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IS THERE ANY CHANCE FOR UKRAINIAN RESEARCHES IN NANOSCIENCE?

Abstract
The article is devoted to revealing the peculiarities of Ukrainian researches in nanoscience and nanotechnology. The comparative analysis of publications, patents and R&D resources in Ukraine and developed countries has been performed. It is shown that the tendency in Ukrainian researches in nanoscience and nanotechnology corresponds to the global trend. But the share of researches in nanomedicine in Ukraine is significantly larger than that of the global ones, while the share of nanoelectronics is too small. The built models allow forecasting the number and share of publications in different branches and demonstrating the gap between Ukraine and other countries.

Key words
nanoscience, publication, patents, trends, forecast

Introduction

Nowadays nanotechnologies are becoming one of the major fields of science and technology in the world, a kind of mainstream for social progress in general. Developed countries are investing huge funds into scientific researches in the sphere. The transition to nanotechnologies, which means a creation of any material with a predetermined atomic structure, provides the most important result — dematerialization of production and a dramatic reduction of power and specific resource consumption. Nanotechnologies are already affecting and can fundamentally change electricity, energy, medicine and many other sectors of economies in the world. There is a problem of assessing the impact of nanotechnology on the development of different economic sectors, as well as mechanisms for state support of this direction in innovative economic development around the world. A few studies concerning the development of nanotechnologies in Ukraine have been done in the recent years [1], [2]. However, they cover a short time period and don't use such an important technique for receiving an objective assessment of Ukrainian and global tendencies as comparative analysis.

Ukraine, on the one hand, has an extensive network of research organizations, fundamental studies on relevant areas of researches, personnel with a high level of qualification, as it is justified by the demand for it in global weight factor. On the other hand, the research results in most cases do not reach the stage of commercialization. Research organizations do not have the financial capacity to build prototypes and ensure protection of the intellectual property rights, and business is not interested in implementation of innovative projects. A similar situation is observed in researches in the field of nanotechnologies.

The main aim of the study is to reveal the common features and peculiarities of R&D in Ukraine and to determine the perspective ways of developing nanotechnologies in Ukraine.

For the purpose we studied the publications of researchers in some developed countries and in Ukraine for the period of 1996—2014 in the field of nanoscience and nanotechnologies in general and in some individual spheres, such as:

- nanomaterials;
- nanoelectronics;
- nanomedicine;

- nanobiotechnology;
- nanotechnology in the energy sector;
- nanotribology.

Then we studied the dynamics of patent publications in nanotechnologies in different countries to determine the possibility for commercialization of nanotechnologies.

Materials and methods

Official statistical data of state institutions and international organizations, publications of a reference character, analytical monographs, annual statistical bulletins, Ukrainian State Statistical Bureau reports serve as an information basis for our research. Abstract database resources "Science Direct", "SCImago Journal & Country Rank", "Ukrainika Naukova" (Ukrainika Scientific), Scientific Electronic Library, Russian National Public Library for Science and Technology made up the information database of publication activities. The level of the R&D patenting in nanotechnologies was analysed by the data of Intellectual Property Organization, State Intellectual Property Service of Ukraine, a specialized database "Inventions (Utility Models) in Ukraine". Models of time series, including trend analysis, were used for forecasting.

Analysis of publication activity

The review of publication activity in the field of nanoscience and nanotechnologies based on Science Direct database 0 proves that the USA, China, Japan, Germany and South Korea are the leading countries in the sphere. The total share of these countries in all publications for the period of 1996—2014 was 54.1 %. The EU countries' share made up 28.1 %, while Ukraine had only 0.3 %. At the same time the indicators of 11 EU countries were even lower in comparison with Ukraine. China is on the top of the list during the past two years, while the USA started to lag behind in the recent 3 years.

Table 1 shows the dynamics in the number of publications in the countries. It demonstrates that globally and in separate countries the number of publications did not decrease except for Japan, where the number of publications was lower than in 2012. It proves the existence of constant interest to R&D work and inventions in this sphere.

