x_t))^2 \to \min \tag{3}$$

For the purpose of assessing the adequacy of the trend models for forecasting the number of publications and patents, the determination coefficient is used (2):

$$R^2 = 1 - \frac{\sum_{i=1}^{k} (y_i + \tilde{y}_i)}{\sum_{i=1}^{k} (y_i - \bar{y}_i)} \tag{4}$$

where k is the number of observations, y_i is the number of publications (patents) in the field under study, $\bar{y} = \sum_{i=1}^{k} y_i / k$ is the average number of publications (patents) for the research period and $\tilde{y}_i$ is the modeled number of publications (patents).

The further analysis implies using mathematical methods to consider the growth rates of the trends in publication and patent activity, as well as their directions (upward or downward) as derivatives (normal and logarithmic, respectively) of the function describing changes in the studied trends. The growth rate of the obtained functions of the trends in the number of scientific publications and patents in the areas associated with scientific support for the advancement of the digital economy is found as derivatives according to the formula:

$$\nu = f'(x) \tag{5}$$

and the growth rate of the functions – as logarithmic derivatives by the formula:

$$T = \frac{f'(x)}{f(x)} \tag{6}$$

The next step of the second stage of the study is using the obtained models to forecast publication and patent activity in the areas related to scientific support for the advancement of the digital economy for the three leaders, other countries of the world except the three leaders, and Ukraine.

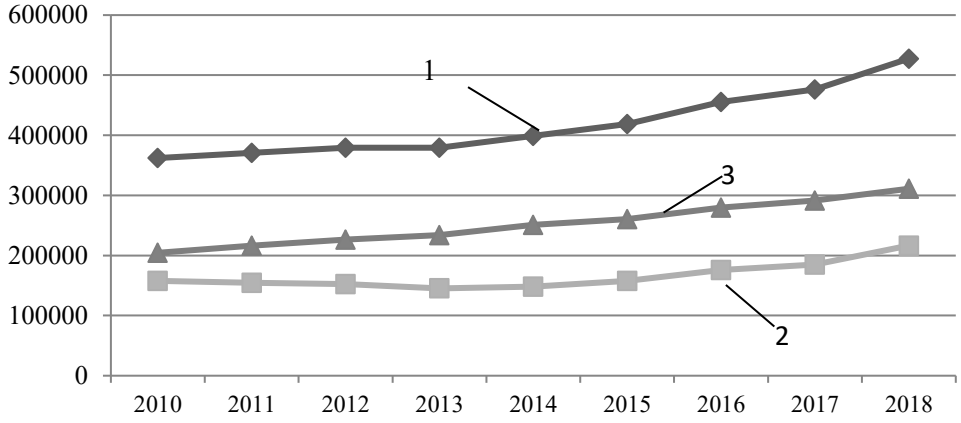
The third stage of the proposed methodological approach involves summarizing the results of the study and outlining prospects for the advancement of the digital economy in the world and in Ukraine.

Thus, the final conclusion as to prospects for the advancement of the digital economy is based on the generalized assessment of the level of world and domestic scientific support.

3. Results and discussion

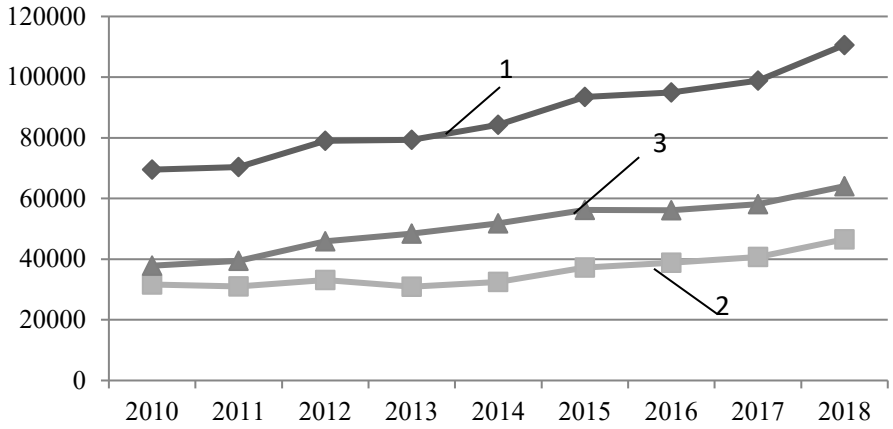
According to the proposed methodological approach for forecasting scientific support for the advancement of the digital economy (Fig. 1), at the first stage, an analysis of the degree of scientific support for the advancement of the digital economy, based on a comparison of publication and patent activity of researchers in the world and Ukraine, was carried out. As can be seen from Figure 2, the number of scientific publications in the subject area of Computer Science for the period of 2010-2018 increases. The share of the top 3 countries amounts to 43.55 % in 2010, 37.19 % in 2014 and 41.04 % in 2018. Compared with the leading countries, Ukraine's share in scientific publications in the area of Computer Science is small, but it increases from 0.33 % in 2010 to 0.55 % in 2018. A similar trend is observed in the following subject categories: Artificial Intelligence (the share of the top 3 countries amounts to more than 42 % in 2018, the share of Ukraine – 0.03 % in 2010 and 0.16 % in 2018 (Fig. 3)); Computer Graphics and Computer-Aided Design (the share of the top 3 countries amounts to about 47 % in 2018, the share of Ukraine – 0.01 % in 2010 and 0.16 % in 2018); Computer Networks and Communications (the share of the top 3 countries amounts to over 38 % in 2018, the share of Ukraine – 3.03 % in 2010 and 2.84 % in 2018), Computer Vision and Pattern Recognition (the share of the top 3 countries amounts to over 40 % in 2018, the share of Ukraine – 0.1 % in 2010 and 0.28 % in 2018), Human-Computer Interaction (the share of the top 3 countries amounts to over 43 % in 2018, the share of Ukraine – 0.02 %).

