# ECONOMIC ASSESSMENT OF INVESTMENT ON THE BASIS OF PRODUCTION FUNCTIONS

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**Abstract:** The problems of determination of volumes, areas and payback periods of break-even investment in production with the capital-labor ratio optimum of the producer are considered. A new methodological approach to project analysis based on optimal capital-labor ratio based on the most popular production functions (Cobb-Douglas, CES-function, linear function, Leontief and Allen functions) in economic studies in their classical and dynamical modifications is proposed. This paper is dedicated to the problems of forecasting of volumes, areas and payback periods of break-even investment in industry based on the most popular production functions in economic studies. Further development of the above problems at the level of theory, methodology and practical research will help to improve the investment climate in industry. The proposed methodology is exemplified on the basis of the temporal data of the industry of Ukraine in forecasting volumes and areas of break-even capital investments, payback periods and management of investment projects.

**Keywords:** economic assessment, break-even investment, production functions, dynamic modification.

## INTRODUCTION

Market relations, first of all, provide for all economic entities to abidance to the principle of breakeven business activity. Achieving the maximum of profit within the current legislation, taking into account the limitations of production resources, is the goal of entrepreneurship. This question is particular actual when investing in new or existing production. It is clear that any investor carries out a detailed analysis of financial conditions and payback periods of investment, predicts potential profit and change of its competitive position before making capital investments. Qualitative and scientifically based forecasting of investment activity is the main precondition for successful doing business in all branches and regions of the country, including food industry. It is too early to say that there is an effective investor in Ukrainian industrial enterprises. There are a number of objective and subjective factors, such as the lack of justified theoretical and methodological approaches to identifying areas and break-even points for investing in enterprises of various industries. So, most current analysts use IRR (internal rate of return) when evaluating the acceptability of investment projects. Although it is proven that it provides substantially inflated estimates of the effectiveness of planned production and financial operations [1]. The questions of the volume of investments and terms of their payback remain to be studied.

## METHODS

This paper is dedicated to the problems of forecasting of volumes, areas and payback periods of break-even investment in industrial enterprises based on the most popular production functions in economic studies. Further development of the above problems at the level of theory, methodology and practical research will help to improve the investment climate in industry. This will allow obtaining reliable forecasts of future parameters of economic systems, such as profitability, production volumes, etc. Among the most important tasks of the article are the following: determination of optimal capital-labor ratio using the most popular production functions in economic researches; substantiation of methodological approach to forecasting volumes, areas and payback periods of break-even investment in industrial enterprises; practical approbation of the proposed methodological approach to the calculation of volumes, areas and payback periods of break-even investment in industrial enterprises on the basis of production functions. The economic and mathematical apparatus of production functions was applied in the process of achieving of the goal of the article and solving of the set tasks. In particular the definition of such indicators as optimal capital-labor ratio, average and marginal returns, product elasticity by production factors, necessity for resources, etc. was carried through.

## LITERATURE REVIEW

Applied aspects of the use of production functions have been considered in the [2], where a function with constant elasticity of substitution of production factors (CES-function). In [3], the Production Function was studied with the ability to evaluate the relationship between changes in the ratio of capital to labor and the marginal rate of substitution. In [4], the features of CES and the Cobb-Douglas production function were studied to assess the possibility of forecasting production. In [5], methodological issues of applying the Cobb-Douglas production function to assess the equilibrium level of production depending on labor and capital are investigated. Henningsen, Henningsen [6] proposed a solution to the problem of estimation of the parameters of the CES-function because it has milder restrictions compared to the most popular in economic studies Cobb-Douglas production function. A certain breakthrough in the study of break-even investment in industrial enterprises with the help of production functions was observed with the appearance of scientific developments [7; 8], which defined formulas for the use of Cobb-Douglas production function in the problems of estimation of payback areas of investment for the first time.