Table 1. The number of publications in the subject category "Nanoscience and nanotechnologies" globally and in the leading world countries

Country	Years																		
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
WORLD	3299	3575	4259	3959	4527	5549	5465	6720	8173	9569	11331	15533	18487	19839	22589	26495	27685	29439	32042
China[1]	132	184	164	213	288	340	358	654	717	1074	1740	2425	3355	3713	4575	5450	6333	7977	9317
USA	1018	866	1254	1147	1274	1396	1522	1893	2289	2834	3239	4202	4936	5245	6173	6647	6875	7024	7393
Germany	413	468	511	446	544	652	723	644	856	810	970	1317	1454	1466	1711	1861	1918	1940	2096
South Korea	77	123	188	159	178	270	251	455	467	606	702	1021	1325	1330	1598	2461	2436	2741	2918
Japan	446	470	499	486	617	838	669	903	1021	1073	1216	1418	1476	1671	1633	1774	1826	1741	1781
Russia	75	158	264	135	259	391	106	199	217	151	190	341	467	508	577	571	712	627	698
Poland	37	58	34	40	64	65	57	68	131	82	112	158	184	155	168	191	247	255	262
Ukraine	13	40	52	49	42	49	38	47	51	61	56	55	88	57	76	72	110	106	133

[1] – except for Hong Kong. It also concerns the following tables.

Source: 0

The results shown in Table 2 prove that researches in nanoscience are attracting more attention. As we can see the share of publications in nanoscience in total publications increased in all countries. China demonstrates the largest annual growth rate of the share (near 12 %), Korea's rate is 10.5 % and Ukraine's rate is 6.9 %, while Poland has the lowest rate of 1.4 %. Judging from the largest share of publications, the researches in Korea are mostly concentrated at nanotechnology. So, we can assume that Korea has the highest effectiveness of researches in the sphere of nanoscience and nanotechnology. The smallest share is observed in Poland at the

end of the period and it did not vary much. Ukrainian scientists are more "mobile" in the scientific area than Polish researchers and they can react to the global trends more quickly.

Table 2. The share of publications in the category "Nanoscience and nanotechnologies" in the total number of publications (in percentage terms)

Country	Years										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
China	0.66	0.67	0.92	1.13	1.33	1.24	1.36	1.41	1.57	1.82	2.06
United States	0.53	0.59	0.64	0,84	0.96	0.96	1.07	1.12	1.12	1.16	1.34
Germany	0.82	0.68	0.78	1.03	1.10	1.05	1.17	1.22	1.21	1.23	1.40
South Korea	1.49	1.64	1.64	2.18	2.62	2.47	2.66	3.74	3.47	3.77	4.04
Japan	0.95	0.89	0.99	1.20	1.25	1.35	1.31	1.39	1.42	1.36	1.55
Russia	0.60	0.39	0.54	0.96	1.27	1.33	1.46	1.33	1.62	1.35	1.38
Poland	0.63	0.35	0.44	0.62	0.66	0.54	0.56	0.60	0.71	0.70	0.73
Ukraine	0.73	0.83	0.84	0.81	1.23	0.81	1.01	0.87	1.20	1.11	1.44

Source: Author's

Basing on the dynamics of publications presented in Table 1, we tried to forecast the publication activities in the world with the help of time series models. Exponential, logarithmic, logistic, linear and quadratic models were tested. The best models built for each country and the global trend are presented in Table 3. Only China, Germany and Poland have an exponential growth in the number of publications, but China's growth rate is twice larger than that of the others. The growth rates of publications in the USA, Japan, Korea and Russia are logistic ones tending to the limits. That is why the growth of the global publication activity in the sphere of nanotechnology is logistic, too. Ukraine's trend corresponds to the quadratic function, which is worse than the exponential but better than the logistic one. This fact brings some hope for developing researches in the sphere.