Fig. 2 Trends in the number of scientific publications in Computer Science, where 1 – the global number of publications , 2 – the number of publications of the top 3 countries, 3 – the number of publications of other countries



Source: developed based on (SCImago Journal & Country Rank, 2019)

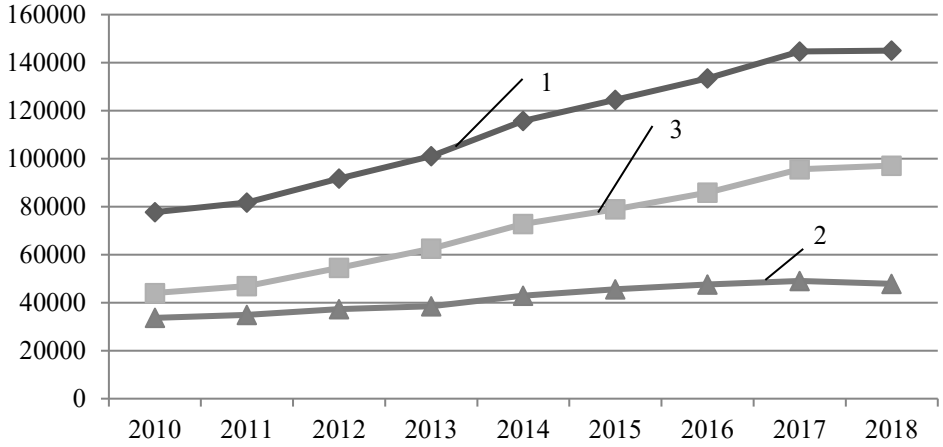
Fig. 3 Trends in the number of scientific publications in Artificial Intelligence, where 1 – the global number of publications, 2 – the number of publications of the top 3 countries, 3 – the number of publications of other countries



Source: developed based on (SCImago Journal & Country Rank, 2019)

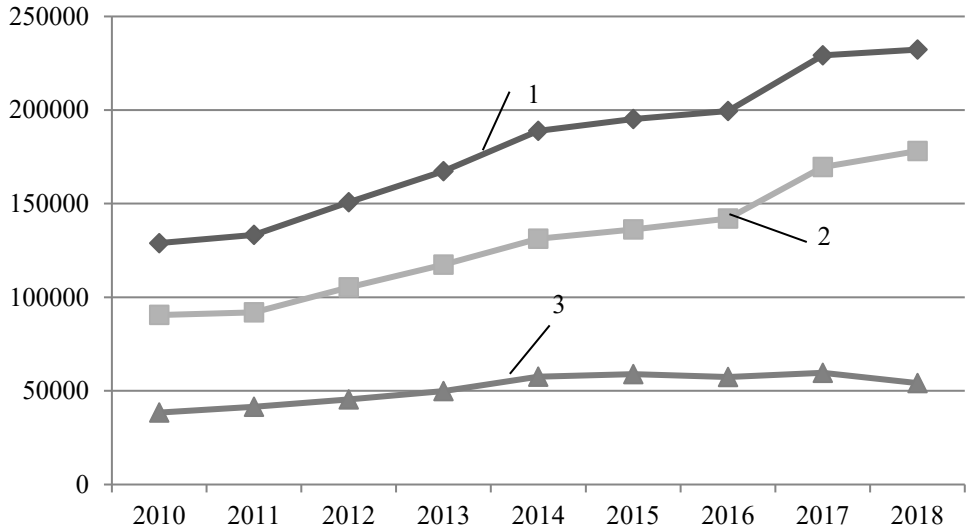
The analysis of the global number of patents related to the advancement of the digital economy, namely, in the field of Digital Communication and Computer Technology, indicates its gradual growth (Fig. 4 and Fig. 5). It should be mentioned that the majority of the global patents related to the advancement of the digital economy belong to the top 3 countries (China, the USA and Japan), and in the field of Digital Communication amounts to 56.67% in 2010 and 66.9% in 2018; in the field of Computer Technology – 70.19% in 2010 and 76.68% in 2018. The increase in the share of leading countries is mainly due to Chinese patents. The share of Ukraine in the global number of patents is very small and tends to decrease: in the field of Digital Communication it amounts to 0.24% in 2010 and 0.03% in 2018; in the field of Computer Technology – 0.11% in 2010 and 0.09% in 2018.

