DOI: 10.55643/fcaptp.4.45.2022.3834

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Received: 03/08/2022
Accepted: 17/08/2022
Published: 31/08/2022



# MODELLING THE IMPACT OF INTELLECTUALIZATION ON ECONOMIC GROWTH IN UKRAINE

## ABSTRACT

Introduction. Implementation of intellectual resources is necessary to form a new paradigm of economic development at the beginning of the XXI century.

Problem Statement. Intellectualization is becoming a major trend of globalization. As developing countries are not competitive enough in these circumstances, it is extremely important for them to increase the pace of intellectualization to ensure their competitiveness.

The purpose of the article is to investigate and establish quantitative relations between intellectual activity and GDP dynamics, as well as to forecast the countries' economic growth on this basis.

Materials and Methods. Cluster analysis for 44 countries and 40 indicators is based on a 10-year period.

Results. The modelling and forecasting of Ukraine's development in the conditions of enhanced intellectualization are carried out. The influence of various factors of intellectualization on the country's GDP is assessed, and the basic and optimistic scenarios and the level of the impact on the country's economic development are calculated. Whereas resource factors are more important for Ukraine and other developing countries, resulting factors are more important for the developed ones. The modelling is based on the authors' three-stage methodology for assessing intellectual leadership. It proves the positive impact of such resulting factors as high-tech exports, patents, trademark applications, and research and development costs. For instance, if high-tech export grows by 5%, Ukraine's GDP will increase quite significantly. However, almost any export growth can have a similar effect.

Conclusions. Attracting foreign intellectual capital has a significant positive effect, which is also confirmed by the modelling of the Ukrainian economy's development. The increasing existing level of research funding by 5% will result in Ukraine's GDP growth of almost $500 per capita.

**Keywords:** intellectual leadership, intellectualization, factors of economic growth, modelling

**JEL Classification:** I23, I25

## INTRODUCTION

Studying driving forces and determinants of robust economic growth has been a topical issue in economic science for many years. The whole evolution of economic science has confirmed that there is a constant search for relations and interdependencies between individual factors and economic development. Along with the rapid scientific and technological progress in the twenty-first century, the range of factors that have a decisive influence on the country's economic dynamics is growing. Recognizing the key role of all resources related to human intellectual activity in the countries' economic development is a well-known postulate. The intense use of intellectual resources, accelerated technologicalization, and digitization are at the heart of the breakthrough development for all advanced countries in the world (Kaleniuk I., Kuklin V., 2012).

The strengthening of competition at the current stage of civilizational development causes new factors and mechanisms of market struggle to come to the fore. These include the growing importance of intellectual resources and creative products as key factors in competitiveness. One of the important tasks of the economic activity of countries in the global environment is the accumulation and implementation of intellectual resources, which can determine the pace of the country's development, in general, shape the global parameters of world economic development. In fact, the intellectualization of society becomes one of the most important conditions for intensive development, expansion of spheres of influence, and realization of national interests. The term "intellectualization of the economy" refers to this type of economic development of the world economy, which is characterized by an increase in the role of knowledge and education as key factors in its provision.

At the level of productive forces, the intellectualization of the global economic system is manifested in the predominance of ensuring the growth of labour productivity of intellectual factors, the growth of their role in the process of technical and economic combination of personal and material factors of production, as well as in the interaction of man with nature, increasing the level of intellectualization of the human worker (Global economy…, 2008).

The strengthening of the intellectual component in all sectors of economic activity is due to the need to solve urgent problems of society, to produce the latest development strategies. This happens both at the expense of own innovative intellectually rich products and by borrowing existing ones from other countries. The question is that under modern conditions, the existing concept of intellectualization of the economy takes on new features and forms. This is reflected in the continuous production of key innovations and the improvement of existing products and processes. Constant attention to increasing the intellectualization of the economy at all its levels enabled the USA, the EU, Japan, and China to occupy the positions of world leaders in scientific, technological, and economic aspects (Lyakh V., Udovik S., 2006). Intellectualization of the economy becomes the main trend of development under the condition of transition to a new type of society, which changes the relations between market participants. Note that these processes are most pronounced in countries close to post-industrial society. In the economies of countries with a rustic system, these processes are quite insignificant, which is due to limited development opportunities.

Identifying the most effective factors of the countries' economic success in modern conditions are the issues of particular interest for economic science. An important task in the context of economic development research is to find out strong relations between individual indicators. Moreover, studying the relations between intellectual activity (resources and outcomes) and GDP growth indicators is of great interest.

A priority direction of development in the context of the Fourth Industrial Revolution and new technological framework formation for modern Ukraine is to complete the economy's industrial structure and to undertake gradual transformation not only into the post-industrial stage but also into the knowledge economy. To ensure the economy's competitiveness today, awareness of the role of knowledge is essential.

## LITERATURE REVIEW

The role of education in the economic development of the country is proved in the works of a large number of scientists T. Schultz (Shultz T., 1975), G. Becker (Becker, 2003), R. Lucas (Lukas R. 1988), П. Ромер (Romer P., 1990) та ін.). The problem of studying the level of influence of education and higher education, in particular, on the level and rate of growth of the national economy E. Denison (Denison E. 1962), W. Brockbank, D. Parson, and others, has long been relevant in the scientific literature. Modern scientists define knowledge and science as the most influential factor in development (R. Lucas, P. Romer, G. Mankiv, D. Romer, D. Weil, D. Scrim, 1992). The development of the theory of human capital as the basis for the formation of the knowledge economy and post-industrial society continues in the XXI century in the works of M. Castells (2006), P. Drucker, D. Bell (1973), E. Toffler, and others.

Aleksandra Skorupinska, and Joan Torrent-Sellens (2017) show that the rates of return on digital investment are relatively much higher than those on investment in other physical components. The results of research by Hong, J.-P. (2017) showed private ICT R&D investment had a stronger relationship with economic growth compared to public ICT R&D investment in Korea. Kretschmer, T. (2012) proved that the assessment of the impact of ICT depends very much on the chosen methodology. Nevertheless, over the last two decades, the increase of ICT by 10% has resulted in higher productivity growth (from 0,5% to 0,6 %).

Choi, C., Hoon Yi, M. (2009) using cross-country panel data, found evidence that the Internet plays a positive and significant role in economic growth after investment ratio, government consumption ratio, and inflation were used as control variables in the growth equation. Meijers, H. (2014) finds a positive impact of the internet on economic growth and trade.


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Internet use does not explain economic growth directly. Openness to international trade variables seems to be highly connected with internet use. Internet use has a higher impact on trade in non-high-income countries rather than in high-income countries, whereas the impact of trade on economic growth is the same for both income groups. ICT capital deepening accounts for 25 per cent of the growth of labour productivity over 1989–98 and 48 per cent over 1994–8, Oulton, N. (2002).

The use of information and communication technology seems to have had a substantial impact on the performance of the US economy, the evidence for other countries is much weaker, Pohjola, M. (2002). Stanley, T. D., Doucouliagos, H., Steel, P. (2018) explore the differential impact of ICT on developed and developing countries and the differential impact of different types of ICT: landlines, cell phones, computer technology and Internet access. ICT has contributed positively to economic growth. However, developed countries have gained much more from computing than developing countries. In contrast, we find little evidence that the Internet has had a positive impact on growth. The analysis by Vu K. (2011) shows that, for the average country, the marginal effect of the penetration of internet users was larger than that of mobile phones, which in turn is larger than that of personal computers.

In the middle of the twentieth century, Robert Solow substantiated the model of exogenous economic growth on the basis of the production function of Cobb-Douglas and the Keynesian model of economic growth R. Harrod-E. Domar (Solow R.M., 1956). Later the researchers began to study in more detail various aspects of the main factors (labour, capital, land) as well as scientific and technological progress.

In the 1950s the Minser model explained the dependence of wages on education and professional experience (Mincer J., 1974). In 1981, George Psacharopoulos supplemented Minser's model by measuring the costs and benefits of education in Return on Education: Complemented by International Comparison.