Table 3. The models for forecasting publication activities in the world countries in the category "Nanoscience and nanotechnologies"

Country	Model, R^2
World countries	$Y_{world}(t) = \frac{1572.09}{0.033213 + e^{-0.21857t}}$, $R^2 = 0.99$, mape=6.9 %
China	$Y_{China}(t) = 183.993\ e^{0.20871t}$, $R^2 = 0.98$, mape=23.9 %
USA	$Y_{USA}(t) = \frac{409.864}{0.043228 + e^{-0.23982t}}$, $R^2 = 0.986$, mape=8.5 %
Germany	$Y_{Germany}(t) = 373.171\ e^{0.095t}$, $R^2 = 0.97$, mape=6.5 %
Japan	$Y_{Japan}(t) = \frac{332.838}{0.15707 + e^{-0.20116t}}$, $R^2 = 0.97$, mape=5.1 %
South Korea	$Y_{Korea}(t) = \frac{49.184}{0.010532 + e^{-0.27132t}}$, $R^2 = 0.99$, mape=8.6 %
Russia	$Y_{Russia}(t) = \frac{14.8761}{0.017837 + e^{-0.30757t}}$, $R^2 = 0.87$, mape=24.8 %
Poland	$Y_{Poland}(t) = 31.876\ e^{0.1159t}$, $R^2 = 0.92$, mape=11.5 %
Ukraine	$Y_{Ukraine}(t) = 0.2881t^2 - 1.3331t + 38.767$, $R^2 = 0.82$, mape=12.3 %

t = 1 corresponds to 1996

Source: Author's

Table 4 shows the forecasting results by the built models for emergence of new publications within the next three years globally and in separate countries. The largest share of scientific publications is observed in China, it makes up more than half of the total amount. The growth in number of publications in Russia, Poland, Ukraine and even Japan is slow. It should be noticed that the analysis was based on the data from Science

Direct 0, so publications in national journals not indexed in the SJR were not taken into account. It is a significant limitation for Ukraine because there are only a few indexed national journals. Despite of this fact, the total number of Ukrainian publications in 2015-2017 will be by 18 % larger than that in the recent three years, while the total number of Polish publications will grow by 1.4 times.

Table 4. Forecast of publishing activities in the world countries in the subject category "Nanoscience and nanotechnologies"

Country	Years		
	2015	2016	2017
World countries	34 290	36 252	37 998
China	11 958	14 733	18 152
USA	7 960	8 242	8 479
Germany	2 489	2 737	3 009
South Korea	3 294	3 542	3 758
Japan	1 917	1 954	1 985
Russia	745	767	783
Poland	324	363	408
Ukraine	127	138	149

Source: Author's

One of the most urgent and biggest problems of Ukrainian science are poor financial resources. That is why we tried to understand the dependency. The relationship between the R&D expenditure [4], [5] and the number of scientific publications in the chosen countries is presented in Figure 1. As one can see there is a controversial dependence. The USA, Germany, Korea and Japan have a higher level of expenditure but the number of publications per 1000 researchers is higher only in the USA and Germany. Moreover, the indicators of publication activity differ significantly among the three leading countries despite the same expenditure level. On the other hand, Poland demonstrates rising in the number of publications, while the level of R&D expenditure is increasing very slowly. A special case is China. Because of the extremely large population and the largest number of researchers but the smallest share of researches, China demonstrates average relative results at the largest absolute ones. So the level of R&D expenditure does not completely determine the publication activity of researchers, but the extremely low level of expenditure (as in Ukraine and Russia) leads to extremely poor results.

We studied the publication activity in the main sphere of nanotechnologies R&D according to the purpose. The distribution was studied basing on the DB Science Direct 0, "Ukrainika Naukova" [1], Russian Electronic Library [7], [8]. It is worth mentioning, that the data for 2014 as well as partially the data for 2013 could not be considered the final ones, as there is a big lag between the publication and its entering the abstract DB.