## RESULTS AND DISCUSSION

Let us consider in more detail the aspects of determining the volumes, areas and payback periods of break-even investment in a new or already operating enterprise with the help of five production functions: Cobb-Douglas, CES-function, linear function, Leontief and Allen functions in their classical and dynamical modifications. To do this, we introduce the following notation: $Y$ – output sold; $K$ – the value of fixed assets (capital); $L$ – payroll (labor); $C$ – the cost of capital and labor for a certain output of sales, for which the relation $C = K + L$ holds. In [9] it is shown that a commodity producer is in a state of internal balance when its capital-labor ratio $K/L$ is optimal. In this case, it receives the maximum output sold of $Y_{\max}$ at a given costs of capital and labor $C_1$ (or minimizes the value of $C_{\min}$ for the fixed output sold $Y_1$). Table 1 shows the formulas of average optimal stockholding for the most popular production functions in the economic research.

Table 1. The optimal equilibrium formulas within the most popular production functions in economic studies

| The name of the production function | Optimal capital-labor ratio $K_1/L_1$ | Designation |
|---|---|---|
| 1. Cobb-Douglas production function | $\frac{\alpha}{\beta}$ | $\alpha, \beta$ – elasticity of output by factors $K, L$ ($0 < \alpha < 1, 0 < \beta < 1$) |
| 2. CES-function | $\left(\frac{A_1}{1-A_1}\right)^{\frac{1}{1+p}}$ | $A_1$ – weight factor of production factor ($0 < A_1 < 1$); $p$ – substitution coefficient ($-1 < p$) |
| 3. Linear production function | any isocost $C_1$ point only in condition $A_1 = A_2$ | $A_1, A_2$ – marginal products of production factors $K, L$ ($0 < A_1$; $0 < A_2$) |
| 4. Leontief production function | $\frac{c_1}{c_2}$ | $c_1, c_2$ – the share of costs of fixed assets and labor payment per unit of output ($0 < c_1, 0 < c_2$) |
| 5. Allen production function | $\frac{A_0 + 2A_2}{A_0 + 2A_1}$ | $A_0, A_1, A_2$ – coefficients of Allen PF ($0 < A_0, 0 < A_1, 0 < A_2$) |

Source: authors-based [9].

Then, if all the variables of the received production function are represented in value terms, the difference $Y - C = P(C)$ is the value of the potential profit from investing. The main prerequisite for such investment is its break-even, which means that the future profit $P(C)$ should not be a negative value. For Cobb-Douglas production function, the requirement is written as follows:

$$P(C) = AK^{\alpha}L^{\beta} - C \geq 0. \quad (1)$$

It is obvious that the maximum economic effect of investing in an already existing production should be expected when the values of $K, L$ of the total future investment $C$ are taken in the ratio of optimal capital-labor (see row 1 in table 1). Taking into account the equations $C_1 = K_1 + L_1$, $K_1/L_1 = \alpha/\beta$ as a result of substituting the expressions $K_1$, $L_1$ into inequality (1) we obtain:

$$A \cdot \left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta} \cdot C_1^{\alpha+\beta} \geq C_1. \quad (2)$$

Hence, the new production will be break-even when provided

$$A \cdot \left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha} \left(\frac{\beta}{\alpha+\beta}\right)^{\beta} \cdot C_1^{\alpha+\beta-1} \geq 1. \tag{3}$$

Depending on the degree of homogeneity γ of Cobb-Douglas production function, there are three possible cases:

1. γ = α + β > 1. In such a situation we can talk about the positive effect of the expansion of production. Obviously, the size of production resources that ensure the profitability of new production will be limited from below. From inequality (3) it follows that it will be break-even when provided

$$C_1 \geq \left[\frac{(\alpha+\beta)^{\alpha+\beta}}{A \cdot \alpha^{\alpha} \beta^{\beta}}\right]^{\frac{1}{\alpha+\beta-1}}, \tag{4}$$

that is, the right-hand side of inequality (4) determines the lower limit of the future capital investment of C1, beginning with which the profit of production will be positive or zero.