Current research analyzes the factors and processes of economic growth due to deeper dependencies. Robert Tamura, Gerald Dwyer, John Devereux and Scott Baier investigate the relationship between human capital accumulation and the dynamics of long-term growth (Tamura R. and others, 2012; 2019). Based on research by Maddison A. (1991), they proposed a simple model of human and physical capital accumulation within the standard Cobb-Douglas production function. The results of the model explain 70 to 80 percent of long-term economic growth by differences in employee characteristics. New research (2019) shows that a change in an employee's baseline data can result in 46% of changes in long-term growth. Thus, the accumulation of human capital over many generations can explain up to half of all long-term changes in living standards.

The XXI century is marked by the emergence of radically new technologies and the latest trends, such as informatization, digitalization, networking and others. In the new context, studying the determinants of economic growth is aimed at identifying more segmented dependencies, and elucidating the impact of ICT on the dynamics and scale of economic development. Jorgenson, D.W., Vu, K. (2005) described the impact of investment in information technology (IT) on the resurgence of world economic growth, seven regions and 14 major economies during the period 1989–2003. The study by Jorgenson, D.W., Vu, K. (2010) analysed the time period from 1989 to 2008. Oliner and Sichel (2000) proved that productivity growth in the US since the 1990s is associated with an investment in information and communication technology (ICT), as ICT capital accounted for 1.1% of the 4.8% output growth rate during 1996-1999. Colecchia, A., Schreyer, P. (2002) compares the impact of ICT capital on economic growth in nine OECD countries. They found significant differences in the countries' ICT investments, although they grew rapidly in all countries.

## AIMS AND OBJECTIVES

Ukraine looks as a consumer rather than a market with significant sales potential on the global map. At the same time, there are practically no barriers to entering the Ukrainian market or they are extremely low. There is no serious competition for the majority of products, while the position and development of own production are still weak. However, despite the considerable potential for development, there are almost no effective instruments for its implementation in the Ukrainian economy. Nevertheless, Ukraine's potential can be proved not only by using theoretical, but also mathematical instruments, by applying a scenario forecast of the economic development based on econometric modelling.

The purpose of the article is to investigate and establish quantitative relations between intellectual activity and GDP dynamics, as well as to forecast the country's economic growth on this basis.

## METHODS

In the scientific literature, one of the most pressing issues is the theoretical and methodological understanding of the essence of the innovation process and its drivers, and the role of knowledge, education and technology in ensuring economic growth.

An important area of research is the analysis of scientific activity and its impact on economic productivity (Solarin S.A., Yen Y.Y., 2016; Inglesi-Lotz R.&Pouris A., 2013). Research activity can be measured by a wide range of indicators: the amount of funding for R&D (in general, per capita, researchers, industries, etc.), the number of researchers (in general and by industry), publications, patents, etc. These general indicators can have their constituent, absolute and relative dimensions, accompanied by a number of interrelated indicators (Kumar R., Stauvermann P., Patel A., 2016; Javed S., Liu S., 2018; Inglesi-Lotz R., Balcilar M., Gupta R., 2014; Vinkler P., 2008). Accordingly, the general economic indicators may have different values: GDP, GDP per capita, export volume, international competitiveness (a complex indicator based on a set of different indicators), and so on.

The World Bank and other international organizations have been studying the main features of the knowledge economy and factors that influence economic growth for a long time. The 1998/1999 World Bank report "Knowledge for Development" focuses on components of the knowledge economy, such as innovation, information infrastructure, institutions and education. Experts of the World Bank emphasize, that countries can significantly accelerate economic growth by raising the level of education, ensuring openness in international trade and building telecommunications infrastructure. Thus, the educational level determines the ability of people to apply knowledge, replenish and increase it; openness to trade, related to the transfer of technological knowledge, and the opportunity to access world technology through goods and services. According to the report, a high level of education, an open economy and a developed information infrastructure provide an increase in GDP per capita (per year) by almost 4%. However, it is obvious that education without innovation capacity and dissemination of knowledge does not lead to economic growth. It is becoming clear that the post-industrial society is a knowledge society, where the means of improving the welfare of the population of any country is knowledge, gained through unimpeded access to information and the ability to work with it. In this regard, the system of training highly qualified people is gaining strategic importance and becoming a tool to ensure the high international competitiveness of the country. A proper qualification can be provided by such an education system that takes into account the processes of globalization, and new forms of learning that have emerged from the use of information technology.

Modern competitive strategies of developed and developing countries and the formation of competitive advantages of innovative nature are reflected in modern views on global competitiveness in the Report "Crossing the Chasm and Building the Future Economy" by the Global Federation of Competitiveness Councils (2020), which emphasizes the priority of learning as a "cornerstone of any future economic strategies". The main factors of inclusive economic growth are connected with the competencies of the future, new knowledge and lifelong learning. The Report highlights such key drivers of countries' competitiveness, as an investment in research and development; education and training for all citizens; strong intellectual property rights; a stable, transparent, and efficient environment that encourages business investment, formation, and growth; open trade; and enabling infrastructure. The basic principles of countries' competitiveness, based on the analysis of global trends and challenges that open new opportunities and pose threats and for the countries are also formulated: building coalitions and multistakeholder public-private platforms based on shared values to address the COVID-19 crisis; building resiliency and the future economy, putting innovation at the centre of crisis response and future building strategies and initiatives, leveraging the potential of novel frameworks developed and implemented during the crisis; focusing on inclusive skills and competencies to retain and enhance critical capabilities across sectors and enable the future economy; empowering local and regional initiatives and capabilities to accelerate response, building resiliency and transition the economy; implementing and promoting the global deployment of functional, forward-looking and technology-enabled Intellectual Property (IP) regimes and institutions capable of supporting economic resiliency and enabling fast-paced innovation; addressing physical and digital infrastructure gaps by setting a clear strategic direction and putting in place sustainable and resilient assets needed for future economies to function and include all demographics; enhancing the response to global challenges and economic transformation via cross border partnerships based on shared values, connection platforms and institutional solutions to accelerate the flows of goods, talent, capital and ideas across nations; re-imagining economic systems and leveraging innovation to build a resilient and sustainable future economy, decoupling growth from environmental impact, transforming the industrial footprint, and fighting climate change; constantly collecting, analysing, and applying lessons learned, and benchmarking strategy, regulation, policy, and business performance and solutions.


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The National Science Foundation (NSF) estimates that the U.S. federal government contributed over $122 billion for R&D in 2016, much of that being conducted at U.S. universities and institutions. Because of this research funding, U.S. universities and institutions have generated over 25 000 invention disclosures and have filed over 16 000 U.S. patent applications for the intellectual property (IP) developed by these R&D funds. The number of PhD and doctoral students has increased dramatically as well.

Annual Report "European Innovation Scoreboard 2020" by the European Commission provides benchmarking of research and innovation results in Europe and other countries - key innovators. With the help of this report, governments have the opportunity to develop roadmaps for the development of national innovation systems and implement programs and strategies for innovation. The main indicator of innovative development of the EU is the Innovation index, which includes such indicators, as intellectual assets, economic effects, human resources (highly skilled labour force, people, aged 20-24 with a university degree), financial investment for research, projects, entrepreneurship (innovative small and medium enterprises) (European…, 2020).

According to this report, countries are divided into the following groups: innovation leaders, countries with the highest innovation index, namely: Switzerland, Sweden, Finland, Denmark, the Netherlands, Luxembourg; innovation followers, countries with innovation activity, which is slightly lower than the first cluster of countries and higher than the EU average (Belgium, Great Britain, Norway, Germany, Austria, Ireland, Iceland, Israel, France, Estonia, Portugal); moderate innovators, where the innovation index is lower than the EU average (Czech Republic, Croatia, Cyprus, Spain, Czech Republic, Malta, Slovenia, Italy, Lithuania, Greece, Slovakia, Hungary, Latvia, Turkey, Serbia, Poland, Croatia) and modest innovators, countries where the level of innovation is much less than 50%. This group includes countries such as Bulgaria, Macedonia, Montenegro, Ukraine and Romania.

