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Tetiana Fasolko, PhD in Economics
ORCID ID: https://orcid.org/0000-0003-4718-2422
Khmelnytskyi University of Management and Law of Leonid Yuzkov, Ukraine
Tetiana Tereshchenko, PhD in Economics
ORCID ID: https://orcid.org/0000-0001-5748-2854
Khmelnytskyi University of Management and Law of Leonid Yuzkov, Ukraine
Olha Fedorchuk, PhD in Economics
ORCID ID: https://orcid.org/0000-0003-2163-8890
Khmelnytskyi University of Management and Law of Leonid Yuzkov, Ukraine

MODELING OF INTERACTION OF THE FACTORS OF DEMAND AND SUPPLY OF ECONOMIC GROWTH

The initial essence of economic growth is to increase the potential and real gross of the national product and manifest it as an increase compared to the previous period, the value of gross domestic product per person. The Keynesian theory of economic development is based on the main postulate of J. Keynes – aggregate demand, so while the development of economic and mathematical models describe economic growth, the key parameter remains the growth of aggregate demand. The offer and the factors that affect the supply and demand remain outside the models.

The article schematically shows the relationship between demand factors, supply factors and economic growth. Supply factors have a direct impact on economic growth, but quantitatively depend on demand factors, mainly on investment. With the help of the apparatus of differential calculus the model of distribution of innovations as the basic condition of intensification of factors of the offer was created. Based on it, the process of innovation of the factors of supply of economic growth has been modeled. At the same time, the innovation model based on the innovation lag has been created. Taking into account formalized schemes and created models, and applying integral calculus, three-factor and one-factor production functions with the corresponding equations of integral figure and curve have been derived.

The growth of fixed capital accumulation ensures its share in GDP of less than 15%. This is much less than the average world's minimum of 22-24%. It means, that these funds are not enough to reproduce the demolished production facilities and social facilities. Accordingly, there are almost no financial resources for basic innovations and technological renewal of the economy. The first investment steps should be taken by the state in conditions of complete deficit of investment resources in the real, research and socio-economic sectors of the national economy and with limited opportunities for public investment with the simultaneous presence of a high degree of risk Therefore, effective methods of debt management in line with sustainable economic growth will allow businesses not only to intensify but also to qualitatively expand their activities with subsequent positive consequences, including solving existing socio-economic and environmental problems and strengthening national security.

Keywords: economic growth, demand factors, supply factors, investment, innovations, model, equation.

Introduction. Economic growth is the ultimate goal of managing the national economy. Actually, its size and steady dynamics guarantees successful social-economic development, full employment and the stable level of welfare of the population. In our opinion, there are direct and indirect factors of economic growth. Since the second group covers regulatory documents, mentality and the quality of public administration, we will consider the first group. The latter include factors of supply and demand, which are the productive components of economic growth. The Keynesian direction of economic theory has favoured demand factors: investing, consuming and saving using the accelerator and multiplier effect. The classical economic theory and its followers considered determinant the following factors of supply: labour, capital, land, knowledge, information, human capital, entrepreneurial abilities, scientific-technological progress, innovations, creating the corresponding production functions.

The analysis of the recent researches. Among the scholars who paid considerable attention to the problem of economic growth and its modelling, it is worth mentioning such as F.Aggiion[1], D.N.Veyl[2], E.Denison[3], O.Domar[4], P.Douglas[5], K.Kobb[6], R.Lukas[7], G.Mankiv[8], G.H.Mead[9], I.Radionova[10], J.V.Robinson[11], D.Romer[12], P.M. Solow[13], J.Tinbergen[14], E.Hansen[15], R.Harrod[16], R. Hicks[17], P.Hovitt[18], and others. So while the development of economic and mathematical models describe economic growth, the key parameter remains the growth of aggregate demand. The offer and the factors that affect the supply and demand remain outside the models.

Methodology and research methods. With the help of the apparatus of differential calculus the model of distribution of innovations as the basic condition of intensification of factors of the offer was created. Based on it, the process of innovation of the factors of supply of the economic growth has been modelled. At the same time, the innovation model based on the innovation lag has been created. Taking into account formalized schemes and created models, and applying integral calculus, three-factor and one-factor production functions with the corresponding equations of integral figure and curve have been derived.

