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Estimation of the impact of investment in fixed assets and employment on GDP using the Cobb-Douglas function

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Abstract. The main objective of the study is to determine the degree of influence of labor and investment in fixed capital on the total volume of output in Kazakhstan. The paper uses the multiple regression analysis method based on the Cobb-Douglas production function. The results of the empirical analysis showed that with a change in investment in fixed capital by 1%, the volume of production will increase by an average of 0.747%. Accordingly, with a change in the number of employed people by 1%, the volume of production will increase by an average of 2.589%. The study revealed a low contribution of technological progress to the development of the manufacturing industry. Based on the analysis, a conclusion was made about the presence of increasing returns to the scale of production, since the sum of the elasticity coefficients of production for capital and labor is greater than one. The high rate of contribution to labor costs (2.589%) indicates that the growth of labor intensity in the manufacturing industry of Kazakhstan has a stimulating effect on the economic growth of production, and also brings a positive economic effect to production.

Keywords: investment in fixed capital, employment, output, Cobb-Douglas function, economic growth.

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Introduction

The development of the manufacturing sector plays an important role in economic development and the standard of living of the population. Analysis of factors influencing product output is the focus of attention of the state and researchers. Currently, there is a need for an objective assessment of the current situation in the development of the manufacturing sector in Kazakhstan and the influence of various factors that determine the state of the production sector in the country's economy. This paper measures the contribution of labor factors and fixed capital investment to total output using statistics from 2000 to 2023 and the Cobb-Douglas production function.

The Cobb-Douglas production function is typically used in economics to describe a technological process where the output of a good is produced from inputs such as labor (L) and capital (K). The model includes data processing and analysis, regression analysis, calculation of statistical indicators and visualization of results. The Cobb-Douglas function's connection to investment lies in its ability to model the impact of changes in the stock of capital on total output. In the context of investment, capital can be thought of as investment in physical capital (eg machinery, equipment, buildings), and the function shows how increased investment can stimulate production. An important characteristic is the ability to calculate returns to scale of production. Thus, the Cobb-Douglas function provides a framework for analyzing the impact of investment on economic growth and productive capacity, making it an important tool in economic planning and policy.

The main goal of the study is to determine the degree of influence of labor factors and investments in fixed capital on the total volume of output in Kazakhstan.

Regression analysis based on the Cobb-Douglas production function allowed us to calculate the coefficients of technological progress, labor costs and capital investments. Each of which demonstrates their contribution to the development of the manufacturing sector of Kazakhstan. Based on the results of the empirical analysis, shortcomings were identified and proposals were made for the further development of the manufacturing sector in Kazakhstan. The low technological level has a negative impact on the development of production; The labor market plays an important role in stimulating the manufacturing sector of the Kazakhstan economy.

Literature review

The Cobb-Douglas production function is the most popular tool in analyzing production volume and the factors influencing it. Estimating the parameters of aggregate production functions is central to much contemporary work on growth, technological change, productivity and labor [1].

The Cobb–Douglas generalized production function formulation is widely used in various fields of economics, not limited to the industrial field, and is undoubtedly one of the most widely used concepts in economics [2].The function allows us to obtain a technological coefficient reflecting the total productivity of factors, as well as elasticity with respect to labor and capital.

The model is widely used to analyze production processes in various sectors of the economy. Empirical research confirms that the Cobb-Douglas production function generally describes the

relationships between inputs and outputs in production processes well, especially over large time and geographic scales [3].

Despite its popularity, the model has some limitations, such as the assumption of constant returns to scale and failure to take into account the dynamics of changes in technologies and resources [4]. The literature has also explored adaptations of the Cobb-Douglas model to account for the specific characteristics of industries and regions [5].Some economists have criticized the Cobb-Douglas model for its simplistic assumptions and have proposed alternative models that take into account more complex relationships among production factors [6]. But despite the critical analysis, there are many researchers who study the impact of fixed capital investment and labor on output using the Cobb-Douglas function. Thus, the following scientists can be noted: Robert Solow is known for his work on economic growth and production theory [7]. His research often uses models based on the Cobb-Douglas function to analyze the impact of investment in capital and labor on economic growth; Stiglitz J. touch on production functions and their application in macroeconomic analysis [8].Rahim A. et al., AktürkE. et al. study the impact of investment in capital and labor on production processes and economic growth, using the Cobb-Douglas function as one of the basic models for analyzing data in various industries and countries [9, 10].