According to the report, Switzerland, Sweden, Finland and Denmark have confirmed their innovative leadership in the region. Compared to other EU countries, Ukraine falls behind Switzerland, the leader of the first group, more than 5 times, Belgium, the leader of the group of "strong innovators" -3,7 times, Cyprus, the leader of the group of "moderate innovators" – 2,7 times, and Bulgaria, the leader of the group of "modest innovators -1,4 times". At the same time, it is ahead of Romania 1,1 times. It is worth mentioning, that the number of people involved in research, in Ukraine is slowly declining. Whereas in 2016 it accounted for 97 912 people, in 2019 it dropped by 19% to 79 262 people. The number of doctors of science in this period accounted for 7-8%, and candidates of science - 20 to 21% of the total number of people with degrees. In 2019 there was a sharp decrease in the number of doctors of sciences from 7 043 to 6 526 and candidates of science – from 18 806 to 16 929. The trend in terms of research and development costs was the opposite. The research expenditures increased by almost 50% from UAH 11 530,7 million in 2016 to UAH 17 254,6 million in 2019. The most significant increase took place from 2017 to 2018, and the level of rising was 1,25 times.

Intellectual factors by their nature are not a permanent phenomenon; they are rapidly evolving, acquiring new forms of manifestation and varieties. ICTs are emerging that are transforming and developing all other intellectual resources, contributing to the emergence of smart technologies. Not only the number of scientists and the cost of R&D become important for the assessment of the country's intellectual resources, but also such indicators as the use of ICT, the number of publications in scientometric publications, the number of patents, etc. That is why it is important for scientific analysis not only to assess the overall impact of intellectual factors on economic growth (although this is also interesting). Of great interest is the assessment of the impact of various intellectual factors on the economic success of the country. As a result of the analysis, the authors determined, that the whole set of intellectual factors is divided into 2 groups: resource (accumulated intellectual resources) and resulting indicators (reflect the results of intellectual activity). The level of resources is characterized by the availability of basic intellectual resources, availability and potential of which generally characterizes the country's (or any other entity's) ability to pursue intellectual activities. At the same time, the availability of intellectual resources is an important condition for leadership, but it does not mean that it is actually achieved. More realistically, it can manifest itself at the next level by characterizing the results obtained by an intellectual activities participant. The level of the intellectual activity's results involves a comprehensive evaluation of specific results: patents, licenses, know-hows, publications, etc. The whole set of indicators for assessing intellectual leadership concerns either the intellectual resources' potential or the intellectual activities' results.

The analytical evaluation of the performance of the countries selected for the analysis indicates that all levels of intellectual leadership are important, but for each country, the set of the most influential factors varies considerably. Thus, for the developing countries, the first resource level factors are most important, whereas for the developed countries the second level factors (intermediate results) are more important, which ensures these countries' presence and their unconditional leadership on the third level indicators (overall progress). In accordance with the tasks set, it is necessary to prove mathematically the importance and influence of individual factors on the national economies' functioning.

The econometric study database includes annual data for 44 countries from 2005 to 2015, according to the data analysis, this period was defined as the period with the largest number of statistics. The countries with developed economies were selected for the analysis: all 35 OECD member states and 9 OECD accession countries were invited for negotiations for the Action Plan of OECD (Organisation…, 2022). The statistical information published on the World Bank's official website was used for the Research Base of this research (World…, 2022). In general, research and modelling are based on more than 20 thousand indicators that have been selected as important for the formation and provision of intellectual leadership. A limitation of our study is the availability of statistics, especially for highly developed countries, in particular the innovative activity of enterprises.

The estimation of econometric models was made both based on a sample from all 44 countries and based on individual groups of countries formed by the degree of the countries' similarity among themselves. This is explained by the fact that the sample under study contains countries that may differ significantly in socio-economic and geopolitical terms of development. Cluster analysis methods were used to divide countries into groups. These methods are related to the multidimensional data classification methods and allow you to divide the subjects into multiple homogeneous groups (clusters, classes) (Everitt B., 2011). The calculations were performed using software MS Excel 2016 (preliminary data analysis), Statistica 10 (cluster analysis), and Stata 11.2 (building of econometric models). This is done by mathematical analysis and modelling based on data from 40 indicators, 44 countries (OECD+), over 10 years. The most important questions are: what factors are most influential in the modern world? What determines the country's leadership? How to identify and rank the most influential factors?

Scientific literature review and modelling methods suggested a quantitative empirical study to be performed in finding actual evidence for solutions to defined scientific problems. Descriptive statistical analysis and visualization methods were applied to organize the research results. Methods of economic and mathematical modelling were also used, in particular: cluster analysis, regression analysis, correlation analysis, and forecasting.

## RESULTS

The forecast of Ukraine's economic development for the period 2016-2022 is based on the analysis of trends in GDP, resource groups, and resulting indicators during the reported period of 2005-2015. In the first stage, one-factor linear regressions of each independent variable's impact on the GDP value were constructed. The data was previously logarithmised in order to reduce the dimension and simplify the model coefficients' interpretation (Baltagi B., 2005; Greene W., 2011; Hsiao C., 2003). Here we consider the selected indicators in more detail (table 1, 2).

**Table 1. The group of resource indicators include.**

| Indicators | Explanation |
|---|---|
| total_mobil | total number of students enrolled abroad, per 1 million inhabitants |
| inbound_mobil_s | total number of students who came from other countries, per 1 million inhabitants |
| gov_tertiary | Public Expenditure on Higher Education, USD per capita |
| gov_educ | public education expenditure, USD per capita; |
| tertiary_gov_exp | higher education expenditure as a percentage of total public expenditure, % |
| educ_gov_exp | education expenditure as a percentage of total government expenditure, % |
| gov_tertiary_GDP | government expenditure on higher education as a percentage of GDP, % |
| gov_educ_DGP | government expenditure on education as a percentage of GDP, % |
| enrol_tert | number of students enrolled in higher education institutions, per 1 million inhabitants |
| enrol_PhD | number of students enrolled in graduate school, per 1 million inhabitants |
| enrol_short | number of students enrolled in higher education institutions (short-term courses), per 1 million inhabitants |
| RD_ per thousand | total number of scientific and technical staff, per 1,000 employees |
| RD_per million | total number of scientific and technical staff, per 1 million employees |
| RD pers | total number of R&D staff, per 1 million inhabitants |

Second group of indicators includes results and performance of intellectual activity (table 2).


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**Table 2. The group of performance indicators include.**

| Indicators | Explanation |
|---|---|
| mobile_sub | mobile cellular subscriptions for 100 people |
| intern_users | part of people using the Internet, % |
| hi-tech_exp_share | share of high-tech exports in the total structure of industrial exports, %; |
| hi-tech_exp | high tech exports, USD per capita |
| ICT_exp | share of ICT goods exports in the total structure of goods exports, %; |
| ICT_imp | share of ICT goods imports in the total structure of goods imports, %; |
| design_nres | industrial design of applications by non-residents, units per 1 million inhabitants |
| design_res | industrial application design by residents, units per 1 million inhabitants; |
| patent_nres | patent applications from non-residents, unit per 1 million inhabitants; |
| patent_res | patent applications from residents, unit per 1 million inhabitants |
| trademark_nres | trademark applications from non-residents, units per 1 million inhabitants |
| trademark_res | trademark applications from residents, units per 1 million inhabitants |
| research_exp | research and development costs, USD per capita |
| research_RD | researchers in research and development, persons per 1 million inhabitants |
| articles | scientific and technical journal articles, ed. per 1 million inhabitants |

Innov_quart2, Innov_quart3, Innov_quart4 – the dummy variables that reflect the enterprises' innovation activity level in the country. The lack of reliable statistics on the innovative enterprises' share for some years makes it impossible to use the innovation activity indicator as a quantitative variable.

In general, the built model for calculating the forecast of the economic development of the country was studied in the previous works of the authors (Kalenyuk I, Tsymbal L., 2020; 2021). The modelling results are presented in Table 3 (Resource Indicators) and Table 4 (Resulting Indicators).

