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Study of the Impact of Unique Technological Competencies on the Economic Growth of Large Enterprises and High-tech Industries

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Abstract. The article suggests a tool for assessing the impact of unique technological competences on the economic growth of large entreprises, companies and hi-tech industires. The main research method is a classical regression analysis used in economics, based on Cobb-Douglas function. In this work economic-mathematical model of the impact of unique technological competencies on the economic growth of high-tech enterprises and industries, representing a production function, using UTC is proposed. The significant influence of the competence factor on the economic growth of high-tech enterprises and industries is shown.

1. Introduction

To conduct the objective quantitative assessment of the impact of unique technological competencies (UTC) on the economy of enterprises and industries (for example, aerospace), it is convenient to use the regression analysis based on the growth theory [1-3]. It is possible to build an economic-mathematical model that reflects the mutual influence of the UTC, along with other factors of production, on economic indicators. Various problems of economic development analysis and forecast can be solved, using this model.

The general requirements for economic and mathematical models include:

1) adequacy – compliance of the model with its original;

2) objectivity – compliance of scientific conclusions with real conditions;

3) simplicity – clearness of the model from secondary factors;

4) sensitivity – the ability of the model to respond to changes in the initial parameters;

5) stability – a small perturbation of the initial parameters should correspond to a small change in the solution of the problem;

6) universality – model adaptability.

Economics uses the production function to model economic growth. The production function is the analytical relation that links the variable values of costs (factors, resources) with the value of output.

General view of the production function is the following:

$$Y = Y(X_1, X_2, \ldots, X_i, \ldots, X_n), \quad (1)$$

where Y is an indicator, characterizing production results; X is a factor indicator of the i-th production resource; n is the number of factor indicators.

Production functions are determined by two groups of conditions: mathematical and economic. Mathematically, it is assumed that the production function must be continuous and twice differentiable. The economic assumptions are as follows: if at least one production resource is missed, production is impossible.

The most common model that meets the specified requirements to the production functions is the Cobb-Douglas function:

$$Y = a_0 K^{a_1} L^{a_2}, \tag{2}$$

where $a_0, a_1, a_2 > 0$ are constants, $a_1 + a_2 < 1$ is the condition of diminishing return to production factors; K is the amount of funds either in terms of value or in natural quantity, say, the number of machine units; L is the volume of labor resources, also in terms of value, or in natural quantity – the number of workers, man-days, etc., and, finally, Y is the output in terms of value or in kind.

However, the classic Cobb-Douglas production function does not take into account the influence of scientific and technological progress and human capital, therefore, does not meet the objectives of this study.

The Dutch economist Jan Tinbergen, the Nobel Prize winner in economics, attempted to calculate the rate of economic growth, taking into account the factor of technological progress. He improved the Cobb-Douglas function by introducing an indicator of the rate of technological progress:

$$Y = a_0 K^{a_1} L^{a_2} e^{rt}, \tag{3}$$

where e is the base of the natural logarithm, and the e^{rt} term is the factor of the temporary (t) change in scientific and technological progress. However, it is difficult to apply this function [3].

The authors of the Mankiw-Romer-Weil model included human capital *(H)* as an independent factor of economic growth, which has an endogenous character, and the production function acquired the following form:

$$Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta}, \tag{4}$$

where α is the coefficient of elasticity of output Y according to the factor of physical capital; β is the coefficient of elasticity of output according to the human capital factor; $1\text{-}\alpha\text{-}\beta$ is the coefficient of elasticity of production according to the factor of labor;AL is the number of units of effective labor.

However, consideration of human capital in the model is made in monetary terms, according to the assessment of investment in human capital – the cost of training, education, career enhancement, health care, migration, information search, etc. At the same time, there is the lack of the influence of the abilities, capabilities and skills of scientists, engineers and other qualified workers to create monopoly products, unattainable for competitors that form the basis of innovation and scientific and technological progress.

To develop these approaches to the consideration of human capital in the economic and mathematical model of economic growth of high-tech enterprises and industries, we propose to consider the possibility to construct a production function with a neutral, according to Harrod, scientific and technical progress, of the following type:

$$Y = a_0 K^{a_1} L^{a_2} C^{a_3}, \tag{5}$$

Where $C \geq 1$ is the number of unique technological competencies, belonging to key employees of an enterprise (industry, economy).

2. Production function construction

To construct an economic-mathematical model, let us transform the equation

$$Y = a_0 K^{a_1} L^{a_2} C^{a_3} \tag{6}$$

into linear form by taking the logarithm

$$\ln(Y) = \ln(a_0) + a_1 \ln(K) + a_2 \ln(L) + a_3 \ln(C). \tag{7}$$

After substitutions

$$\ln(Y) = Y',$$
$$\ln(a_0) = a_0',$$
$$\ln(K) = K',$$
$$\ln(L) = L',$$
$$\ln(C) = C',$$

we get a linear equation:

$$Y' = a_0' + a_1 K' + a_2 L' + a_3 C'. \tag{8}$$

Next, executing the least squares method, let us define the parameters a_0, a_1, a_2, using the economic data of Rostec State Corporation (Table 1).