2. γ = α + β < 1. In this case, we can talk about the negative effect of scale-up. Obviously, the size of production resources that ensure break-even of new production, in such a situation will be limited from above. From inequality (3) it follows that it will be break-even at

$$C_1 \leq \left[\frac{A \cdot \alpha^{\alpha} \beta^{\beta}}{(\alpha+\beta)^{\alpha+\beta}}\right]^{\frac{1}{1-(\alpha+\beta)}}, \tag{5}$$

and the upper limit of investment C1 when the profit of production will be positive or zero could be found.

3. γ = α + β = 1 (with linear homogeneity of Cobb-Douglas production function) there is a zero effect of expansion of production, which means that the profitability of new production does not depend on the size of the invested total capital C1, but determined by the magnitude of the parameters of production function. Indeed, from inequality (3) follows that new production will be profitable in the condition

$$A\alpha^{\alpha}\beta^{\beta} \geq 1. \tag{6}$$

As mentioned above, in the case of modeling time series of output sold, fixed assets and labor costs according to the individual enterprise (branch, region) a dynamic modification of the classical Cobb-Douglas function the Cobb-Douglas-Tinbergen production function is used. The basic inequality for it is the following:

$$Ae^{\omega t} \left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha} \left(\frac{\beta}{\alpha+\beta}\right)^{\beta} C_1^{\alpha+\beta-1} \geq 1. \tag{7}$$

Here t is the indicated time (t = 1, 2, ..., N), ω is the growth rate of output sold Y on account of the so-called "neutral scientific and technological progress", i.e. on account of all factors except K, L.

From the formula (7) follow the expressions similar to (4), (5):

1. $\gamma = \alpha + \beta > 1$.

$$C_1 \geq \left[ \frac{(\alpha+\beta)^{\alpha+\beta}}{Ae^{\omega t}\alpha^{\alpha}\beta^{\beta}} \right]^{\frac{1}{\alpha+\beta-1}}, \quad (8)$$

2. $\gamma = \alpha + \beta < 1$.

$$C_1 \leq \left[ \frac{Ae^{\omega t}\alpha^{\alpha}\beta^{\beta}}{(\alpha+\beta)^{\alpha+\beta}} \right]^{\frac{1}{1-(\alpha+\beta)}}. \quad (9)$$

The third case (γ = α + β = 1), with the linear homogeneity of the Cobb-Douglas-Tinbergen production function, opens additional analysis possibilities which allow to estimate the payback period of future investments. Indeed, with the zero effect of expansion of production, the profit of investment does not depend on the size of the invested total capital C1, but is determined only by time t. From inequality (7) it follows that the project will be break-even when

$$e^{\omega t} \geq \frac{(\alpha+\beta)^{\alpha+\beta}}{A \cdot \alpha^{\alpha}\beta^{\beta}} = \frac{1}{A \cdot \alpha^{\alpha}(1-\alpha)^{1-\alpha}} = A^{-1}\alpha^{-\alpha}(1-\alpha)^{\alpha-1} = A^{-1}f(\alpha). \quad (10)$$

The function f (α) = $\alpha^{-\alpha}(1-\alpha)^{\alpha-1}$, which is defined in the interval [0, 1], and its natural logarithms are presented in Table 2.

Table 2. Function f (α) = $\alpha^{-\alpha}(1-\alpha)^{\alpha-1}$ values and its natural logarithms

| $\alpha$ | 0,1 | 0,2 | 0,3 | 0,4 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 |
|---|---|---|---|---|---|---|---|---|---|
| $f(\alpha)$ | 10,995 | 5,977 | 4,279 | 3,397 | 2,828 | 2,405 | 2,050 | 1,725 | 1,399 |
| $\ln f(\alpha)$ | 2,397 | 1,788 | 1,454 | 1,223 | 1,040 | 0,877 | 0,718 | 0,545 | 0,336 |