**Table 3. Resource Indicators influencing GDP - One-Factor Econometric Models for Ukraine.** *(Source: Calculated by the author on the base (Organisation…, 2022; World…, 2022).*

| Indicators | $a_1$ | $a_0$ | $R^2$ | F-criterion | Equation with one-factor econometric models |
|---|---|---|---|---|---|
| total_mobil | 0.0719 | 7.503*** | 0.008 | 0.07 | $GDP = 7.503 + 0.072 total\_mobil$ |
| inbound_mobil_s | 0.262 | 6.220*** | 0.109 | 1.1 | $GDP = 6.220 + 0.0262 inbound\_mobil$ |
| **gov_tertiary** | **0.529**** | **5.775***** | **0.414** | **6.37**** | $GDP = 5.775 + 0.529 gov\_tertiary$ |
| **gov_educ** | **0.591**** | **4.835***** | **0.422** | **6.56**** | $GDP = 4.835 + 0.591 gov\_educ$ |
| tertiary_gov_exp | 0.121 | 7.451*** | 0.016 | 0.14 | $GDP = 7.451 + 0.121 tertiary\_gov\_exp$ |
| educ_gov_exp | -0.108 | 9.480*** | 0.042 | 0.39 | $GDP = 9.480 - 0.108 educ\_gov\_exp$ |
| gov_tertiary_GDP | 0.28 | 7.404*** | 0.047 | 0.45 | $GDP = 7.404 + 0.28 gov\_tertiary\_GDP$ |
| gov_educ_GDP | 0.0496 | 7.662*** | 0.008 | 0.07 | $GDP = 7.662 + 0.496 gov\_educ\_GDP$ |
| Enrol_tert | 0.286 | 4.87 | 0.017 | 0.15 | $GDP = 4.87 + 0.286 Enrol\_tert$ |
| **Enrol_PhD** | **2.595***** | **-9.153*** | **0.623** | **14.84***** | $GDP = -9.153 + 2.595 Enrol\_PhD$ |
| Enrol_short | -0.353 | 11.23** | 0.064 | 0.62 | $GDP = 11.23 - 0.353 Enrol\_short$ |
| RD_ per_thous | -0.51 | 8.873*** | 0.082 | 0.8 | $GDP = 8.873 - 0.51 RD\_per\_thous$ |
| RD_per_mil | -0.405 | 11.15** | 0.059 | 0.57 | $GDP = 11.15 - 0.405 RD\_per\_mil$ |
| RD_persons | -0.436 | 11.39** | 0.064 | 0.61 | $GDP = 11.39 - 0.436 RD\_persons$ |

It has been determined that the three most important indicators influencing GDP at the resource level are the following: government expenditures on higher education (gov_tertiary), government expenditures on education (gov_educ), and the enrollment fees for PhD degrees (Enrol_PhD). No statistically significant effect on GDP for other resource group indicators was found. Macroeconomic indicators are also significantly influenced by the resulting indicators based on the econometric modelling. The models influencing individual factors are summarized in Table 4.

**Table 4. Resulting Indicators, Influencing GDP - One-Factor Econometric Models for Ukraine.**

| Indicators | $a_1$ | $a_0$ | $R^2$ | F-criterion | Equation with one-factor econometric models |
|---|---|---|---|---|---|
| **mobile_sub** | **0.701*** | **4.640**** | **0.352** | **4.88*** | $GDP = 4.640 + 0.701 mobile\_sub$ |
| intern_users | 0.00467 | 7.871*** | 0.088 | 0.87 | $GDP = 7.871 + 0.005e\ rn\_users$ |
| hi-tech_exp_share | 0.0118 | 7.926*** | 0.004 | 0.04 | $GDP = 7.926 + 0.012hi - tech\_s\ hare$ |
| **hi-tech_exp** | **0.625***** | **5.792***** | **0.651** | **16.82***** | $GDP = 5.792 + 0.625hi - tech\_exp$ |
| **ICT_exp** | **0.856**** | **7.190***** | **0.399** | **5.98**** | $GDP = 7.190 + 0.856ITC\_exp$ |
| ICT_imp | -0.11 | 8.330*** | 0.103 | 1.04 | $GDP = 8.330 - 0.11ITC\_imp$ |
| **design_nres** | **0.559*** | **5.694***** | **0.323** | **4.29*** | $GDP = 5.694 + 0.559design\_nres$ |
| design_res | 0.0275 | 7.922*** | 0.107 | 1.08 | $GDP = 7.922 + 0.028design\_res$ |
| **patent_nres** | **2.153***** | **-0.622** | **0.607** | **13.90***** | $GDP = -0.622 + 2.153patent\_nres$ |
| patent_res | -0.57 | 10.33*** | 0.087 | 0.85 | $GDP = 10.33 - 0.57patent\_res$ |
| **trademark_nres** | **2.304***** | **-4.810***** | **0.893** | **75.44***** | $GDP = -4.810 + 2.304trademark\_nres$ |
| trademark_res | 0.638 | 4.197 | 0.138 | 1.41 | $GDP = 4.197 + 0.638trademark\_res$ |
| **research_exp** | **0.849***** | **5.304***** | **0.694** | **20.39***** | $GDP = 5.304 + 0.849research\_exp$ |
| tech_RD | -0.267 | 9.897* | 0.02 | 0.18 | $GDP = 9.897 - 0.267tech\_RD$ |
| articles | 0.399 | 6.020* | 0.052 | 0.49 | $GDP = 6.020 + 0.399articles$ |

Among the resulting indicators such as mobile_sub, hi-tech_exp, ICT_exp, ICT_exp, design_nres, patent_res, the trademark_nres and research_exp have an important and statistically significant influence on GDP. However, in the second stage of forecasting, we didn't use the variables such as mobile_sub, ICT_exp, and design_nres because of the low values for the data approximation reliability ($R^2$ for these models does not exceed 40%).

For the indicators that have a significant impact on the economic development level, a one-factor model series of this type was made:

- Linear regression: $y = a_0 + a_1 x$,
- Exponential regression: $y = a_0 e^{a_1 x}$,
- Logarithmic regression: $y = a_0 + a_1 ln(x)$,
- Power regression: $y = a_0 x^{a_1}$,

*where y is a dependent variable value, x is an independent variable value, $a_0$, and $a_1$ are the model coefficients to be estimated.*

Using several types of models allows us to choose the specification that reflects the real data in the best way.

Forecasting was made according to baseline and optimistic scenarios. In the baseline scenario, the independent variables' values for the forecast are taken as a continuation of the current trend in 2005-2015, while in the optimistic scenario the independent variables' values are assumed to be by 5% higher than the baseline values.

Figure 1 presents the correlation field of points, linear, exponential, logarithmic, and power trend lines, the corresponding regression equations and the data approximation reliability for this trend ($R^2$) for the selected resource indicators.