The study of the impact of fixed investment on output is a key topic in economics, especially when using the Cobb-Douglas production function and other models. PeterP., Enaami at all consider the main theoretical problems that arise when calculating the dependence of production volume on the amount of production resources used, such as labor and capital [11, 12]. Investment in fixed assets such as machinery, equipment, buildings and infrastructure are considered key factors determining the level of production.

Many empirical studies confirm the positive impact of investment in fixed capital on production processes and economic growth [13]. Increased capital investment typically results in increased productivity, improved technology, and expanded production capacity.

Biddle J. examines the role of technological progress in economic growth. As the author notes, investment in fixed assets also stimulates technological progress, which can improve the efficiency of production processes and facilitate the creation of new products and services [14].

Hung and Cheng consider sectoral and regional differences in production function research [15]. The impact of capital investment on output may vary depending on the economic sector and regional characteristics. For example, in high-tech industries or developing regions, investment may have a more pronounced effect on output growth [16, 17].

Methodology

This article uses a regression analysis method based on the Cobb-Douglas production function. This function is an economic and mathematical model for analyzing production factors and their role in economic development.

The Cobb-Douglas function is expressed in the following standard form:

$$Y = a_0 K^{a1} L^{a2} \quad (1)$$

Where:

– Y – production volume,

– a_0 – technological coefficient reflecting available technologies and level of efficiency,

– K is the amount of capital used,

– L is the amount of labor,

– a_1 and a_2 are the elasticities of production for capital and labor, respectively, showing how much the volume of production will change if one of these factors changes by one percent.

Output elasticity measures the responsiveness of output to changes in the level of labor or capital used in production, other things being equal. Sometimes the meaning of this term is stricter, requiring that the function display a constant scale of returns. This means that doubling the use of capital K and labor L will also double output Y. This is true if $a_1 + a_2 = 1$.

There are several possible relationships between a1 and a2:

– $a_1 + a_2 > 1$ indicates increasing returns to scale. Under existing conditions, it is beneficial to expand the scale of production to increase output.

– $a_1 + a_2 < 1$ indicates diminishing returns to scale. Under existing conditions, expanding the scale of production leads to a decrease in output.

– $a_1 + a_2 = 1$ indicates that production has constant returns to scale, which means that doubling all input factors will result in doubling output.

Thus, the Cobb-Douglas function provides a framework for analyzing the impact of investment on economic growth and productive capacity, making it an important tool in economic planning and policy.

To visualize the regression model, the "plotCD" function in the Python program is used. With the help of which two three-dimensional graphs are constructed: the first for a model with a constant scale of production (assuming the same elasticity of capital and labor) and the second for a model with a variable scale (with different coefficients for capital and labor). The graphs include original data points and regression surfaces, showing how output (Y) varies as a function of capital (K) and labor (L).

Results

At the first stage of constructing the Cobb-Douglas production function, statistical data was collected from the official website of the Bureau of National Statistics of the Agency for Strategic Planning and Reform of the Republic of Kazakhstan. Source data are selected for the period from 2000 to 2023 (Table 1).

Based on the Cobb-Douglas function and the collected data, a multiple regression model of a power type was built, in which output (Y) is the dependent variable, investment in fixed capital (K) and employment (L) are the independent variables.

The main task is to find the coefficients a_0, a_1 and a_2 so that the calculated Y is as close as possible to the known Y. So, in order to find the unknown parameters of the equation, the existing function (1) is transformed to a linear form. To get rid of the exponents a_1 and a_2, we logarithm the left and right sides of the production function using the natural logarithm:

$$Ln(Y) = Ln(a_0) + a_1Ln(K) + a_2Ln(L) \quad (2)$$

To get a truly linear function, let's perform a change of variables:

$$Ln(Y) = Y', Ln(a0) = a_0', Ln(K) = K', Ln(L) = L' \quad (3)$$

As a result, we obtain a linear function:

$$Y' = a_0' + a_1K' + a_2L' \quad (4)$$

Using the least squares method we will find the unknown parameters. The inputs are Y', K' and L'. Let's calculate their values using formula (3) in MS Excel (Table 1).

