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METHODOLOGICAL ASPECTS OF ANALYZING AND OPTIMIZING THE PROCESSES OF INNOVATIVE RENEWAL OF ENTERPRISES' FIXED ASSETS

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Purpose. Renewal of fixed assets is the most important factor in ensuring sustainable development and competitiveness of enterprises. The process of updating fixed assets is a fundamental aspect of investment activity, directly affecting production efficiency and long-term growth. The purpose of this study is to develop and analyze a mathematical model that describes the dynamics of equipment replacement, taking into account the growth rates of the cost of fixed assets, their return on investment and service life. The study tests the hypothesis that optimizing the processes of updating fixed assets increases the efficiency of production systems by increasing their productivity and promoting sustainable technical development.

Design / methodology / approach. The study uses a quantitative and analytical approach using economic and mathematical modeling to describe the process of updating fixed assets. A structured scheme of the dynamics of equipment renewal is proposed, which allows assessing changes in the age structure and proportions of fixed assets over time. In addition, an optimization approach has been developed that takes into account an indicator that quantifies the change in return on investment during the technical update of fixed assets. Using balance sheet calculations, the study models investment scenarios and assesses the impact of different renewal strategies on production growth.

Findings. The analysis revealed the main patterns of fixed asset renewal and their impact on production efficiency. In particular, it was demonstrated that the total cost of fixed assets has a consistent growth trajectory over time. Equipment renewal also affects the age structure of fixed assets, affecting overall production efficiency.

The coefficient that takes into account the return on assets is a key indicator that shows that when the return on assets of new equipment exceeds the return on assets of existing equipment, the growth rate of production outpaces the growth rate of fixed assets. Conversely, when the return on assets decreases, production growth lags behind the growth of fixed assets.

The study illustrates how the choice of renewal strategy, investment intensity, and technological quality of new equipment together determine the overall efficiency of fixed asset replacement programs.

Practical implications. The proposed model and optimization approach provide enterprises with valuable tools for strategic investment planning and fixed assets management. In particular, taking into account the resource innovation coefficient, enterprises can make more informed decisions on the timing and scale of equipment renewal. The results obtained can be used to optimize investment strategies in order to achieve higher production efficiency. The model can be applied to various industries where capital-intensive production requires constant updating of equipment and technological progress.

Originality / value. This study contributes to the field of innovative renewal of fixed assets by introducing a new mathematical model for analyzing and optimizing this process. The inclusion of the resource innovation coefficient offers a new approach to measuring the impact of innovations on production efficiency. The results of the study create a theoretical basis for future research on investment decision-making and serve as a practical guide for enterprises seeking to improve the efficiency of their activities through optimal strategies for updating the technical base.

Key words: fixed assets, return on assets, renewal, innovation, growth rate, resource innovation coefficient.

Problem statement

Effective renewal of fixed assets is a key factor in ensuring the stable development of the enterprise. However, the choice of the optimal strategy for the reproduction of fixed assets is complicated by the need to take into account many factors that influence this process, in particular, the investment capabilities of the enterprise, the service life, and the growth rates of the cost of fixed assets, the return on investment of new and old equipment. Uncertainty in making decisions on replacing equipment can lead to a loss of productivity and a decrease in the efficiency of the enterprise's activities and competitiveness. Thus, it is relevant to study the quantitative patterns of the dynamics of the renewal of fixed assets and to develop economic and mathematical models that will allow predicting these dynamics, assessing the impact of innovative components on the growth rates of the relevant resource flows and finding optimal options for investment decisions.

Hypotheses formulation and presentation of goals

The article tests the hypothesis that optimizing the process of updating fixed assets allows for an increase in the efficiency of the production system, in particular the growth rate of production volumes, due to more rational use of investment resources and updating of fixed assets, taking into account their productivity.

The purpose of the article is to develop and analyze models of the dynamics of updating fixed assets, taking into account the growth rate of their cost, return on investment, and innovative characteristics of new equipment. The research is aimed at identifying quantitative patterns in the process of replacing existing fixed assets with new ones, developing and assessing the impact on the growth rate of production volumes of an indicator that characterizes the change in return on investment, as well as forming optimization approaches to the effective technical development of enterprises.

Analysis of recent research and publications

The issue of renewal of fixed assets and its impact on the innovative development of enterprises is the subject of research by many scientists. Considerable attention in the economic literature is paid to the issue of reproduction of fixed assets, which includes simple and extended renewal of production funds. Studies show that the renewal process affects not only the technical level of production, but also the economic indicators of enterprises, in particular labor productivity, cost of production and profitability. A number of works by domestic and foreign scientists have studied the theoretical aspects of the formation and effective use of fixed assets [1–7].

Methodological approaches to the analysis of the dynamics of fixed assets are based on the concepts of capital circulation and the accumulation of resources to finance the processes of renewal of fixed assets. In works [8–13], attention is focused on the use of mathematical models to predict the renewal rates and their impact on the economic indicators of enterprises.

The developments considered in the literature were to some extent used by us for quantitative assessment of the effectiveness of innovative renewal of fixed assets, as well as in approaches to solving the currently insufficiently studied problem – modeling the renewal process of fixed assets for the purpose of optimization, taking into account a number of factors that influence it.

Thus, the study of the patterns of the dynamics of renewal of fixed assets remains a relevant area of research, which has both theoretical and practical significance. Further development of this area will contribute to the improvement of methods of management of production assets and increasing the efficiency of investment processes at enterprises.