DOI: 10.55643/fcaptp.4.45.2022.3834

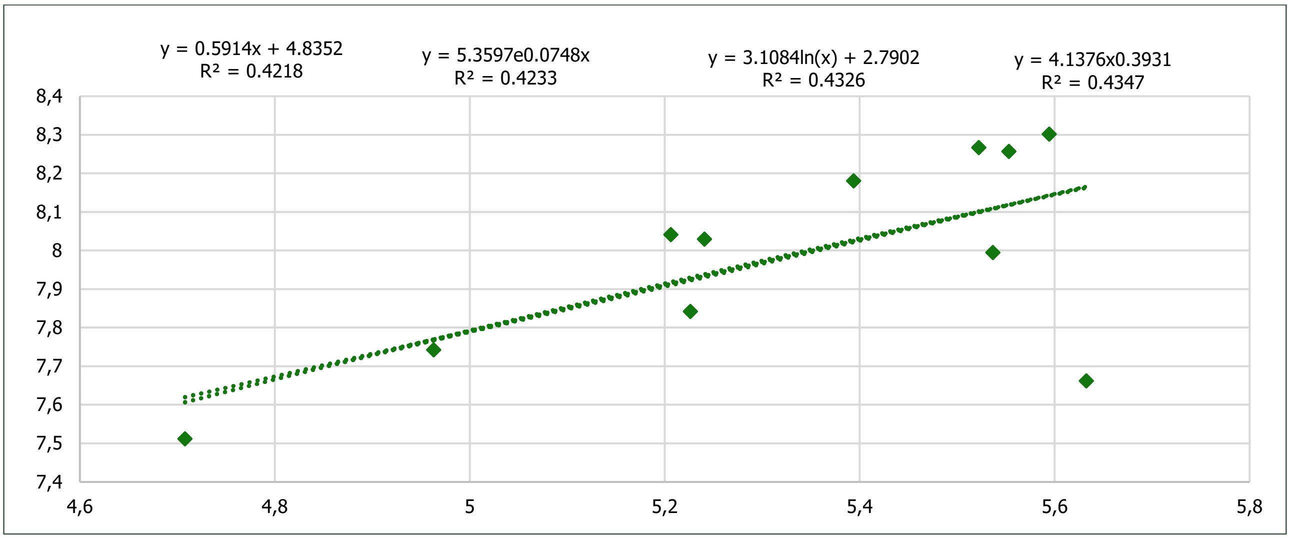


**Figure 1. Government spending on education, USD US per capita.**

For the resource indicators that have the greatest impact on GDP, the one-factor econometric model equations can be provided, in particular, the indicator of government expenditure on education:

- Linear regression: $GDP = 4.835 + 0.591 gov\_educ$,
- Exponential regression: $GDP = 5.360e^{0.075 gov\_educ}$,
- Logarithmic regression: $GDP = 2.790 + 3.108\, ln\, ln\, (\, gov\_educ)$,
- Power regression: $GDP = 4.137 gov\_educ^{0.393}$.

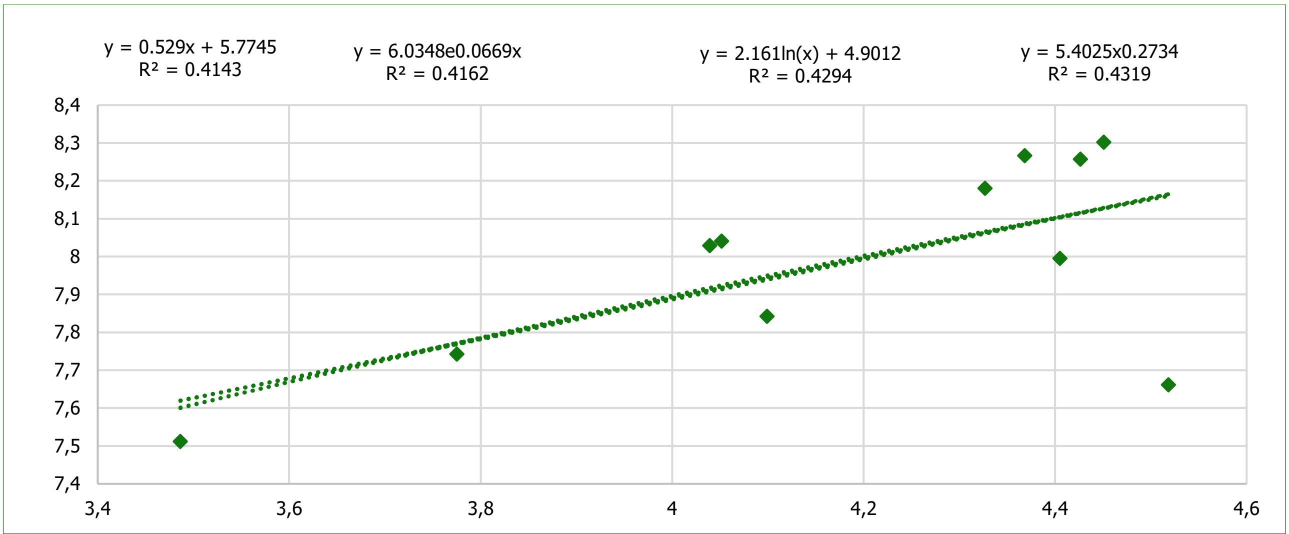


**Figure 2. Government spending on tertiary education, USD US per capita.**

We can define one-factor econometric model equation for such indicator as "public expenditure on higher education" as follows:

- Linear regression: GDP=5.775+0.529gov_tertiary,
- Exponential regression:  GDP=6.035e^{0.070gov_tertiary},
- Logarithmic regression: GDP=4.901+2.161{ln}ln\ (\ gov_tertiary),
- Power regression: GDP=5.403gov_tertiary^{0.273}.

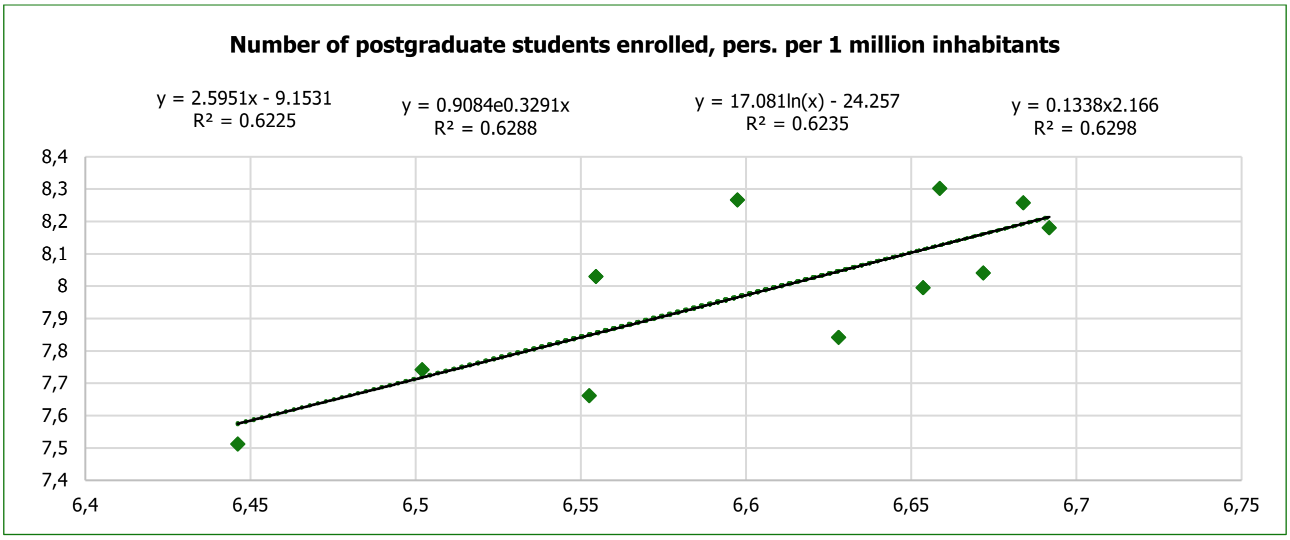


**Figure 3. The resource indicators influencing GDP - one-factor econometric models of different specifications.**

Taking into consideration the number of people enrolled in post-graduate degrees relative to the total population and, in particular, the conversion per 1 million population, we can determine the one-factor econometric model equation as follows:

- Linear regression: $GDP=-9.153+2.595Enrol\_PhD$,
- Exponential regression: $GDP=0.908e^{0.329Enrol\_PhD}$,
- Logarithmic regression: $GDP=-24.257+17.081\ln(Enrol\_PhD)$,
- Power regression: $GDP=0.134Enrol\_PhD^{2.166}$.