Table 1. Initial statistical and calculated data for Kazakhstan for constructing regression

Period	Production volume, million tenge (Y)	Investments in fixed assets, million tenge (I)	Employed population, thousand people (L)	Y'	I'	L'
2000	1 799 344	595 664	6201,0	14,4	13,3	8,7
2001	1 997 384	943 398	6698,8	14,5	13,8	8,8
2002	2 342 959	1 099 986	6708,9	14,7	13,9	8,8
2003	2 845 871	1 327 864	6985,2	14,9	14,1	8,9
2004	3 878 766	1 703 684	7181,8	15,2	14,3	8,9
2005	5 281 085	2 420 976	7261,0	15,5	14,7	8,9
2006	6 547 448	2 824 523	7403,5	15,7	14,9	8,9
2007	7 856 476	3 392 122	7631,1	15,9	15,0	8,9
2008	10 194 681	4 210 878	7857,2	16,1	15,3	9,0
2009	9 121 525	4 585 298	7903,4	16,0	15,3	9,0
2010	12 105 526	4 653 528	8114,2	16,3	15,4	9,0
2011	15 929 052	5 010 231	8301,6	16,6	15,4	9,0
2012	16 851 775	5 473 161	8507,1	16,6	15,5	9,0
2013	17 833 994	6 072 687	8570,6	16,7	15,6	9,1
2014	18 529 225	6 591 482	8510,1	16,7	15,7	9,0
2015	14 903 099	7 024 709	8433,3	16,5	15,8	9,0
2016	19 026 781	7 762 303	8553,4	16,8	15,9	9,1
2017	22 790 209	8 770 572	8585,2	16,9	16,0	9,1
2018	27 218 063	11 179 036	8695,0	17,1	16,2	9,1
2019	29 380 342	12 576 793	8780,8	17,2	16,3	9,1

2020	27 028 506	12 270 144	8 732,0	17,1	16,3	9,1
2021	37 606 243	13 242 233	8807,1	17,4	16,4	9,1
2022	48 777 089	15 251 104	8971,5	17,7	16,5	9,1
2023	46 991 787	17 649 300	9534,1	17,8	16,7	9,2
Note – Compiled by the authors based on source [18] and formula (3)						

Next, we will build a multiple regression to find the required coefficients using the "Data Analysis" package of the MS Excel program. As a result, the following data were obtained (Table 2).

Table 2. Regression results

Regression statistics				
Plural R	0,991744			
R-square	0,983556			
Normalized R-squared	0,98199			
Standard error	0,133008			
Observations	24			
Analysis ofvariance				
	df	*SS*	*MS*	*F*
Regression	2	22,22071	11,11035	628,0216
Remainder	21	0,371512	0,017691	
Total	23	22,59222		
	Coefficients	Standard Error	t-statistic	P-Value
Y-intersection	-18,4835	9,852631	-1,87599	0,044626
I'	0,747766	0,159749	4,680878	0,000128
L'	2,589147	1,36336	1,899093	0,041377
Note: Compiled by the authors based on data obtained using MS Excel				

According to Table 2, both coefficients have a positive sign, which means the relationship between the factors is direct, that is, an increase in each factor leads to an increase in output. Thus, the elasticity of production with respect to capital was 0.747, which indicates that with a change in investment in fixed capital by 1%, the volume of industrial production will increase on average by 0.747%. Accordingly, if the employed population changes by 1%, the volume of industrial production will increase on average by 2.589%.

Since the sum of the elasticity coefficients of production for capital and labor ($a_1 + a_2$) is equal to 3.34, that is, more than one, it means that we conclude that there are increasing returns to the scale of production.

Let's find the value of a_0, for this we transform a_0':a_0 = EXP(a_0') = 9,3914E-09.

After calculating all coefficients, it is necessary to find Y calculated. To do this, we substitute the found values of a0, a1 and a2 into the formula (1):

$$Y = 9{,}39E - 09 * K^{0{,}747} L^{2{,}589} \quad (5)$$

Formula 5 shows that in the modern development of production processes, the share of labor costs is 2.589%, which is the largest value among all production factors. This indicates that the main factor influencing the development of production in Kazakhstan is labor resources, the growth of which will lead to an increase in output. The impact of investment in fixed assets was 0.747%, which is much lower than the economic benefits brought by the labor factor. In addition, formula 5 demonstrates that the share of technological progress compared to other factors is the smallest and almost equal to zero (9.39E-09). Which indicates the low level of efficiency of available technologies in Kazakhstan. The technological coefficient is a measure of the technological level of production, which affects the total productivity of production factors (capital and labor). Although the technology coefficient brings positive economic benefits, they are quite minimal compared to other factors.