The aim of the research is to create the model of interconnections of factors of demand and supply of economic growth and implementation of statistical prediction.

We will try to formalize intra- and between-group interconnections of factors of economic growth.

Research results. Let's start with the supply factors. Definitive active is labour (*L*), and the determining passive – land, or natural resources (*N*). The result of their interaction is capital (*C*):

$$L + N = C \Leftrightarrow g \tag{1}$$

It was from this process that economic growth began (*g*). Subsequently, the capital actively interacts with labour and land, increasing production volumes and accelerating economic growth:

$$\sum\left(N+L+C\right)_1 \to GDP_o < GDP_1 \Leftrightarrow g_1 \uparrow > g_0 ... \sum\left(N+L+C\right)_n \to GDP_{n-1} < GDP_n \Leftrightarrow g_n \uparrow > g_{n-1} ... \tag{2}$$

where GDP_o is the previous social product, and GDP_1 – the next social product. Work is gradually being enhanced by knowledge (*K*) and information (*In*), which collectively forms human capital (*H*):

$$L + K + In = H \tag{3}$$

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Accordingly, its qualitative-quantitative parameters influence the degree of use of natural resources and physical capital, and consequently affect the level of scientific and technological progress (*e, i*):

$$\begin{array}{ccc} H + C + N & \rightarrow & H^i + C^i + N^i \rightarrow i_0 < i_1 < i_2 ... < i_n ... \\ \downarrow & & \downarrow \\ GDP & < & GDP^e \\ \downarrow & & \downarrow \\ g & < & g^e \rightarrow e_0 < e_1 < e_2 ... < e_n ... \end{array} \tag{4}$$

It should be noted that the parameters *e* and *i* are the positive influence of the scientific-technological progress. However, the magnitude *i* shows the degree of efficiency, productivity and impact of production factors due to their modernization. Instead, the indicator *e* is the proportion of the science-intensive, creativity and innovation of GDP. If the state and the private sector contribute to scientific-technological development, then the indicators *e* and *i* have and tend to increase with all positive impacts for the population, economy and environment[1].

Having briefly described the relationship between the factors of the supply, let's turn to the factors of demand of economic growth. They originate from the creation of the initial public product:

$$L + N = C \Leftrightarrow g \Leftrightarrow I \tag{5}$$

where *I* stands for investments. In the course of growth of the social product, the volume of all factors of the demand of economic growth increases:

$$\sum (N + L + C) \uparrow \rightarrow GDP_o < GDP_1 \uparrow \rightarrow \sum \left(I + S_a + S_p + Cn\right) \uparrow \rightarrow GDP_2 \uparrow \Leftrightarrow g \uparrow \tag{6}$$

It is worth noting that the most effective demand factors are consumption (*Cn*), investment (*I*) and active savings (S_a), when passive savings (S_p) inhibit economic development until it becomes the active savings or direct investments. In fact, consumption and savings are also transformed into investments through the process of buying and selling goods and services, purchasing securities and bank deposits.

We should add that innovation of supply factors is impossible without investing:

$$\left(I + S_a + S_p + Cn\right) \uparrow \rightarrow I^i \uparrow \rightarrow \left(H^i + C^i + N^i\right) \uparrow; \quad i \uparrow \rightarrow GDP^e \uparrow; \quad e \uparrow \tag{7}$$

Thus, we have seen that the factors of demand and supply of economic growth do not bring beneficial effect on their own and separately from each other, but only in close interaction and mutual reinforcement.

Consequently, the schemes (6) and (7) can be simplified and reduced to direct dependence of national production, economic growth and innovative development on investments:

$$GDP = f(I); \quad g = f(\Delta I); \quad e, \quad i = f(I) \tag{8}$$

The experience of advanced innovation-oriented countries proves that the speed of the dissemination of innovations is proportional to their number, provided that sufficient investment resources are available. Since the number of scientific discoveries, creative ideas and intentions is quite large, it can be assumed that the number of practical innovations over time changes continuously. Then, the speed of growth of innovations is called the speed of their dissemination.