As we can see, for all three models the magnitude of the data approximation reliability in different trend types is not significantly different, but the best specification here is power regression. Therefore, we used the power regression to build the forecast for 2016-2022. The forecasted results are shown below:

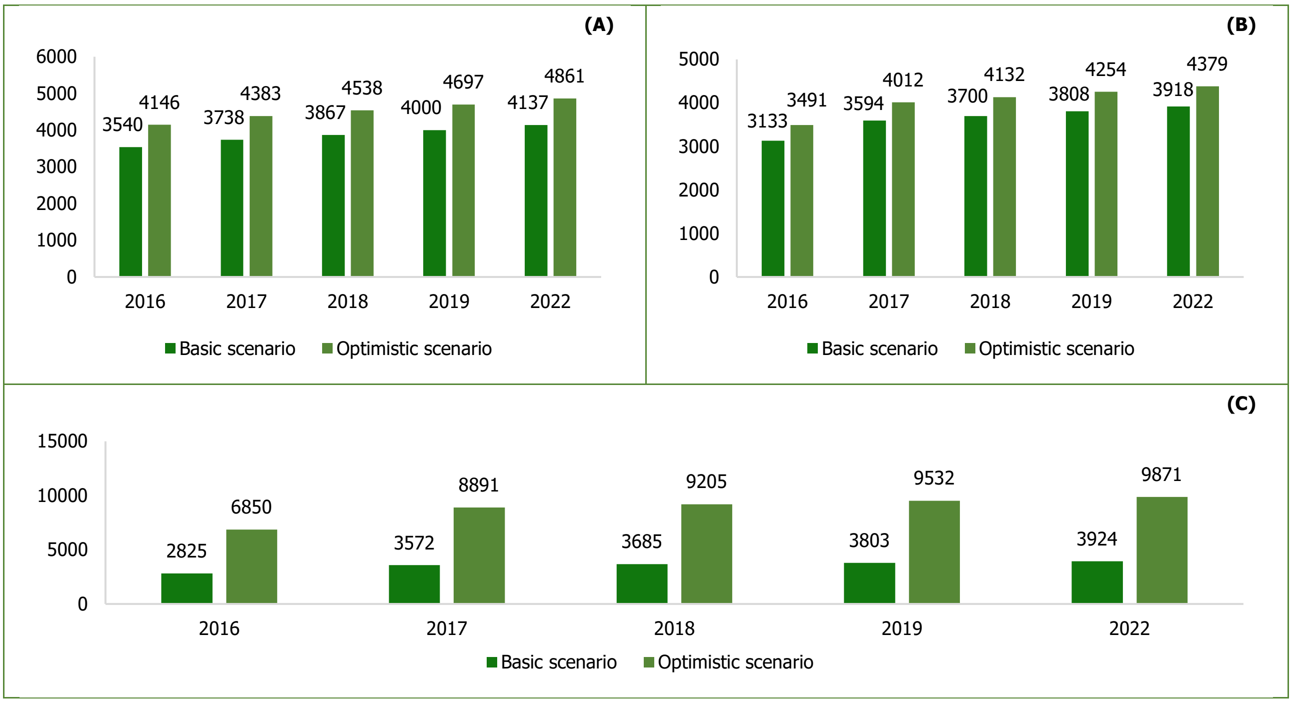


**Figure 4. Forecasting GDP dynamics based on one-factor econometric models (resource factors influencing GDP) (basic and optimistic scenario).** Government spending on education, USD per capita (A); Public expenditure on higher education, USD US per capita (B); Number of postgraduate students enrolled, pers. per 1 million inhabitants (C).


DOI: 10.55643/fcaptp.4.45.2022.3834

The most influential determinants of the country's GDP growth were identified: government expenditure on education, government expenditure on higher education, and the number of students enrolled in post-graduate degrees (PhD students) [30]. Thus, an increase in government expenditure on education by 5% of the baseline can lead to an increase in the macroeconomic index to USD 4.861 per capita. Forecasting the impact of public expenditure on higher education indicates that GDP may rise to USD 4.379 per capita (in case expenditure on higher education grows by 5%). An increase in the number of PhD students in the optimistic scenario may lead to a GDP growth of USD 9.871 per capita (Figure 2).

As we can see, the resource indicators have a significant positive impact on the economic development of Ukraine, which is confirmed by the corresponding forecasts. In this case, the optimistic scenario shows high GDP growth rates in response to resource growth by just 5%.

In terms of resulting indicators, the growth is rather moderate.

Figures 5-9 present the correlation field of points, linear, exponential, logarithmic, and power trend lines, the corresponding regression equations, and the data approximation reliability for this trend ($R^2$) for the selected resulting indicators.

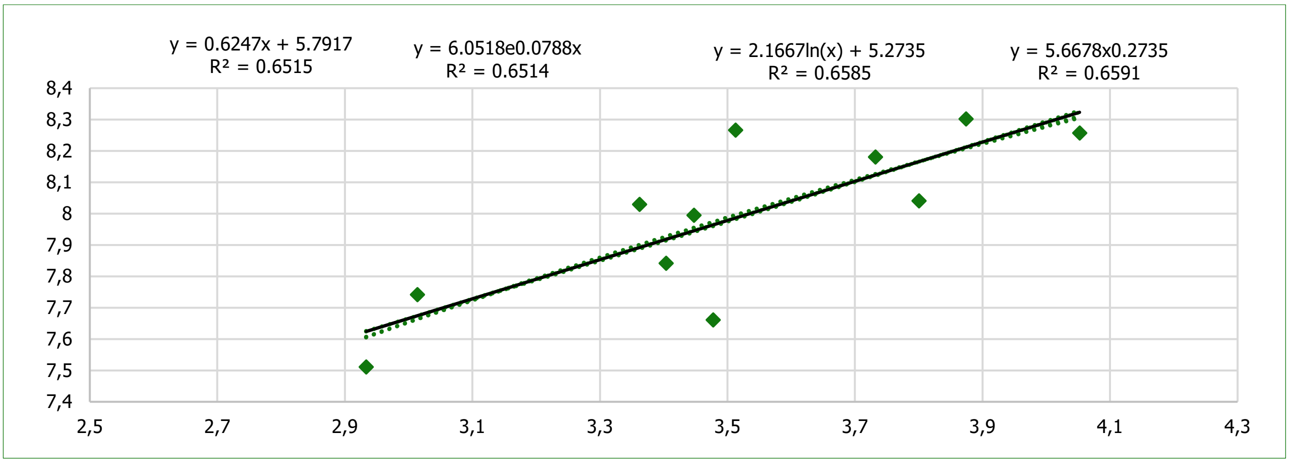


**Figure 5. Resource factors influencing GDP value – one-factor econometric models of different specifications.** High-tech exports, USD US per capita.

Equation with one-factor econometric models:

- Linear regression: $GDP = 5.792 + 0.625hi - tech\_exp$,
- Exponential regression: $GDP = 6.052e^{0.079hi - tech\_exp}$
- Logarithmic regression: $GDP = 5.274 + 2.167\, ln\, ln\, (\, hi - tech\_\, exp\, exp\, )$ ,
- Power regression: $GDP = 5.668hi - tech\_$.

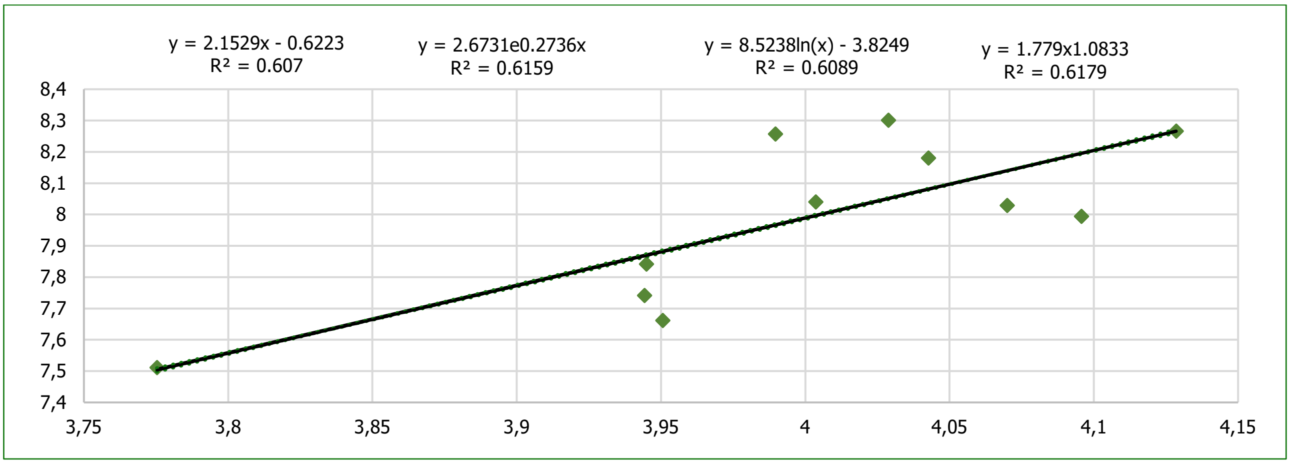


**Figure 6. Resource factors influencing GDP value – one-factor econometric models of different specifications.** Non-resident patent applications, unit. per 1 million inhabitants.