Source: Created by the authors

Logarithmic inequality (10), we obtain

$$t \geq \frac{\ln f(\alpha) - \ln A}{\omega}. \quad (11)$$

The right part (11) gives an opportunity to determine the time t1, from which the planned investment becomes profitable. It is clear that researchers will be interested in the non-negative values of time t0 follow from inequality (11). Therefore, with positive "neutral scientific and technological progress" (ω > 0), the inequality lnf(α) > lnA must be satisfied. With negative "neutral scientific and technological progress" ($\omega < 0$) it is opposite: $\ln f(\alpha) < \ln A$. Thus, in the first case ($\omega > 0$) at $\alpha \approx 0.5$ (the elasticity of production by production factors is approximately the same) according to the table 2, the inequality $\ln A < 1.04$ must be satisfied, and in the second case, the inverse $\ln A > 1.04$. Scale parameter A, while all other parameters are equal, characterizes the efficiency of the studied market and production system: the higher the A, the higher its productivity, and vice versa. In the case of a positive effect of expansion of production ($\gamma = \alpha + \beta > 1$), parameter A is related to the value C by inverse dependence (see formulas (4), (8)). Therefore, we can make the following conclusion: in the conditions of effective functioning of the market-production system (parameter A is high) the break-even areas of investment are determined by low values of the initial capital C. And, conversely: at inefficient functioning of the market-production system (parameter A is low) break-even areas of investment are determined by the high values of the initial capital C.

In the case of a negative effect of expansion of production ($\gamma = \alpha + \beta < 1$), parameter A is related to the value C with a direct dependence (see formulas (5), (9)). Therefore, we can make the following conclusion: in the conditions of efficient functioning of the market-production system (parameter A is high) break-even areas of investment are determined by high values of the initial capital C. And vice versa: in case of inefficient functioning of the market-production system (parameter A is low), break-even areas of investment are determined by low values of the initial capital C. With the linear homogeneity of the Cobb-Douglas-Tinbergen production function ($\gamma = \alpha + \beta = 1$), the efficiency of the market-production system is not related to the break-even areas (values of initial capital C). In this case, parameter A indirectly and inversely makes influence on time t (see formula (11)). As an example of the use of production functions to determine the value of the additional investment C1 and the area of break-even investment in existing production (within the real demand for bakery products) let us consider the calculations made by the authors according to the data of the bakery enterprise of Southern Ukraine for 8 years (t = 8). Obtained Cobb-Douglas-Tinbergen production function has the following form:

$$Y = 0{,}28237 e^{-0{,}05348t} K^{0{,}09216} L^{1{,}33952}. \quad (12)$$

The logarithmic part of model (12) is statistically reliable as a whole (Fisher's F-criterion is 32.76) and by individual regression coefficients; the adjusted coefficient of determination RC2 = 0.912; standard error 0.127. The basic mathematical and statistical characteristics of bakery production calculated on the basis of production function (12) are given in Table 3.

Table 3. The basic parameters of bakery production obtained on the basis of the production function of Cobb-Douglas-Tinbergen

| Indicator | $K$ | $L$ |
|---|---|---|
| 1. Average return | $Y/K = 0{,}28237 e^{-0{,}05348t} K^{-0{,}90784} L^{1{,}33952}$ | $Y/L = 0{,}28237\, e^{-0{,}05348t} K^{0{,}09216} L^{0{,}33952}$ |
| 2. Marginal return | $\partial Y/\partial K = 0{,}02602 e^{-0{,}05348t} K^{-0{,}90784} L^{1{,}33952}$ | $\partial Y/\partial L = 0{,}37824 e^{-0{,}05348t} K^{0{,}09216} L^{0{,}33952}$ |
| 3. Elasticity | 0,09216 | 1,33952 |

| | | |
|---|---|---|
| 4. Resources required | $K=\left(\dfrac{Y}{0,28237\,L^{1,33952}e^{-0,05348t}}\right)^{10,85069}$ | $L=\left(\dfrac{Y}{0,28237\,K^{0,09216}e^{-0,05348t}}\right)^{0,74654}$ |
| 5. Capital-labor ratio | $K/L = 910379\ e^{\,0,58031t}\,Y^{\,10,85069}L^{-15,53550}$ | |