The general results show that the largest share of scientific publications is devoted to nanomaterials both globally (47.3 %) and in Ukraine (51.5 %) and Russia (33.7 %). Application of nanotechnologies in medicine against the rest of nano-areas has not gained the leading importance globally and in Russia yet. The same is true concerning nanotribology. A specific feature of Ukrainian nano-research is a comparatively high share of R&D in the spheres of nanobiotechnologies and nanomedicine. It brings a hope to develop new methods in solving health care problems, providing food products safety and improving agricultural production in Ukraine. With regard to the problem of global population ageing and national provision for safe food products, these spheres are promising for commercialization both globally and in Ukraine. But the nanoelectronics' share is very low, and this fact is a matter of concern as the high technology industry based on nanoelectronics is losing scientific support in Ukraine.

To assess the future situation we have built the models of trends in the number of scientific publications both globally and in Ukraine and Russia. They are presented in Table 5. The best models were obtained for the global trends. All of them are exponential ones with quite a high growth rate. The rate of nanotechnology in the energy sector is the greatest and that of nanomaterials is the lowest. The best model was built for number

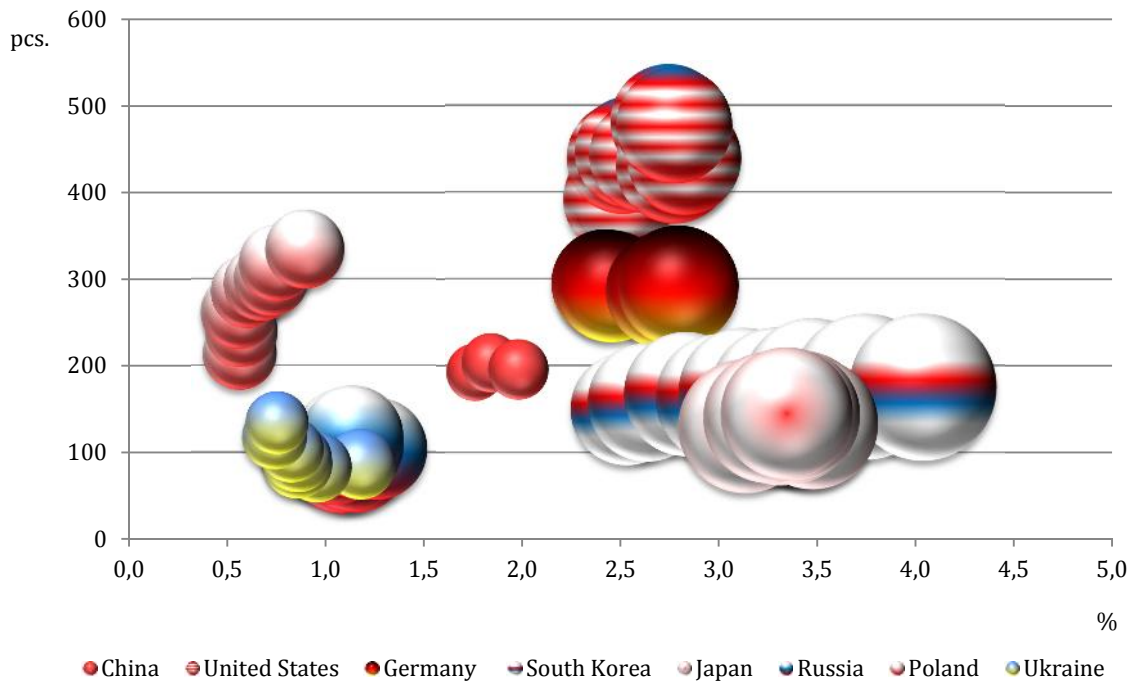

Fig. 1. The number of publications per 1000 researchers vs. total intramural R&D expenditure as a percentage of Gross Domestic Product. The size of the bubble reflects the number of researchers in R&D (per million people)
Source: Author's

of publications in nanobiotechnologies and nanomedicine In Ukraine. The number of publications concerning nanomaterials varies strongly, there is no model for this sphere as well as for nanotribology and nanotechnology in the energy sector in Russia. The model for Ukrainian publications in nanotribology is doubtful because of the small coefficient of determination. Low accuracy of the predicted values for the Ukraine and Russia (mape) is explained by volatile dynamics and small numbers, especially in Ukraine. However the forecast allows us to see the general trend. The common feature in the models for Ukrainian nano-research is a low growth rate. The models for the four spheres of nanotechnologies R&D in Russia are logarithmic ones, so the growth in these spheres slows down.