Equation with one-factor econometric models:

- Linear regression: $GDP = -0.622 + 2.153 patent\_nres$,
- Exponential regression: $GDP = 2.673 e^{0.274 patent\_nres}$,
- Logarithmic regression: $GDP = -3.825 + 8.524\, ln\, ln\, (\, patent\_nres)$,
- Power regression: $GDP = 1.779 patent\_nres^{1.,083}$.

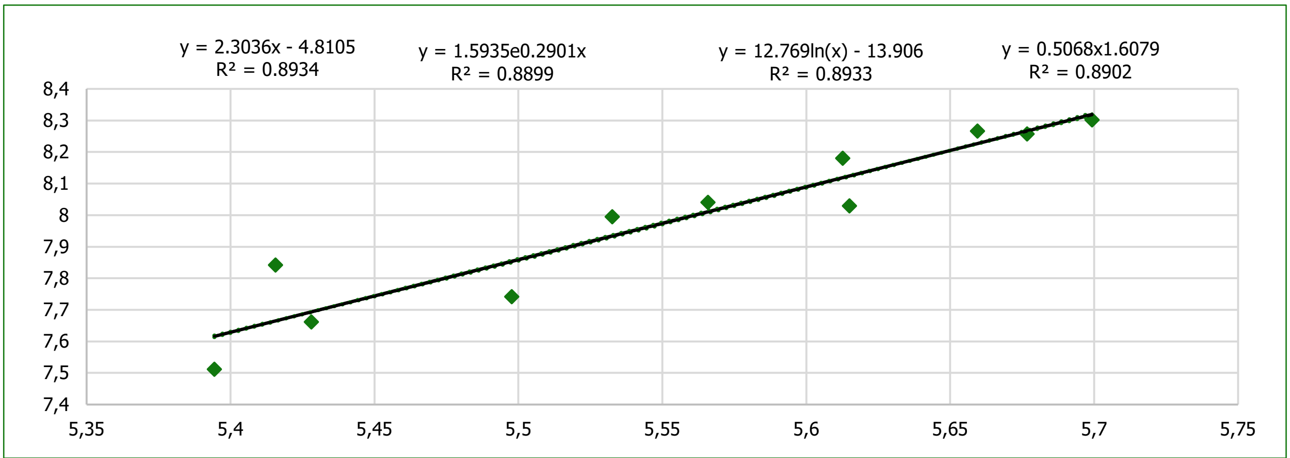


**Figure 7. Resource factors influencing GDP value – one-factor econometric models of different specifications.** Trademark applications from non-residents, units per 1 million inhabitants.

Equation with one-factor econometric models:

- Linear regression: $GDP = -4.811 + 2.04 trademark\_nres$,
- Exponential regression: $GDP = 1.594 e^{0.29 trademark\_nres}$,
- Logarithmic regression: $GDP = -13.906 + 12.769\, ln\, ln\, (\, trademark\_nres)$,
- Power regression: $GDP = 0.507 trademark\_nres^{1.608}$.

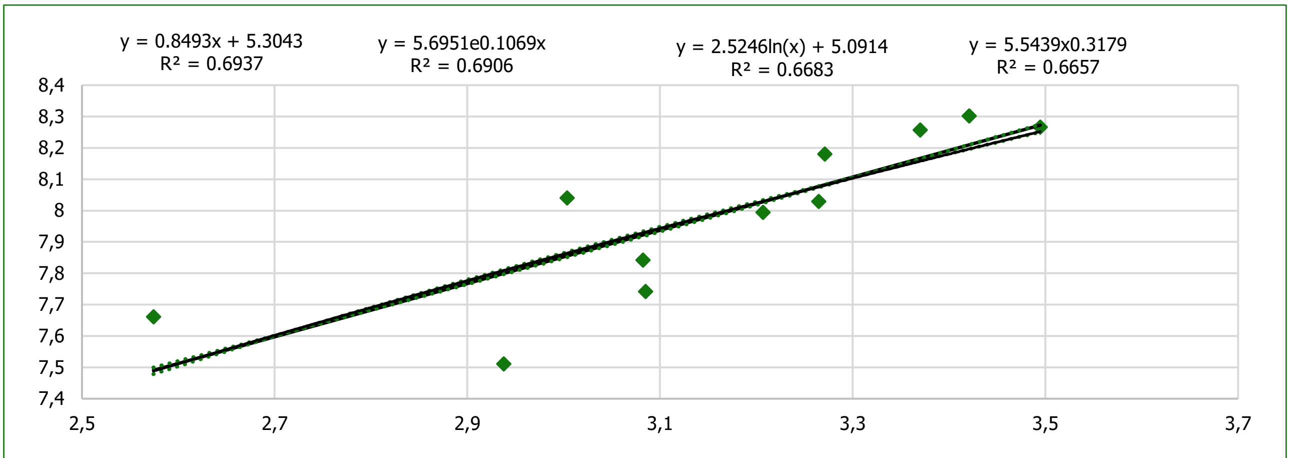


**Figure 8. Resource factors influencing GDP value – one-factor econometric models of different specifications.** Research and Development Costs. USD per capita.

Equation with one-factor econometric models:

- Linear regression: $GDP = 5.304 + 0.849 research\_exp$.
- Exponential regression: $GDP = 5.695 e^{0.107 research\_exp}$
- Logarithmic regression: $GDP = 5.091 + 2.525\, ln\, ln\, (\, research\_\, exp\, exp\, )$ .
- Power regression: $GDP = 5.544 research\_$.

Among the resulting indicators are the number of users of mobile phones, high-tech exports, ICT exports, industrial design and trademark applications from non-residents and their patent activity, as well as research and development costs, which have a considerable and statistically significant impact on GDP. For each of the resulting indicators, a field of scatter points


DOI: 10.55643/fcaptp.4.45.2022.3834

was developed in order to determine the best method for modelling and forecasting. It is found that for the first two variables the best specification is a power regression, while for the last two the best specification is linear regression. The estimated GDP values using the selected regressions are given below.