Source: Created by the authors

According to Table 3, a 1 percent increase in the cost of bakery enterprise fixed assets in the studied period led to a rise in the output of bakery products by only 0.09%, and a 1% increase in labor costs ensured an increase in production by almost 1.34%. It means that each 1 UAH invested in bakery enterprise labor costs needs only 0.07 UAH of investment to the enterprise fixed assets for the maximum production of bakery products. Such a low correspondence of live and deliberate labor indicates an excess of fixed assets and a significant unused production capacity of the studied enterprise. Since for Cobb-Douglas-Tinbergen production function (12), which describes the dependence of bakery production on the size of the more important production resources in the enterprise, $\gamma = \alpha + \beta = 0,09216 + 1,33952 = 1,43168 > 1$, then the inequality (8 ) makes it possible to find the lower limit of C1's future capital investment when production profits will not be negative. The lower level for investing in studied bakery production for the next year (at t = 9) is equal to:

$$C_1 \geq \left[\frac{(\alpha+\beta)^{\alpha+\beta}}{Ae^{\omega t}\alpha^{\alpha}\beta^{\beta}}\right]^{\frac{1}{\alpha+\beta-1}} = \left[\frac{1,43168^{1,43168}2,71828^{0,48132}}{0,28237\cdot 0,09216^{0,09216}1,33952^{1,33952}}\right]^{\frac{1}{0,43168}} = 126.018.$$

Therefore, the minimum value of start-up capital for investment in new break-even bakery production on the basis of the studied bakery enterprise was not less than 126 thousand UAH. The value of $C_1$ in this case depends inversely on the value of parameter $A$ of production function (12). The small value of parameter $A$ = 0.282 and the relatively large parameter $C_1$ = 126 thousand UAH indicate low efficiency of bakery enterprise functioning, as well as negative trends in the external environment of the enterprise. The deficiencies in the existing domestic fiscal policy of the state significantly influenced on the calculations of the parameters of the production function, which was manifested in the low values of parameter $A$ and rather large values of the $C_1$ parameter. Considering by analogy with formulas (1), (2), it is possible to determine the volumes, areas and terms of break-even investment for economic phenomena and processes that are adequately described by the CES-function, the linear function, the Leontief and Allen functions in their classical and dynamical modifications.

Classic CES-function:

$$Y = A_0[A_1K_1^{-p} + (1-A_1)L_1^{-p}]^{-\frac{\gamma}{p}}.$$

Introduce the notation:

$$\frac{A_1^{\sigma}}{A_1^{\sigma}+(1-A_1)^{\sigma}} = Q; \quad \frac{(1-A_1)^{\sigma}}{A_1^{\sigma}+(1-A_1)^{\sigma}} = M, \qquad (13)$$

where $\sigma = 1/(1 + p)$ - the elasticity of technological substitution of capital by labor.

1. $\gamma > 1$.

$$C_1 \geq \left\{ \frac{[A_1 Q^{-p} + (1 - A_1) M^{-p}]^{\frac{\gamma}{p}}}{A_0} \right\}^{\frac{1}{\gamma - 1}}. \quad (14)$$

2. $\gamma < 1$.

$$C_1 \leq \left\{ \frac{A_0}{[A_1 Q^{-p} + (1 - A_1) M^{-p}]^{\frac{\gamma}{p}}} \right\}^{\frac{1}{1 - \gamma}}. \quad (15)$$

3. $\gamma = 1$.

$$A_0 \geq [A_1 Q^{-p} + (1 - A_1) M^{-p}]^{\frac{1}{p}}. \quad (16)$$

CES-function dynamic modification $Y = A_0 \mathrm{e}^{\omega t} [A_1 K_1^{-p} + (1 - A_1) L_1^{-p}]^{-\frac{\gamma}{p}}$.