Fig. 4 Trends in the number of patents in the field of a) Digital Communication, b) Computer Technology, where 1 – the global number of publications, 2 – the number of publications of the top 3 countries, 3 – the number of publications of other countries



Source: developed based on (WIPO, 2019)

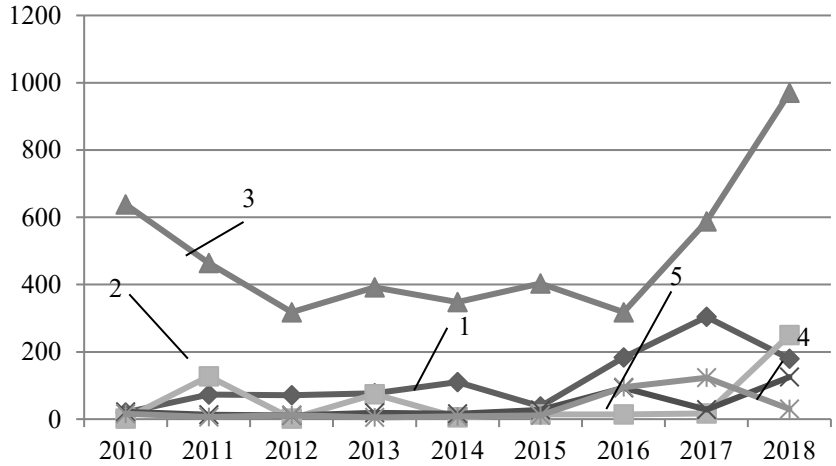
Fig. 5 Trends in the number of patents in the field of a) Digital Communication, b) Computer Technology, where 1 – the global number of publications, 2 – the number of publications of the top 3 countries, 3 – the number of publications of other countries



Source: developed based on (WIPO, 2019)

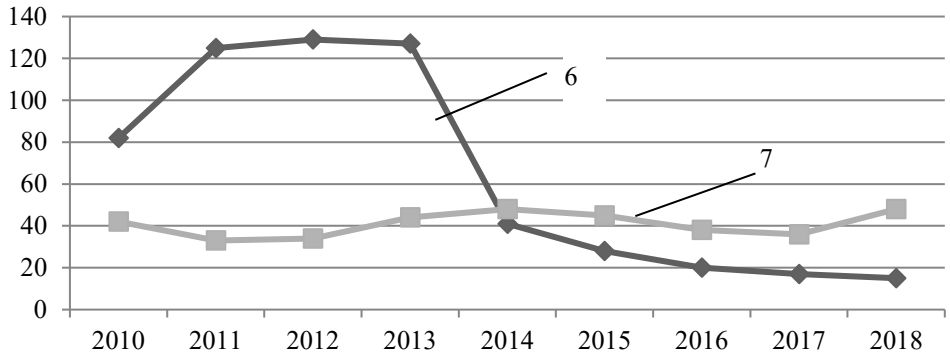
In general, the analysis of the trends in scientific support for the advancement of the digital economy in Ukraine demonstrates that it is unstable, prone to jumping and falling, which complicates the forecasting (Fig. 6, Fig. 7).