The constructed Cobb-Douglas production function is adequate to the initial data, that is, the calculated Y is as close as possible to the initial statistical data of production output. This can be visually seen in Figure 1, which demonstrates the correspondence between the calculated Y and the original Y.

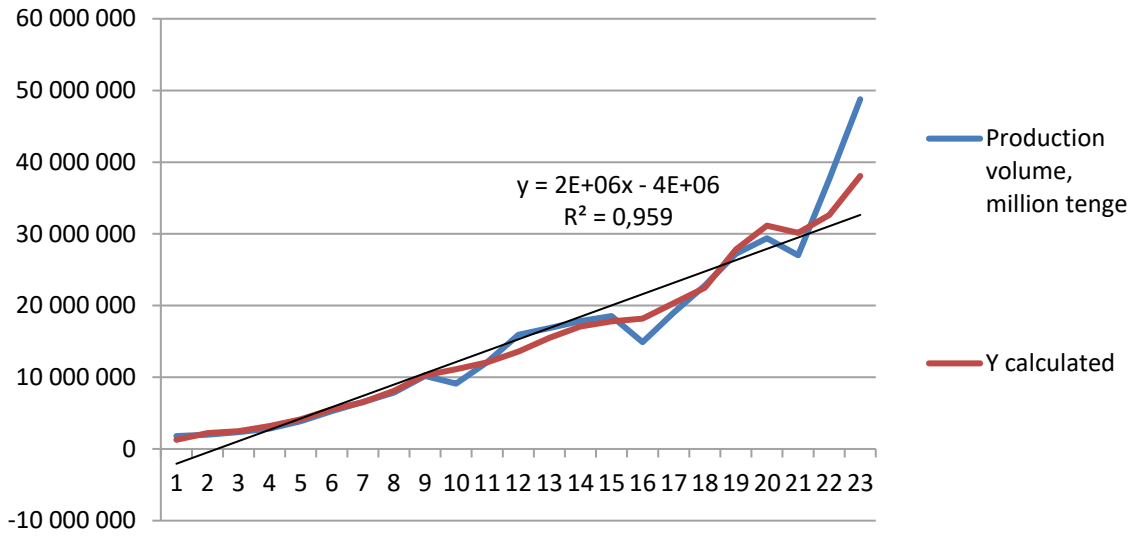


Figure 1 Estimated value of output Y

Note – compiled by the authors based on data obtained using MS Excel

Thus, based on the production function, the calculated value of output is determined, which is as close as possible to the actual values of Y.

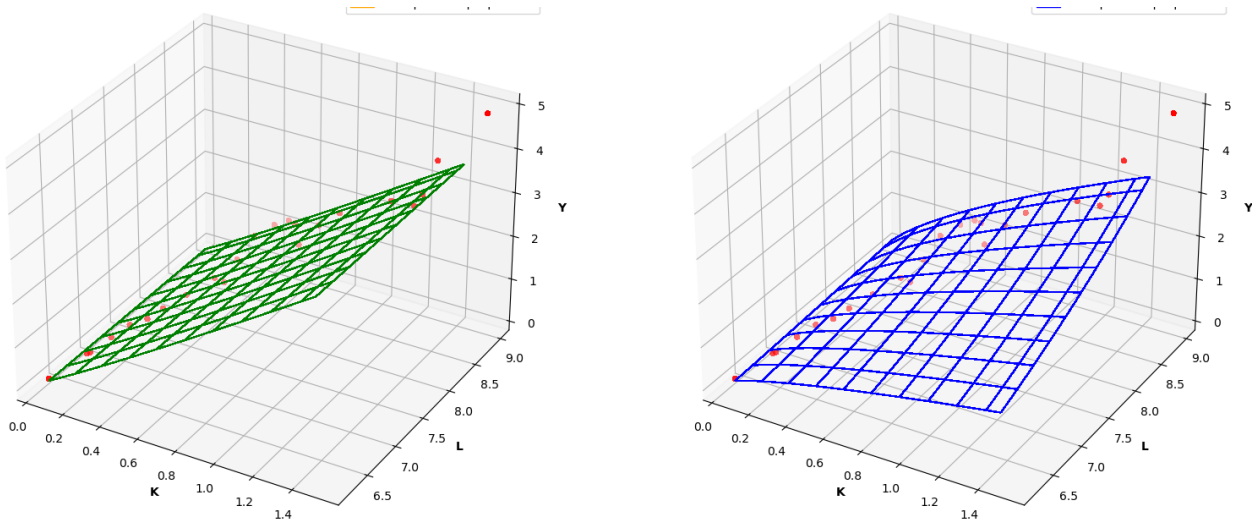
According to the regression results, the coefficient of determination (R-square) has a fairly high value of 0.98206, and the value of the normalized R-square is 0.98027, both coefficients are quite close. This result between R-squared and normalized R-squared indicates that the goodness-of-fit of the model is largely independent of the number of independent variables and

sample size. Approximately 98% of the variability in the "Output" variable is explained by the influence of the independent variables "Investment in fixed capital" and "Labor input". Which is quite a high figure.