Table 5. Models for forecasting trends in the number of publications by the spheres of nanotechnologies R&D.

Sphere of nanotechno-logies R&D	**Models for forecasting the number of scientific publications**		
	Globally	**In Ukraine**	**In Russia**
Nanomaterials	$y=2353.74*e^{0.105871t}$, $R^2=0.98$, mape=3.7 %	Random (100; 160)	y = -473.77+223.94*LN(t), $R^2=0.88$, mape=17.0 %
Nanoelectronics	$y=1034.78*e^{0.130405t}$, $R^2=0.99$, mape=2.8 %	$y = 2.1947*e^{0.142571*t}$, $R^2=0.74$, mape=22. 1%	y = -297.107+151.18*LN(t) $R^2=0.72$, mape=27.4 %
Nanobiotechno-logies	$y=303.361*e^{0.163925*t}$, $R^2=0.98$, mape=10.4 %	$Y(t) = \frac{0.25759}{0.001448 + e^{-0.385t}}$, $R^2=0.95$, mape=23.2 %	y = -308.162+141.857*LN(t), $R^2=0.88$, mape=27.8 %
Nanomedicine	$y=21.7361*e^{0.155316*t}$, $R^2=0.96$, mape=11.4 %	$y = -49.8+5.733*t$, $R^2=0.95$, mape=24.4 %	y = -62.545+6.6182*t, $R^2=0.85$, mape=36.1 % (exclude 2004, 2006)
Nanotechnology in the energy sector	$y=99.1287*e^{0.181985*t}$, $R^2=0.97$, mape=9.5 %	$y = -6.459+0.8243*t$, $R^2=0.71$, mape=37.0 % (exclude 2011, 2014)	Random (15;60)
Nanotribology	$y=17.5268*e^{0.117786*t}$, $R^2=0.88$, mape=10.5 %	$y = 1.567*e^{0.109*t}$, $R^2=0.58$, mape=21.0 %	Random (2;10)

Source: Author's

With the help of building the models we forecasted the number of new publications in the spheres. During the next three years the total number of the publications in all the studied areas would exceed the volumes of the publications in the recent three years by 1.5 times. And R&D in nanobiotechnologies, nanomedicine and nanotechnology in the energy sector have the largest share increase in the global process (Table 6), while the share of nanomaterials decreases. In Ukraine there observed the same tends for all the spheres except for nanoelectronics. And during the next three years the nanobiotechnology's share will be the largest. However, the growth rates of the total number of publications and those in the four spheres are lower than in whole in the world. The deviations from the global weight factors for R&D in Russia are not significant except for nanomaterials but the growth rate is larger. So the distribution of R&D in Russia among the spheres corresponds to the global trends.

Table 6. Forecast of new publications emergence by the spheres of nanotechnologies R&D

Years	Spheres of nanotechnologies						
	Nano-materials	**Nano-electronics**	**Nano-biotechnologies**	**Nano-medicine**	**Nanotechnology in the energy sector**	**Nano-tribology**	**Total publica-tions**
Globally							
2015	19 559	14 045	8 050	486	3 775	185	46 099
2016	21 743	16 002	9 484	567	4 528	208	52 532
2017	24 171	18 231	11 173	662	5 432	234	59 904
Forecasted weight factor for the sphere	41.3	30.5	18.1	1.1	8.7	0.4	
Ukraine							
2015	112	38	136	65	10	14	374
2016	113	44	147	71	11	15	400
2017	148	51	155	76	12	17	459
Forecasted weight factor for the sphere	30.2	10.7	35.5	17.2	2.6	3.8	
Deviation from the global weight factor	-11.1	-19.8	17.4	16.1	-6.1	3.4	
Deviation from the global growth rate	-0.09	0.03	-0.01	0.03	-0.14	-0.01	-0.06
Russia							
2015	197	156	117	70	48	9	597
2016	208	163	124	76	32	5	608
2017	218	170	130	83	32	7	641
Forecasted weight factor for the sphere	33.8	26.5	20.1	12.4	6.1	1.1	
Deviation from the global weight factor	-11.3	-1.3	3.7	9.4	-1.2	0.6	
Deviation from the global growth rate	0.14	0.06	0.08	0.17	0.21	-0.09	0.11