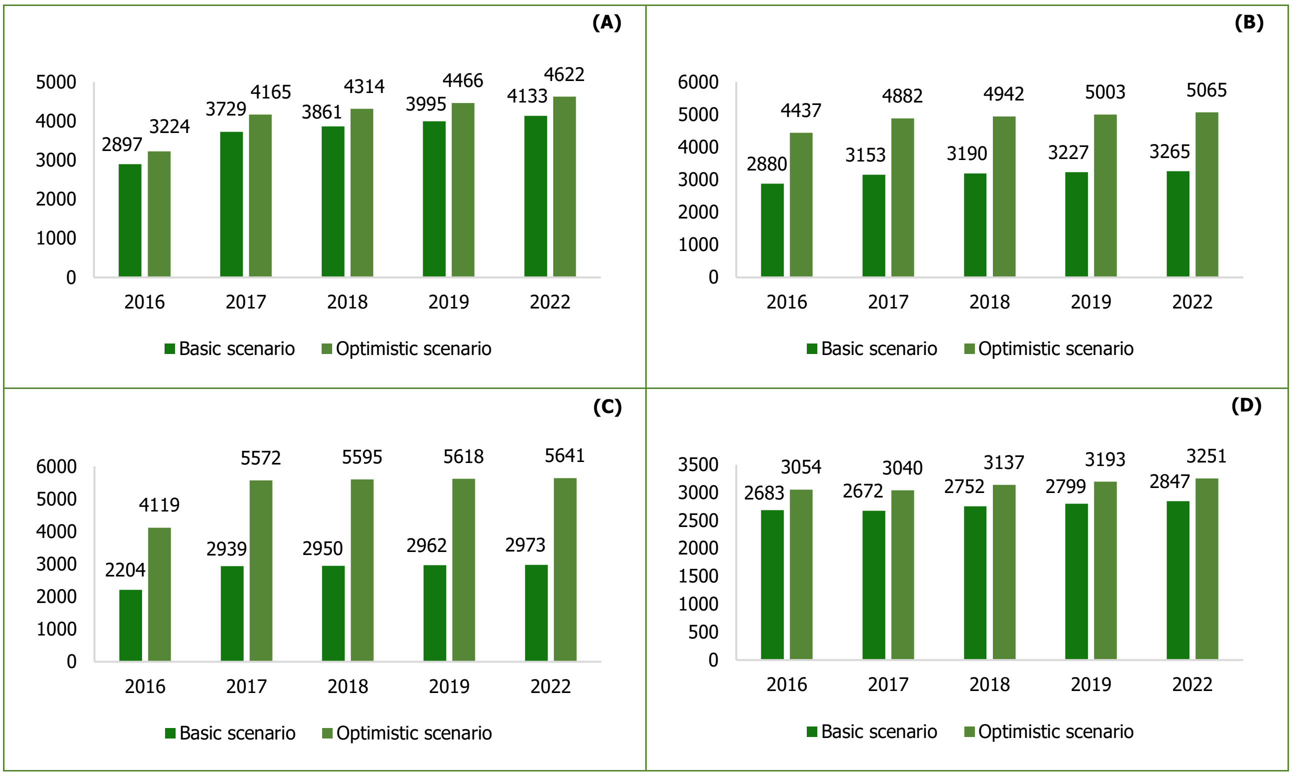


**Figure 9. Forecasting GDP dynamics based on one-factor econometric models (Resulting Factors influencing GDP) (basic and optimistic scenario).** High-tech exports. USD per capita (A); Non-resident patent applications. per 1 million inhabitants (B); Trademark applications from non-residents. per 1 million inhabitants (C); Research and Development Costs. USD per capita (D).

## DISCUSSION

The modelling results proved the positive impact of such resulting factors as high-tech exports, patents, trademark applications, research and development costs. For instance, as high-tech exports grow by 5%. Ukraine's GDP grows quite significantly; however, almost any export growth can have a similar effect. Involving foreign intellectual capital has a significant positive effect, which is also confirmed by the modelling of the Ukrainian economy's development (Laverde-Rojas H., Correa J., Jaffe K., Caicedo. M., 2019; Mincer J., 1958). Increasing research funding by 5% to its existing level will increase Ukraine's GDP by about $500 per capita. Since the forecast period includes the period in that real indicators already exist, we can check whether these models are real and how they are implemented. The indicators that are most closely approximated to real ones are reflected in the model that describes how expenditure on science and research influences the GDP size and growth in Ukraine, while the forecasted indicators' deviation in the baseline scenario fluctuates around $50 (Figure 9).

The modelling and forecasting confirmed that to implement the increased focus on such factors as financing of education, higher education, and science, support of R&D activities, and stimulation of high-tech exports is very important for the country's development. The obtained calculations proved the necessity of intensifying the state's participation in the processes of intellectualization, changing the development strategy, making its own model of breakthrough development based on the latest scientific achievements and implementing them in economic activity.

Therefore, the resources are the key to ensuring the successful development of the economy of Ukraine. Whereas most of them have been gradually declining since 2010, government involvement remains either partial or offset by negative factors. The analysis of the impact of individual factors on developing countries' economic development shows that it is more efficient to accumulate quality resources capable of being transformed into capital or productive resources that become a source of further development. It is worth paying special attention to the number of scientific staff, participation in scientific projects, financing of science, stimulation of business participation (tax. administrative, etc.) in R&D, stimulation of foreign business involvement in scientific projects (Crossing the Chasm…. 2020).

In general, further intellectualization of economic development is aimed at expanding opportunities and competitive advantages of the country, primarily through opportunities to increase productivity, reduce the energy intensity of GDP, increase economic security, reduce dependence on other countries and participants in economic processes, reduce environmental burden, increase technologicalization of the economy.

Ensuring Ukraine's successful economic development is determined by the necessary and sufficient prerequisites, and significant intellectual potential. At the same time, it is possible to implement them only if a well-reasoned state policy on activation of the country's intellectual potential is provided with consideration of the best international practices aimed to increase the intellectual capital assets. Stimulating innovation activity of both residents and non-residents at maximum extent. Intellectual activity and forming an institutional environment to support the intellectual capital assets' growth and successful, economically effective implementation are of particular importance.

## CONCLUSIONS

The econometric modelling made it possible to confirm that the factors related to intellectual activity are very important for GDP growth of the economy of Ukraine. The most important factors are those related to direct financing of education, higher education, and science. The high dependence of GDP growth on the increase in the number of postgraduate students, the number of patent applications, trademark applications, and high-tech exports was also revealed in this work.

A methodological approach to assess a number of intellectual factors influencing GDP growth can be applied in more in-depth research. Thus, an unconditional scientific interest is identifying the main dependencies between such factors as the ICT spread and networking (which can be measured by a variety of indicators), virtual business forms' development, the number of start-ups, etc. It is clear that for each country, both the key factors set and their impact on GDP growth can differ significantly. That is why validated modelling and forecasting must be at the heart of any country's policy that is aimed at successful development in the context of knowledge economy, rapid digitization, virtualization, and networking of all economic relations.

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## МОДЕЛЮВАННЯ ВПЛИВУ ІНТЕЛЕКТУАЛІЗАЦІЇ НА ЕКОНОМІЧНЕ ЗРОСТАННЯ В УКРАЇНІ

Вступ. Реалізація інтелектуальних ресурсів необхідна для формування нової парадигми економічного розвитку на початку XXI століття.

Постановка проблеми. Інтелектуалізація стає основною тенденцією глобалізації. Оскільки країни, що розвиваються, недостатньо конкурентоспроможні за цих обставин, для них надзвичайно важливо збільшити темпи інтелектуалізації, щоб забезпечити свою конкурентоспроможність.

Мета статті – дослідити та встановити кількісні зв'язки між інтелектуальною діяльністю та динамікою ВВП, а також на цій основі спрогнозувати економічне зростання країн.

Матеріали та методи. Кластерний аналіз для 44 країн і 40 індикаторів базується на 10-річному періоді.

Результати. Здійснено моделювання та прогнозування розвитку України в умовах посилення інтелектуалізації. Оцінено вплив різних факторів інтелектуалізації ВВП країни, розраховано базовий та оптимістичний сценарії та рівень впливу на економічний розвиток країни. У той час як для України та інших країн, що розвиваються, важливіші ресурсні фактори, для розвинутих – результативні. В основі моделювання лежить розроблена авторами триетапна методика оцінки інтелектуального лідерства. Це доводить позитивний вплив таких результуючих факторів, як високотехнологічний експорт, патенти, заявки на торгові марки, витрати на дослідження та розробки. Наприклад, якщо експорт високих технологій збільшиться на 5 %, ВВП України зросте досить суттєво. Проте майже будь-яке зростання експорту може мати подібний ефект.

Висновки. Значний позитивний ефект має залучення іноземного інтелектуального капіталу, що також підтверджується моделюванням розвитку економіки України. Збільшення існуючого рівня фінансування досліджень на 5 % призведе до зростання ВВП України майже на 500 доларів на душу населення.

**Ключові слова:** інтелектуальне лідерство, інтелектуалізація, фактори економічного зростання, моделювання

**JEL Класифікація:** I23, I25


DOI: 10.55643/fcaptp.4.45.2022.3834