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If $\iota(t)$ stands for the number of scientific discoveries, creative ideas and intentions at the moment of time t, then $\frac{d\iota}{dt}$ will be the speed of innovations dissemination.

Since the speed of the dissemination of innovation $\frac{d\iota}{dt}$ is proportional to the number of scientific discoveries, creative ideas and intentions, then appears constant κ such that:

$$\frac{d\iota}{dt} = \kappa\iota \tag{9}$$

By hypothesis $\iota(t)$ and $\iota'(t)$ are inalienable, that is why the coefficient κ is also inalienable. Obviously, they examine only the chance $\kappa > 0$, because when $\kappa = 0$ there won't be innovations dissemination. The equation (9) is the simplest example of the differential equation of innovations dissemination, and its desired unknown is the function $\iota = \iota(t)$ which enters the equation with its derivative $\iota'(t)$. Accordingly, any function of the form $\iota = Ce^{\kappa t}$ is a solution of the equation (9). It should be mentioned that C is some constant, which is the solution of the equation (9), e is such number where the angular coefficient of the tangent to the graph of the function $y = e^x$ at a point $x = 0$ is equal to one. In other words, the number e is the basis for which the coefficient of proportionality of the innovations dissemination and their quantity, under the condition of sufficient resources of investments is equal to one. That is, e is the number where the derivative of the function $y = e^x$ is equal to the same function: $(e^x)' = e^x$. Thus:

$$\frac{d\iota}{dt} = \frac{d}{dt}(Ce^{\kappa t}) = C\frac{d}{dt}e^{\kappa t} = C\kappa e^{kt} = \kappa(Ce^{\kappa t}) = \kappa\iota \tag{10}$$

Let's make some remarks about how the differential equation (9) and its general solution (10) are used in the study of the process of propagation of innovations. Obviously, the coefficient κ depends on the type of innovations and external conditions (regulatory framework, degree of education, science, state policy, interest in innovations, etc.). If we know the value of the coefficient κ and the volume μ_0 of innovations at some point in time t_0, then by the formula (10) we find their volume at any time t. Let $\iota(t_0) = \mu_0$, then $\mu_0 = Ce^{\kappa t_0}$, $C = \mu_0 e^{-\kappa t_0}$, $\iota(t) = \mu_0 e^{\kappa(t-t_0)}$ and hence this function, at the same time, is the solution of equation (9), but at the same time it satisfies its initial condition.

Consequently, equation (9) has great number of solutions, and the task of the initial condition identifies single solution from this set. In practice, this situation arises quite often. It is known that some kind of innovation (for example, long-term investments in large-scale innovation projects during a military conflict, political instability, etc.) under these conditions extends according to the law $\iota = \iota(t)$ that satisfies the equation of form (9), but the coefficient κ is not known. It is necessary to determine the coefficient κ and to find the law of distribution of innovations of this type. In this case, the general solution (10) of the equation (9) has two unknowns C and κ. By the above solution from the initial condition, we find the constant C and we obtain:

$$\iota(t) = \mu_0 e^{\kappa(t-t_0)} \tag{11}$$

To find an unknown κ, we should define the volume of innovations at some point in time $t_1 > t_0$; let this volume be equal to μ_1. Then: $\mu_1 = \mu_0 e^{\kappa(t_1-t_0)}$, $\kappa(t_1 - t_0) = \ln\frac{\mu_1}{\mu_0}$ and so $\kappa = \frac{1}{t_1 - t_0}\ln\frac{\mu_1}{\mu_0} = \frac{\ln\mu_1 - \ln\mu_0}{t_1 - t_0}$.