Table 1. Statistic data for a production function construction

Period	Y = Sales proceeds over a year, billion rubles	K = Balance cost of non-current assets, billion rubles	L = Average staff number X average monthly earnings, billion rubles	C = Estimate for the number of UTC
2011	430	291	9,82	145
2012	497	382	10,17	140
2013	597	591	10,27	165
2014	807	788	13,47	200
2015	1065	946	15,35	212
2016	1268	862	16,22	244
2017	1466	1196	18,43	236

Source: Reports on the implementation of the Innovation Development Program of Rostec State Corporation for 2011-2017

It is difficult to determine the data of quantitative evaluation C of the number of UTC in the Rostec State Corporation enterprises, due to the fact that the system-based work on the UTC identification and description has just started. As of today, preliminary work has been carried out only in two holdings of the Corporation (Table 2).

Table 2. Correlation between the number of UTC and the number of patents

Holding	The number of patents on inventions, obtained in the last three years (2014-2017)	The number of identified UTC
Holding 1	179	16
Holding 2	320	37

Source: compiled by the author.

When there is the lack of data on the total number of UTC in the Corporation, it can be assumed that the number of UTC is proportional to the number of patents on devices and production methods. The number of patents on inventions, obtained in the last three years before the reporting progressive total should be taken into account, since the introduction of the invention and its economic effect is delayed. While constructing the model, we will assume that the estimate of the number of UTC is 1/10 of the number of patents for three years. This assumption corresponds to the practice of "umbrella" patenting, when approximately 10 patents are issued to protect one basic technology.

Using the method of least squares, we get the following values of model parameters:

$$a_0 = 1.076396232,$$
$$a_1 = 0.204234015,$$
$$a_2 = 1.023199735$$
$$a_3 = 0.507745261$$

3. Checking the adequacy of the production function

In the initial approximation, the adequacy of the constructed mathematical model can be estimated by comparing the graphs of measured and calculated values of the sales revenue Y.

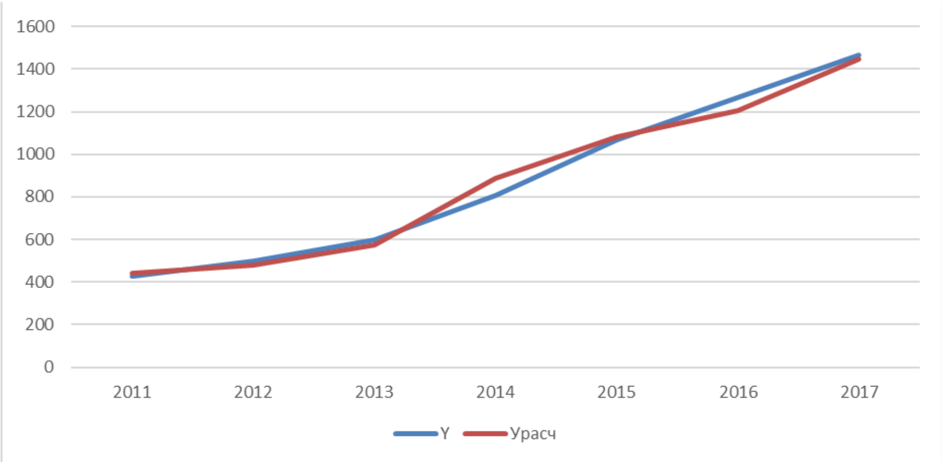

Figure 1. Comparison of statistical and calculated data

The pure mathematical test of the adequacy of the model is carried out, using the Fisher criterion.
Fisher criterion:

$$F_{est} = \frac{\sum (Y_{i\,est} - Y_{avg\,est})^2}{m} \cdot \frac{n-m-1}{\sum (Y_i - Y_{i\,est})^2} \tag{9}$$

Where α = 0.99 is the probability belief, m = 3 is the number of factors, n = 7 is the number of observations.

The mathematical model is considered adequate if

$$F_{est} > F_{table}, \tag{10}$$

where F_{table} can be determined with the help of the F.INV program of MS Excel.

In this case,

$$F_{est} = 76.51887262$$
$$F_{table} = 29.45669513$$

4. Production function analysis

Let us conduct an economic analysis of the results (Table 3).

Table 3. Economic results of the model

Period	μ_K	μ_L	μ_C	ν_K	ν_L	ν_C	γ_{KC}
2011	1,523908	45,193	3,068774	0,311234	46,24147	1,558155	5,006381
2012	1,249563	46,9907	3,421122	0,255203	48,08087	1,737059	6,806566
2013	0,970593	55,86734	3,481345	0,198228	57,16344	1,767636	8,917181
2014	1,124407	65,76124	4,432301	0,229642	67,28688	2,25048	9,79994
2015	1,144714	70,52484	5,109868	0,23379	72,161	2,594511	11,09763
2016	1,400272	74,38259	4,951783	0,285983	76,10824	2,514244	8,791578
2017	1,208185	78,4135	6,134592	0,246753	80,23268	3,11481	12,62321

Source: compiled by the author.