The Fisher test is a measure of the overall significance of a regression model. A high F-statistic (547.58) and a P value close to zero (sig.0.00) indicate that the overall regression model is statistically significant.

In general, regression analysis demonstrates a fairly reliable and adequate model; there is a significant connection between investments in fixed capital, labor costs and output. The results of regression analysis indicate that the constructed production function corresponds to the initial data and can be used in the future to analyze the efficiency of resources K and L.

Based on the original data, two graphs are generated, one for constant scale values (a) and the other for variable scale values (b). Graph 2a shows the regression of output on (K) and (L) on a constant scale, while graph 2b shows the regression of output on (K) and (L) on a variable scale (Figure 2).



а) Regression of output on a constant scale

б) Regression of output on variable scale

Figure 2 Relationship between capital (K), labor (L) and production (Y) according to the Cobb-Douglas function

Note – compiled by the authors based on data obtained using the Python program

The image shows two 3D surfaces, each showing specific regression surfaces for the same set of data points. Both graphs visualize the relationships between three variables: (K), (L) and (Y).

The left panel (a) represents a regression model that indicates a production function with constant returns to scale, that is, doubling all inputs (such as capital (K) and labor (L)) will result in doubling output (output). This means that the production function has the same output proportions for any level of input scaling. In mathematical terms, if the production function F(K, L) has constant returns to scale, then the following formula holds:

$$F(aK, aL) = aF(K, L) \quad (6)$$

Where:

a is any positive number.

The right panel (b) represents a regression model demonstrating that the production function has variable returns to scale. Here, as the figure shows, in contrast to the left graph (a), changes in (K) and (L) lead to a non-linear change in (Y). In mathematical terms, this means that the production function does not obey rule (6). Rather, the ratio of change in output to change in input is not constant. The right graph (b) demonstrates that the labor input factor has a greater impact on production volumes than the fixed capital investment factor.

The red dots in both graphs represent real data, and the purpose of constructing a regression surface is to best approximate that data. These graphs can be used in economic modeling or other applications where it is important to understand the impact of various inputs on production performance.

Conclusion

In this article, based on the application of the Cobb-Douglas function, it was found that the influence of the labor factor on the dynamics of production volume is the largest (2.589%), which means that an increase in labor intensity in the manufacturing industry of Kazakhstan has a stimulating effect on economic growth. The impact of investment in fixed capital on production volumes was 0.747%. The study revealed a low contribution of technological progress (9.39E-09) to the development of the manufacturing industry. In the context of the Cobb-Douglas function, the resulting technological coefficient indicates the insufficient efficiency of using capital and labor to produce goods and services.

The results of the regression analysis showed the presence of a significant relationship between investments in fixed capital, labor costs and output: more than 98% of the variability of the "product output" variable is explained by the influence of the independent variables "investments in fixed capital" and "labor costs". It has been proven that the constructed production function corresponds to the initial data and can be used in the future to analyze the efficiency of resources K and L.

The trends identified during the analysis are due to the presence of certain problems in the manufacturing sector of Kazakhstan, including insufficient innovative potential, low capital investments, low level of industrial technologies and their maintenance. The following can be proposed as measures to solve existing problems:

– prioritize the development of industrial technologies and improve the management system in the manufacturing industry;

– increase the level of implementation of scientific achievements and production technologies in the industrial sector;

– improve the innovative potential of the manufacturing industry;

– introduce advanced technologies and high-tech machines and equipment into production;

– increase investment in research and development of high-tech production technologies;

– improve the quality, professional training of the workforce, purposefully train specialists for the production sector, reforms are needed in the production labor market, the movement of labor to the industrial sector of the economy and the training of professional production personnel;

– review and improve existing industrial policy.