Fig. 6 Trends in the number of a) scientific publications in Ukraine, b) patents in Ukraine, where 1 – Artificial Intelligence, 2 – Computer Graphics and Computer-Aided Design, 3 – Computer Networks and Communications, 4 – Computer Vision and Pattern Recognition, 5 – Human-Computer Interaction, 6 – Digital Communication, 7 – Computer Technology



Source: developed based on (SCImago Journal & Country Rank, 2019; WIPO, 2019)

Fig. 7 Trends in the number of a) scientific publications in Ukraine, b) patents in Ukraine, where 1 – Artificial Intelligence, 2 – Computer Graphics and Computer-Aided Design, 3 – Computer Networks and Communications, 4 – Computer Vision and Pattern Recognition, 5 – Human-Computer Interaction, 6 – Digital Communication, 7 – Computer Technology



Source: developed based on (SCImago Journal & Country Rank, 2019; WIPO, 2019)

At the second stage of the study, in accordance with the methodological approach (Fig. 1), models for forecasting publication activity (Tbl. 1) and the number of patents (Tbl. 2) were constructed; the adequacy of the obtained models was assessed with the use of R^2 criterion; the growth rates were determined based on the obtained functional models; the publication activity and the number of patents for the obtained models were forecasted.

The 2nd order polynomial function turned out to be the most adequate for analyzing the trends in publication activity and forecasting it. To assess the adequacy of the obtained forecast models, the determination coefficients were calculated. The values found indicate the adequacy of the obtained models for forecasting the number of publications by the subject areas/categories (R^2 from 0.848 to 0.9913) in the world and top 3 countries. However, the agreement of the models describing the trends in publication activity of Ukrainian scientists in the subject categories of Artificial Intelligence (R^2 = 0.6176), Computer Vision and Pattern Recognition (R^2 = 0.6634) with the actual data is only 61%, 66% respectively; the agreement of the obtained models for the subject categories of Computer Graphics and Computer-Aided Design (R^2 = 0.3724), Human-Computer Interaction (R^2 = 0.3845) with the actual data is only 37%, 38%, which makes it impossible to speak of reliability of the forecast results.

Table 1. Forecasting publication activity by subject areas in the world and Ukraine

Subject area	Country/group of counties	Model	Coefficient of determination, R^2	Growth rate of the trend function, T	Forecast		
					2020	2021	2022
Publications by all subject categories in the area of Computer Science	World	$y = 2832.6x^2 - 8832.8x + 373238$	0.9913	$\frac{5662.2x - 8832.8}{2832.6x^2 - 8832.8x + 373238}$	568170	618821	675138
	Top 3 countries	$y = 2279.4x^2 - 16394x + 175770$	0.9714	$\frac{4558.8x - 16394}{2279.4x^2 - 16394x + 175770}$	239770	271243	307275
	Ukraine	$y = 61.652x^2 - 410.85x + 1693.5$	0.9411	$\frac{123.304x - 410.85}{61.652x^2 - 410.85x + 1693.}$	3750	4634	5641
Artificial Intelligence	World	$y = 229.95x^2 + 2631.8x + 66267$	0.974	$\frac{459.9x + 2631.8}{229.95x^2 + 2631.8x + 66267}$	115580	123040	130961
	Top 3 countries	$y = 332.15x^2 - 1546.2x + 33054$	0.9554	$\frac{664.3x - 1546.2}{332.15x^2 - 1546.2x + 33054}$	50807	56235	62329
	Ukraine	$y = 2.2208x^2 + 3.0922x + 31.548$	0.6176	$\frac{4.4416x + 3.0922}{2.2208x^2 + 3.0922x + 31.548}$	284	334	388
Computer Graphics and Computer-Aided Design	World	$y = 521.02x^2 - 1054.2x + 24551$	0.9357	$\frac{1041.04x - 1054.2}{521.02x^2 - 1054.2x + 24551}$	66111	75998	86927
	Top 3 countries	$y = 363.48x^2 - 1638.4x + 11497$	0.9692	$\frac{726.96x - 1638.4}{363.48x^2 - 1638.4x + 11497}$	31461	37455	44177
	Ukraine	$y = 6.8615x^2 - 58.181x + 129.74$	0.3724	$\frac{13.723x - 58.181}{6.8615x^2 - 58.181x + 129.74}$	234	319	419
Computer Networks and Communications	World	$y = 176.67x^2 + 39.651x + 20743$	0.9547	$\frac{353.34x + 39.651}{176.67x^2 + 39.651x + 20743}$	38806	42556	46659
	Top 3 countries	$y = 116.15x^2 - 557.14x + 8932.9$	0.9245	$\frac{232.3x - 557.14}{116.15x^2 - 557.14x + 8932.9}$	14976	16858	18972
	Ukraine	$y = 29.031x^2 - 261.8x + 882.88$	0.859	$\frac{58.062x - 261.8}{29.031x^2 - 261.8x + 882.88}$	1167	1515	1921
Computer Vision and Pattern Recognition	World	$y = 546.02x^2 - 3220.2x + 28877$	0.8897	$\frac{1092.04x - 3220.2}{546.02x^2 - 3220.2x + 28877}$	51277	59523	68861
	Top 3 countries	$y = 303.47x^2 - 2328.8x + 13650$	0.848	$\frac{606.94x - 2328.8}{303.47x^2 - 2328.8x + 13650}$	20709	24753	29404