Average resource efficiency:

$$\mu_K = \frac{Y}{K} = \frac{a_0 K^{a_1} L^{a_2} C^{a_3}}{K} = a_0 K^{a_1 - 1} L^{a_2} C^{a_3},$$

$$\mu_L = \frac{Y}{L} = \frac{a_0 K^{a_1} L^{a_2} C^{a_3}}{L} = a_0 K^{a_1} L^{a_2 - 1} C^{a_3},$$

$$\mu_C = \frac{Y}{C} = \frac{a_0 K^{a_1} L^{a_2} C^{a_3}}{C} = a_0 K^{a_1} L^{a_2} C^{a_3 - 1}.$$

Comparing the average resource efficiency μ_L , μ_K и μ_K, we can see that the average payoff from the use of competencies essentially exceeds the average payoff from the use of capital. The average payoff from labor is even higher, which is typical for production functions, but in practice, the increase of labor consumption is possible to a very limited extent.

The average efficiency of capital for 7 years is decreasing, while the average efficiency of labor and competences is growing.

Resource limiting efficiency:

$$\nu_K = \frac{\partial Y}{\partial K} = a_0 a_1 K^{a_1 - 1} L^{a_2} C^{a_3},$$

$$\nu_L = \frac{\partial Y}{\partial L} = a_0 a_2 K^{a_1} L^{a_2 - 1} C^{a_3},$$

$$\nu_C = \frac{\partial Y}{\partial C} = a_0 a_3 K^{a_1} L^{a_2} C^{a_3 - 1}.$$

The resource limiting efficiency $\nu \nu_K, \nu_L$ and ν_C determines the extent to which the output will increase and, consequently, the revenue *Y*, if the corresponding resource (for example, the amount of fixed capital) increases by one. The limiting efficiency of the resource ν_C is more than a sequence higher than the limiting efficiency of the capital ν_K.

Elasticity of output, depending on resource consumption:

$$\delta_K = \frac{\partial Y}{\partial K}\frac{K}{Y} = \frac{a_0 a_1 K^{a_1 - 1} L^{a_2} C^{a_3} K}{a_0 K^{a_1} L^{a_2} C^{a_3}} = a_1,$$

$$\delta_L = \frac{\partial Y}{\partial L}\frac{L}{Y} = \frac{a_0 a_2 K^{a_1} L^{a_2 - 1} C^{a_3} L}{a_0 K^{a_1} L^{a_2} C^{a_3}} = a_2,$$

$$\delta_C = \frac{\partial Y}{\partial C}\frac{C}{Y} = \frac{a_0 a_3 K^{a_1} L^{a_2} C^{a_3 - 1} C}{a_0 K^{a_1} L^{a_2} C^{a_3}} = a_3.$$

The elasticity of resources in the model is constant for all resources. The coefficient $a_3 = 0.507745261,$ for example, shows that the increase of the number of used UTC by 1% leads to the revenue increase by 0.51%. In relation to the data of 2017, it means that the addition of one UTC adds 0.51/2.36 · 1466 = 317 billion rubles to the revenue of the Corporation on average.

Resource replacement rates:

$$\gamma_{KC} = \frac{\nu_C}{\nu_K} = \frac{\partial Y}{\partial C} : \frac{\partial Y}{\partial K} = \frac{a_0 a_3 K^{a_1} L^{a_2} C^{a_3 - 1}}{a_0 a_1 K^{a_1 - 1} L^{a_2} C^{a_3}} = \frac{a_3 K}{a_1 C},$$

$$\gamma_{LC} = \frac{\nu_C}{\nu_L} = \frac{\partial Y}{\partial C} : \frac{\partial Y}{\partial L} = \frac{a_0 a_3 K^{a_1} L^{a_2} C^{a_3 - 1}}{a_0 a_2 K^{a_1} L^{a_2 - 1} C^{a_3}} = \frac{a_3 L}{a_2 C}.$$

The rate of resource replacement shows the proportion of resources interchangeability at the same output.

If we reduce the consumption of resource *C* by 0.42% (this is equivalent to losing one UTC), we must increase (build up) the consumption of resource *K* (fixed capital) by 5.36%, in other words, by 64 billion rubles to maintain the output level.

We see the impact of unique technological competences level on economic growth as predicted in [4-7]. The practical ways of competence management are outlined in [8-9] for machine-buliding industry.

5. Conclusion

1. An economic-mathematical model of the impact of unique technological competencies on the economic growth of high-tech enterprises and industries, representing a production function, using UTC as one of the factors is proposed.
2. The model demonstrated the adequateness to the observed data, illustrated by the economic parameters of one of the large high-tech corporations.
3. The significant influence of the competence factor on the economic growth of high-tech enterprises and industries is shown.

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