Substituting the found value of the coefficient *κ* in the solution (11), we obtain:

$$\iota(t) = \mu_0 e^{\frac{t-t_0}{t_1-t_0}\ln\frac{m_1}{m_0}} \quad or \quad \iota(t) = \mu_0 \left(\frac{\mu_1}{\mu_0}\right)^{\frac{t-t_0}{t_1-t_0}}.$$

Modeling of the process of dissemination of innovations proves that the speed of innovations of supply factors is proportional to the number of practical innovations in qualitative improvement of the resource base. Consequently, if *λ(t)* denotes the volume of production factors that have not yet been subjected to the process of innovation by the time *t*, then the speed of innovation $\frac{d\lambda}{dt}$ satisfies the following equation:

$$\frac{d\lambda}{dt} = -\kappa x(t) \tag{12}$$

where *κ* is a positive coefficient, defined only by the type of innovations. In the equation (12) before *κ* is put a minus sign, because $\lambda(t) > 0, \quad a \quad \frac{d\lambda}{dt} < 0$. Equation (12) is called the differential equation of the innovation of the factors of economic growth. As in the previous models, any function of the form $\lambda = Ce^{-\kappa t}$ is the solution of the equation (12). Accordingly, *e* is the number where the angular coefficient of the tangent to the graph of the function $y = e^x$, at the point $x = 0$ is equal to one. In other words, the number *e* is the basis for which the coefficient of proportionality is equal to one, that is, *e* is the number where the derivative of function $y = e^x$ is equal to the same function: $(e^x)' = e^x$. Constant *C* is the arbitrary value that specifies general solution of the equation (12). It can be found from the initial condition at some time t_0. Let $\lambda(t_0) = \nu_0$. Then under the condition $t = t_0$, we get $C = \nu_0 e^{\kappa t_0}$. So, the solution of the model will be:

$$\lambda = \nu_0 e^{-\kappa(t-t_0)} \tag{13}$$

In practice, the speed of innovation of the factors of the supply of economic growth is characterized by the so-called time lag – the period between the birth of the scientific or creative idea and the first impact from its practical application. Let's denote this period through *T* and express *κ* through *T*. Proceeding from the equation (13), under the condition $t = t_0 + T$ we get $\frac{\nu_0}{2} = \nu_0 e^{-\kappa T}$, and then $\kappa T = \ln 2, \quad \kappa = \frac{\ln 2}{T}$. Thus $\lambda = \nu_0 e^{-\frac{t-t_0}{T}\ln 2} \quad or \quad \lambda = \nu_0 2^{-\frac{t-t_0}{T}}$. In particular, if $t_0 = 0, \quad then \quad \lambda = \nu_0 2^{-\frac{1}{T}}$.

It should be noted that the process of innovation of production factors, and thus the creation of higher-quality resources, satisfy the following condition: the speed of quantitative-qualitative change of the factors of the supply of economic growth is proportional to some function from their available quantity and the degree of quality at the time considered. Let's assume that *λ(t)* are the quantitative-qualitative parameters of the production factors at time *t*. Then for the process under consideration, the equation $\lambda' = \kappa f(\lambda)$ is valid, where *f* is a function of *λ* that characterizes this process, and *κ* is the coefficient of proportionality. The coefficient *κ* can be constant, that is, it does not depend on the time *t*, but it can also depend on *t*. For example, in the equation of dissemination of innovation, the coefficient *κ* will not be constant if the conditions (regulatory framework, degree of education, science, state policy, interest in innovations, etc.), under which the innovations disseminate, change. Consequently, in the general case we have the equation $\lambda' = \kappa(t) f(\lambda)$.

Now let's move on to the modeling of economic growth by supply and demand factors. Let's assume that *G* is a set of points of the plane *M*, on which the volumetric coordinate system is introduced, and let *x, y, z* are the coordinates of the point *M*. Since between the points of the plane and the pairs of numbers $(x;\quad y;\quad z)$ there is mutually single-valued liability, we assume that *G* is the set of points $(x;\quad y;\quad z)$.