Source: Author's

Our analysis shows some perspectives for Ukrainian researches in nanoscience and nanotechnology. The biggest advantage is to focus the attention of business on researches in the sphere of nanomedicine and nanobiotechnology, while the state grants should support fundamental and applied researches in nanoelectronics and nanotechnology in the energy sector.

Analysis of patents publication

The next step was the assessment of patent activity in nanotechnologies. Only a few countries including China, the USA, South Korea, Japan and Germany are the undoubted leaders in terms of this indicator in recent years.

They have 80 % of the total number of published applications in the sphere of micro-structural and nanotechnology 0. The annual number of published patents in Ukraine is extremely small in comparison with that in Poland (Table 7).

Table 7. Total number of patent publications in the sphere of micro-structural and nanotechnology by the applicant's origin

Country	Years										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
China	47	105	154	200	269	301	540	698	1207	1260	1510
USA	654	549	477	496	543	549	530	530	677	655	695
Germany	216	223	223	240	243	323	301	301	311	307	373
South Korea	203	233	308	440	416	610	761	619	452	454	387
Japan	575	676	620	679	612	617	482	475	459	446	473
Russia	8	7	10	28	69	139	202	220	213	251	201
Poland	1	2	2	2	7	8	4	12	14	23	21
Ukraine	2	1	1	1	4	1	1	3	5	18	8

Source: [9], [0], [11]

The consideration of relative indicators of patent activity shows at first sight positive features for Ukraine concerning the patents in the sphere of nanotechnology (Table 8). Unfortunately, the comparison is made against the overall low patent activity across all technologies.

Table 8. The share of patent publications in the sphere of micro-structural and nanotechnology in the total number of patent publications by the applicant's origin (in percentage terms)

Country	Years										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
China	0.10	0.14	0.16	0.17	0.17	0.16	0.23	0.25	0.28	0.24	0.23
United States of America	0.17	0.14	0.12	0.13	0.13	0.14	0.14	0.14	0.17	0.15	0.15
Germany	0.13	0.13	0.13	0.14	0.14	0.18	0.17	0.17	0.17	0.17	0.21
South Korea	0.18	0.16	0.18	0.25	0.27	0.39	0.47	0.37	0.26	0.24	0.21
Japan	0.11	0.13	0.12	0.14	0.13	0.13	0.10	0.11	0.10	0.09	0.11
Russia	0.03	0.02	0.04	0.11	0.22	0.43	0.70	0.75	0.70	0.81	0.77
Poland	0.04	0.07	0.08	0.08	0.27	0.29	0.12	0.34	0.30	0.40	0.34
Ukraine	0.02	0.04	0.06	0.04	0.13	0.04	0.04	0.13	0.23	0.74	0.67

Source: Author's

The results of studying the relation between patent publications and R&D expenditure are quite different from the previous comparison. As we can see in Figure 2, there is almost linear dependence except for the unstable case of Korea. The lowest level of financial support to R&D in Ukraine and Poland results in the poor patent publication activity. The largest number of patents is demonstrated by Japan and Korea. This fact allows concluding that these countries conduct more applied researches and there are more close links between science (universities, research centres) and business (enterprises, TNCs). Financial capability is crucial for making such a background for commercialisation as a sufficient number of patents.