1. $\gamma > 1$.

$$C_1 \geq \left\{ \frac{[A_1 Q^{-p} + (1 - A_1) M^{-p}]^{\frac{\gamma}{p}}}{A_0 e^{\omega t}} \right\}^{\frac{1}{\gamma - 1}}. \quad (17)$$

2. $\gamma < 1$.

$$C_1 \leq \left\{ \frac{A_0 e^{\omega t}}{[A_1 Q^{-p} + (1 - A_1) M^{-p}]^{\frac{\gamma}{p}}} \right\}^{\frac{1}{1 - \gamma}}. \quad (18)$$

3. $\gamma = 1$.

$$t \geq \frac{\ln[A_1 Q^{-p} + (1 - A_1) M^{-p}]}{\omega p} - \frac{\ln A_0}{\omega}. \quad (19)$$

Since $t \geq 0$, the inequality must be satisfied:

$$\frac{\ln[A_1 Q^{-p} + (1 - A_1) M^{-p}]}{p} \geq \ln A_0. \quad (20)$$

Classic linear production function: Y = A1K +A2L.

$$A_1 = A_2 = A \geq 1. \quad (21)$$

Linear production function dynamic modification Y = A1K +A2L + Δt, where Δ is the average absolute increase in sales, which reflects the impact on Y of all factors except K and L.

$$t \geq \frac{C_1(1-A)}{\Delta} \quad (22)$$

when Δ < 0.

Leontief production function $Y = \min\left(\frac{K}{c_1}; \frac{L}{c_2}\right)$.

1. Production is in optimal conditions ($K/L = c_1/c_2$).

Then the additional C1 investment is calculated within the real demand for the products manufactured by this enterprise, provided by next ratio

$$K_1/L_1 = c_1/c_2. \quad (23)$$

2. The optimum production conditions are broken.

1) There is a relative excess of fixed assets.

Then, within the real demand for products manufactured by this producer, it is necessary to additionally attract labor in the amount of

$$\frac{c_2K - c_1L}{c_1c_2} \text{ monetary units.} \quad (24)$$

This will increase production to $K/c_1$ monetary units.

2) There is a relative excess of labor.

Then, within the real demand for products manufactured by this enterprise, it is necessary to additionally attract fixed assets in the amount of

$$\frac{c_1L - c_2K}{c_1c_2} \text{ monetary units.} \quad (25)$$

This will increase production to the level of $L/c_2$ monetary units.

Classic Allen production function $Y = A_0KL - A_1K^2 - A_2L^2$.

Introduce the notation:

$$\frac{A_0 + 2A_2}{A_0 + A_1 + A_2} = S; \quad \frac{A_0 + 2A_1}{A_0 + A_1 + A_2} = T. \tag{26}$$

$$C_1 \geq 4(A_0ST - A_1S^2 - A_2T^2)^{-1}, \tag{27}$$

Dynamic modification of Allen production function $Y = A_0KL - A_1K^2 - A_2L^2 + \Delta t$.

$$t \geq \frac{1}{\Delta}\left[C_1 - \frac{1}{4}\left(A_0STC_1^2 - A_1S^2C_1^2 - A_2T^2C_1^2\right)\right]. \tag{28}$$

**CONCLUSIONS**

Thus, the traditional use of production functions as an effective tool for mathematical and statistical modeling and forecasting can be substantially expanded and deepened by the using the most popular in economic studies production functions in their classical and modified variants. The relationships that have been based on it open up new possibilities for the researcher in forecasting volumes and areas of break-even capital investments, payback periods and management of investment projects as well as changing trading cycles [12]. As prospects for further exploration in this direction, it is necessary to point out the necessity to extend the proposed developments for other two-factor production functions, for example, to the Solow function, to production function with linear elasticity of substitution of factors, etc.

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