	Ukraine	$y = 2.6721x^2 - 16.237x + 35.905$	0.6634	$\frac{5.3442x - 16.237}{2.6721x^2 - 16.237x + 35.905}$	141	181	226
Human-Computer Interaction	World	$y = 1796x^2 - 7057.5x + 81472$	0.9476	$\frac{3592x - 70757.5}{1796x^2 - 7057.5x + 81472}$	190497	221156	255406
	Top 3 countries	$y = 1078.2x^2 - 6068x + 37532$	0.9451	$\frac{2156.4x - 6068}{1078.2x^2 - 6068x + 37532}$	107820	130462	155261
	Ukraine	$y = 0.9773x^2 - 0.1227x + 3.6667$	0.3845	$\frac{1.9546x - 0.1227}{0.9773x^2 - 0.1227x + 3.6667}$	98	118	141

Source: developed based on (SCImago Journal & Country Rank, 2019)

Table 2. Forecasting patent activity by field of technology in the world's countries and Ukraine

Field of technology	Country/ group of countries	Model	Coefficient of determination, R^2	Growth rate of the trend function, T	Forecast		
					2020	2021	2022
Digital Communication	World	$y = -140.52x^2 + 10818x + 63197$	0.9854	$\frac{-281.04x + 10818}{-140.52x^2 + 10818x + 63197}$	157325	165192	172778
	Top 3 countries	$y = -37.282x^2 + 7671.9x + 33733$	0.989	$\frac{-74.564x + 7671.9}{-37.282x^2 + 7671.9x + 33733}$	106724	113613	120427
	Ukraine	$y = -1.0141x^2 - 5.0093x + 122.05$	0.6838	$\frac{-2.0282x - 5.0093}{-1.0141x^2 - 5.0093x + 122.05}$	9	6	4
Computer Technology	World	$y = -486.45x^2 + 18517x + 116166$	0.9764	$\frac{-972.9x + 18517}{-486.45x^2 + 18517x + 116166}$	252691	260993	268321
	Top 3 countries	$y = 291.15x^2 + 9331x + 84572$	0.9758	$\frac{5662.2x - 8832.8}{291.15x^2 + 9331x + 84572}$	206997	222442	238470
	Ukraine	$y = 0.2348x^4 - 3.8586x^3 + 20.114x^2 - 34.507x + 50.714$	0.9862	$\frac{0.9392x^3 - 11.5758x^2 + 40.228x - 34.507}{0.2348x^4 - 3.8586x^3 + 20.114x^2 - 34.507x + 50.714}$	206	407	734

Source: developed based on (WIPO, 2019)

The 2nd order polynomial function, which allows forecasting patent activity with a high degree of reliability, using the obtained values of the determination coefficient, turned out to be the most adequate for analyzing the trends in and forecasting the number of patents by the fields of technology in the world and the top 3 countries. However, in case of Ukraine, the resulting models are less reliable: Digital Communication (R^2 = 0.6838). To forecast the number of domestic patents in the field of Computer Technology, a 4th order polynomial model with R^2 = 0.9862 was obtained but such models provide the possibility only for short-term forecasting.

Thus, the forecasting results indicate an upward trend in patent and publication activity aimed to ensure the advancement of the digital economy in the world in the coming years. At the same time, if the current situation persists, the share of Ukraine in the global number of patents and publications will remain extremely low.

4. Conclusion

Thus, the need to enhance scientific support for the advancement of the digital economy in countries of the world in order to prevent the widening of the gap between the digitalization level of developed and developing economies is justified. A methodological approach for forecasting scientific support for the advancement of the digital economy based on bibliometric and patent analyzes is proposed. The forecast models obtained allow forecasting publication and patent activity of scientists in areas related to the digitalization of the economy. Table 1 shows the results of the forecast of publication activity in the world, the top three countries and Ukraine. The growth of publication activity in the leading countries and the world in general, according to the proposed models, is expected to be higher than in Ukraine. The forecast demonstrates that the inequality in the level of scientific support for the advancement of the digital economy between leading countries of the world and Ukraine will increase in the near future if immediate measures to stimulate own researches in the field of digital technologies are not taken at the state level. Stimulation of domestic scientific developments in the field of digital technologies at the state level must begin with an increase in state funding in this area, as well as with the introduction of tax incentives for enterprises that link innovation activities with the introduction of these technologies.

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