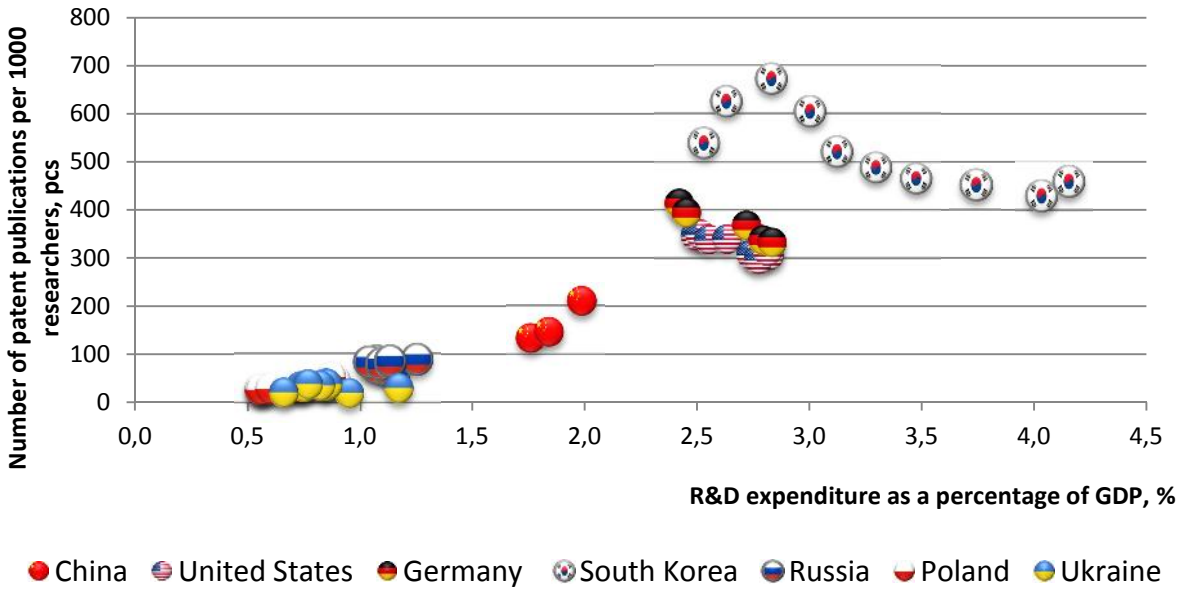

Fig. 2. The number of patent publications per 1000 researchers vs. total intramural R&D expenditure as a percentage of Gross Domestic Product.
Source: Author's

The most of patent applications are submitted to SIBSU under the national procedure. To determine the patent activity in the sphere of nanotechnologies, the data retrieval was performed by IPC index B82 "Nanotechnologies" for all the years available in DB 0 except for 2015. The retrieval results showed that the number of patents sharply increased in 2008. However, the total number of the valid patents in the sphere "Nanotechnologies" nowadays is only 87. Many patents have a wide field of application, they relate mainly to technologies of creating nanomaterials, nanoliquids and nanocovering and can be used in various industrial processes. The largest part of the patents concerns medicine (25) and the number of patents in nanobiotechnology is comparatively large too (17 for agriculture and 13 for food production). This allows concluding that researches in these spheres are more applicable and could present some kind of commercial prospect.

Summary and conclusions

Lisbon Strategy encourages EU countries to increase the volume of investments on research and development (R&D) 0. There is a goal to achieve the R&D expenditure ratio amounting to 3% of GDP. This is a challenge even for countries with a high level of economic development, but almost all EU and developed countries were increasing their expenditure in previous years.

The R&D support in Ukraine is extremely poor, so this area is under the poverty line and neither theoretical nor experimental, nor effective applied researches are possible. To reach the level of developed countries and an appropriate level of competitiveness among European countries, Ukraine should expand the state financial support to scientific and technological development.

The peculiarity of the Ukrainian research field is a high proportion of developments in nanomedicine and nanobiotechnology both in scientific publications and patent applications. That's why these spheres should be considered as the most competitive advantages of the nanotechnology development in Ukraine and should gain a state support in commercialization. To maintain the existing potential, Ukraine has to provide the state support to local development, especially at the stage of fundamental research, and institutional support to the interaction of science and business at the stage of applied research.

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