The conformity *f*, which for each point $(x;\quad y;\quad z)$ of the set *G* matches a certain real number $f(x;\quad y;\quad z)$, is called the function of the point $(x;\quad y;\quad z)$, or the function of three variables. In our case, the three-factor production function $GDP^e = f(H^i;\quad C^i;\quad N^i)$ parameters of which *x, y, z* are defined on the set *G* – $f: G \rightarrow R \quad or \quad f(x;y;z) \quad (x;y;z) \in G$. We deduce the equation of the curve of this production function, which at each of its points is tangent to the given angular coefficient $f(x;\quad y;\quad z)$. In other words, we need to find the function $y = \varphi(x;\quad z)$ that satisfies the equation $y' = f(x;\quad y;\quad z)$, where *y'* is the derivative of *x* and *z* from the desired function. This equation is called the differential equation, the function *φ(x; z)* is its solution, and the figure given by the equation $y = \varphi(x;\quad z)$ is the integral one.

We focused our attention on the fact that the quantitative-qualitative parameters of the supply factors completely depend on the amount of investment. Let's consider one single case. Suppose that the function *f* depends only on *x* (single-factor production function $GDP^e = f(I^i)$) and is defined on some interval $]a;\quad b[$. Then the equation $y' = f(x)$ is solved with the help of indefinite integrals, where all solutions are given by the formula $y = \int f(x)dx$. This formula has the implicitly arbitrary constant *C*. Indeed, if *F(x)* is some initial function of *f(x)*, then $y = F(x) + C$. Consequently, the equation $y' = f(x)$ has many solutions. Any curve, given by the equation, $y = F(x) + C$ with the fixed *C*, is the solution of the given task. It is known from the theory of definite integrals that any continuous function $f(x)$ has primitive, and this primitive is the integral with variable upper line. So, $y = \int_{x_0}^{x} f(t)dt + C \quad or \quad GDP^e = \int_{I_0^i}^{I^i} f(t)dt + C$. The curve given by this equation passes through the point with coordinates $x_0, \quad C$. So, through every point $(x_0;\quad y_0)$ where $x_0 \in]a;\quad b[$ passes the single integral curve $y = \int_{x_0}^{x} f(t)dt + y_0 \quad or \quad GDP^e = \int_{I_0^i}^{I^i} f(t)dt + GDP_0^e$.

Before switching to statistical simulation, the brief analysis of investment policy and economic growth in Ukraine should be undertaken. After the long recession that started in 2012, Ukraine's slow economic growth rate of 1.3% was recorded in 2016. Its reasons were rather unexpected and consist in adapting the national business to complex macroeconomic, political, military and foreign economic realities, which contributed to the active increase in capital investment. At the same time, national producers try to stay in the markets, competing with foreign firms. It should be noted that the gross accumulation of the basic capital in comparison with 2015 increased by 16.7%. Among the spheres of economic activity, agricultural enterprises lead by the growth rate of investment by (+ 64.3%). Thus, the transport and communications sector is followed by the index of + 22.9%. Industry is characterized by the increase in investment of 15.5%[1]. The access to external and internal liquid resources has caused the concentration of capital investment in these areas. Reinvestment of the own funds has become the significant source of financing of investments of economic entities. The reason for the active growth of investments in utilities was the increase in the share of their financing from the state and local budgets from 4.4 to 5.9%. However, capital expenditures of the consolidated budget of Ukraine are executed less than 70%. The policy of fiscal decentralization contributed to the increase in the share of investments from local budgets to 4.8% of total expenditures[2].

[1] Fasolko, T., Chaikovska, I. (2017). Economic and mathematical model of the distribution of the borrowed money as debt management tool. *Financial and Credit Activity: Problems of Theory and Practice (Web of Science)*, 328-336. DOI: https://doi.org/10.18371/fcaptp.v2i23.96023. http://fkd.org.ua/article/view/96023.

[2] Ibid.

In addition, in Ukraine, there is a noticeable increase in foreign direct investment, which is a positive signal for the national economy. According to the Doing Business rating, Ukraine ranks the 80th among 190 countries of the world. This is three positions higher than in 2018. World Bank experts note that one point in the Doing Business rating will allow the country to additionally attract 500-600 million American dollars of investment resources. It is not difficult to see that in 2020, it is planned to decrease the volume of foreign direct investment in Ukraine.