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Contribution of the authors

All authors confirm that their authorship meets the criteria and are responsible for all aspects of the work. The greatest contribution is distributed as follows:

Atabayeva A.K. – the concept and design of the study, collection, analysis and interpretation of the results of the work, writing the text;

Kurmanalina A.K. – generalization of research materials, writing the manuscript, interpretation of the results, design of tables and figures, final approval of the manuscript version for publication;

Kalkabayeva G.M. – the idea of research, writing a manuscript, collecting and systematizing literature data, conducting a literary review, and formulating research conclusions.

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Кобб-Дуглас функциясын пайдалана отырып, негізгі капиталға инвестиция мен жұмыспен қамтудың ЖІӨ-ге әсерін бағалау

Аннотация. Зерттеудің негізгі мақсаты – Қазақстандағы өндірістің жалпы көлеміне негізгі капиталға еңбек пен инвестицияның әсер ету дәрежесін анықтау.

Бұл жұмыс Кобб-Дуглас өндірістік функциясына негізделген көп регрессиялық талдау әдісін пайдаланады. Бұл функция өндіріс факторларын және олардың елдің экономикалық дамуындағы рөлін талдаудың экономикалық-математикалық моделі болып табылады.

Зерттеу нәтижелері зерттелетін айнымалылар арасындағы оң байланысты анықтауға және зерттелетін факторлардың ұлғаюы өндіріс көлемінің ұлғаюына әкелетінін анықтауға мүмкіндік берді. Атап айтқанда, эмпирикалық талдау негізгі капиталға инвестиция көлемінің 1%-ға өзгеруі кезінде өндіріс көлемі орта есеппен 0,735%-ға өсетінін көрсетті. Тиісінше, жұмыспен қамтылған халық саны 1%-ға өзгерсе, өндіріс көлемі орта есеппен 2,737%-ға артады. Зерттеу нәтижесінде өңдеу өнеркәсібінің дамуына технологиялық прогрестің үлесінің төмендігі анықталды.

Талдау нәтижелеріне сүйене отырып, капитал мен еңбек үшін өндірістің икемділік коэффициенттерінің қосындысы бірден үлкен болғандықтан, өндіріс ауқымында өсу қайтарымы бар деген қорытындыға келді. Еңбек шығындарына салымның жоғары нормасы (2,737%) Қазақстанның өңдеу өнеркәсібіндегі еңбек сыйымдылығының артуы өнімнің экономикалық өсуіне ынталандырушы әсер ететінін, сонымен қатар өндіріске оң экономикалық пайда әкелетінін көрсетеді. Біздің ойымызша, өңдеуші еңбек нарығында, жұмыс күшінің экономиканың өңдеуші секторына қозғалысы мен кәсіби өндірістік кадрларды даярлауда реформалар қажет. Қазақстандағы өңдеу өнеркәсібінің, ғылым мен техниканың инновациялық жүйесіндегі өзекті проблемаларға инновациялық әлеуеттің жеткіліксіздігі, капиталдық салымдардың аздығы, өнеркәсіптік технологиялардың төмен деңгейі және оларды қолдау жатады.

Түйін сөздер: Негізгі капиталға инвестиция, жұмыспен қамту, өнім көлемі, Кобб-Дуглас функциясы, экономикалық өсу

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Оценка влияния инвестиций в основной капитал и занятости на ВВП с применением функции Кобба-Дугласа

Аннотация. Основная цель исследования – определение степени влияния труда и инвестиций в основной капитал на общий объем выпуска продукции в Казахстане. В работе использован метод множественного регрессионного анализа на основе производственной функции Кобба-Дугласа. Результаты исследования позволили выявить положительную связь между изучаемыми переменными и установить, что увеличение изучаемых факторов приводит к увеличению выпуска продукции. Результаты эмпирического анализа показали, что при изменении инвестиций в основной капитал на 1% объем производства увеличится в среднем на 0,735%. Соответственно, при изменении численности занятого населения на 1% объем производства увеличится в среднем на 2,737%. Исследование выявило низкий вклад технологического прогресса в развитие обрабатывающей промышленности. По результатам анализа сделан вывод о наличии возрастающей отдачи от масштаба производства, так как сумма коэффициентов эластичности производства по капиталу и труду больше единицы. Высокая ставка вклада в затраты на оплату труда (2,737%) свидетельствует о том, что рост интенсивности труда в обрабатывающей промышленности Казахстана оказывает стимулирующее воздействие на экономический рост производства, а также приносит положительный экономический эффект производству.

Ключевые слова: инвестиции в основной капитал, занятость населения, объем выпускаемой продукции, функция Кобба-Дугласа, экономический рост

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