It should be mentioned that the growth of accumulation of the basic capital ensured its share in GDP less than 15%. This is much less than the minimum-needed average world index of 22-24%. That is, these funds are insufficient for reproduction of worn-out production facilities and social objects. Accordingly, for basic innovations and technological renovation of the economy, there are almost no financial resources. It should be noted that in the advanced countries this index is higher than the average in the world, and every year the innovation gap between Ukraine and the leading national economies grows and deepens the gap of competitiveness for domestic goods.

Having studied the statistical data, we received the dynamics of financial (direct foreign) and capital investments in comparison with GDP of Ukraine for 2006-2019 (Table 1).

Table 1

Dynamics of GDP and Investment Volumes in Ukraine [12]

Year	Capital investments	Foreign direct investments in Ukraine (mln. UAH	Total	GDP (mln. UAH)
2006	13958	28300,22	42258,22	544153
2007	17552	49949,55	67501,55	720731
2008	19481	57481,08	76962,08	948056
2009	21410	37522,35	58932,35	913345
2010	189061	51541,84	240602,84	1082569
2011	259932	58156,02	318088,02	1316600
2012	293692	67334,22	361026,22	1408889
2013	267728	35708,55	303436,55	1454931
2014	241764	4873,55	246637,55	1566728
2015	215800	64682,17	280482,17	1979458
2016	289836	69371,22	359207,22	2383182
2017	265832	48271,14	314103,14	2982920
2018	268141	40756,61	308898,61	3558706
2019	303624	37439,14	341063,14	3974564

To study this dependence, we use the method of statistical equations and dependencies of O.I. Kulynych, the calculation of parameters of which is based on the computation of the comparison coefficients, which determine the ratio of the individual values of the sign to its minimum level. The comparison ratios will show the degree of change in the value of the sign to the acceptable comparison base. On the basis of the comparison coefficients of the resultant and factor characteristics, we calculate the parameter of the equation of dependence. To calculate the equation parameters, we use the author's program product by R.O.Kulynych "Estimation of single-element dependencies of economic phenomena and processes by the method of statistical equations of dependencies".

The program offered the best function "Logical Direct Dependence" (LDD):
LDD No1:

$$Y_X = \frac{1}{\frac{1}{y_{\min}} - bd_{\frac{1}{x_{\min}} - \frac{1}{x_i}}} \qquad (14)$$

The program has made the necessary calculations. The levels of the correlation coefficient $r_{xy} = \frac{\sum d_x d_y}{\sqrt{\sum d_x^2 \sum d_y^2}} = 0,99$ and the index of correlation $R = \sqrt{1 - \frac{\sum \left(d_y - d_{yx}\right)^2}{\sum d_y^2}} = 0,99$ coincide, which means that there is a close link between the total investment and GDP, and the high value of the correlation index confirms the correct choice of the type and direction of correlation.

To evaluate the stability of the correlation between the data, we calculate the coefficient of stability of the correlation $K = 1 - \frac{\sum \left| d_y - bd_x \right|}{\sum d_y} = 0,853$. The calculated value indicates high level (from 0,8-0,9) of the stability of this dependence, which makes it possible to carry out econometric calculations. The parameter *b*=0,061 in this equation means that when the magnitude of deviations of the coefficient of comparison of the factor mark per unit changes, the size of the deviations of the theoretical values of the resultant trait increases by 0.061 times. Consequently, the dependence equation, according to our statistics, has the form:

$$Y_X = \frac{1}{\frac{1}{y_{\min}} - bd_{\frac{1}{x_{\min}} - \frac{1}{x_i}}} = \frac{1}{4,19 - 0,061 d_{\frac{1}{x_{\min}} - \frac{1}{x_i}}} \qquad (15)$$

Conclusions. Despite positive developments, Ukraine's economy needs a thorough structural adjustment and comprehensive modernization. As it was noted, the modern world economy generates active introduction of innovations in all spheres of the economy. Consequently, it becomes impossible without investments in innovations, and the latter are entirely dependent on the favourable regulatory, political and military climate. Nowadays it is necessary to implement a series of anti-corruption measures and demonopolization of the economy. If in the coming years effective reforms are implemented and the military conflict is settled down in Ukraine, the national economy can reach the level of the highly developed countries, as even under the current difficult conditions there is slight recovery.

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