Research methods

The methodological basis of this study is based on a combination of quantitative modeling, mathematical analysis and optimization methods. The study is devoted to the process of innovative renewal of fixed assets, the study of the dynamics of equipment replacement, investment efficiency, the impact of innovations on production growth. The following research methods were used: economic and mathematical modeling, balance sheet method, modeling of investment strategies, optimization approach, comparative analysis of renewal scenarios, verification of empirical data.

Presentation of the main material

One of the main areas of investment activity of enterprises is the expanded reproduction of fixed assets. Accumulation resources are used for simple reproduction of FA, replacement of existing equipment with more advanced ones, updating technologies, reconstruction and new construction. There is a certain capital circulation. The introduction of new FA requires corresponding capital expenditures. During operation, the self-sufficiency of the spent funds is achieved through depreciation and profit, and an accumulation fund is created to finance the acquisition of new production assets. These new FA, even with their unchanged cost, already have new qualitative characteristics.

The methodology for analyzing the dynamics of fixed assets is based on the use of the scheme of their renewal developed by us, presented in Fig. 1, which depicts their movement over time. The specified scheme is considered in the variant T of periods (years) of equipment service and for the growth rate of the cost of fixed assets (η_F).

Year 0	Year 1	Year 2	Year 3	…
$1 \rightarrow$	η^3	$\eta^3 \rightarrow$	η^3	…
η	$\eta \rightarrow$	η^4	η^4	…
η^2	η^2	$\eta^2 \rightarrow$	η^5	…
…	…	…	…	…
η^{T-1}	η^{T-1}	η^{T-1}	η^{T-1}	…

Fig. 1. General model of the dynamics of the renewal of the FA for rates η_F

Source: *own development.*

To describe the renewal process, the diagram uses relative values that do not affect its essence.

Each column of this diagram contains the FA that are in operation in the current year under consideration. According to the diagram, FA with a value of 1 are operated for the last year and are replaced by new funds with a value of η^3 in the next year of the production system's operation. FA with a value of η are operated for the penultimate year and are replaced by new funds with a value of η^4 , etc. The retirement of funds and their replacement with new ones are shown in the diagram by arrows.

Let us build, for example, a quantitative scheme for equipment renewal at given renewal rates (η_F =1.1 – FA growth rates, FA service life T = 3) (Fig. 2).

Years	Year 0	Year 1	Year 2	Year 3
	1 →	1.331	1.331	1.331
	1.100	1.100 →	1.464	1.464
	1.210	1.210	1.210 →	1.611
Σ	3.310	3.641	4.005	4.406

Fig. 2. Model of the dynamics of the renewal of the FA for T=3 and $\eta_F = 1.1$

Source: own development.

This scheme of replacing existing equipment with new ones allows us to analyze important properties of this process. The age structure and proportions between age groups of fixed assets are described from the point of view of the time factor. From the point of view of the change in time of the total cost of FA, it can be seen that over time their total cost changes at a constant rate. The developed scheme can be generalized for any growth rates of fixed assets and their service life. This scheme also allows us to analyze the dynamics of production volumes, the number of employees and other parameters of the production system.

Based on the above scheme, we will simulate the dynamics of equipment renewal at the return on investment, which is different for existing and new equipment. This will allow us to simulate the dynamics of production volumes. We will denote the return on investment of existing and new equipment as f_1 and f_2, respectively.

Taking into account the return on investment indicators calculated for existing and new equipment, the scheme of production dynamics is as follows (Fig. 3).

Year 0	Year 1	Year 2	Year 3
$f_1 1$ →	$f_2\eta_F^3$	$f_2\eta_F^3$	$f_2\eta_F^3$ →
$f_1\eta_F$	$f_1\eta_F$ →	$f_2\eta_F^4$	$f_2\eta_F^4$
$f_1\eta_F^2$	$f_1\eta_F^2$	$f_1\eta_F^2$ →	$f_2\eta_F^5$

Fig. 3. Diagram of production dynamics for existing and new equipment

Source: own development.

According to the scheme (Fig. 3), the growth rate of production in the first replacement period is determined by the ratio:

$$\eta_P = \frac{f_2\eta_F^3+f_1(\eta_F+\eta_F^2)}{f_1(1+\eta_F+\eta_F^2)}. \quad (1.1)$$

This relationship can be expressed in the following form:

$$\eta_P = \frac{f_2\eta_F^3+f_1\ 1+\eta_F+\eta_F^2\ -f_1}{f_1(1+\eta_F+\eta_F^2)}. \quad (1.2)$$

After dividing the numerator of the fraction by the denominator, we get:

$$\eta_P = \frac{f_2}{f_1}K_{on} + 1 - K_{vyb}, \quad (1.3)$$

where K_{on} – the renewal rate of fixed assets; K_{vyb} – the rate of disposal of fixed assets.

The rate of disposal is determined by the expression:

$$K_{vyb} = K_{on} - \Delta\eta_F, \tag{1.4}$$

where $\Delta\eta_F -$ growth rate of the cost of FA ($\Delta\eta_F = \eta_F - 1$).

Thus, the growth rate of production is:

$$\eta_P = \frac{f_2}{f_1} K_{on} + 1 - K_{on} + \Delta\eta_F \tag{1.5}$$

or

$$\eta_P = \eta_F + \quad \frac{f_2}{f_1} - 1 \quad K_{on}. \tag{1.6}$$

Therefore, the growth rate of production is equal to the growth rate of FA plus some "innovation additive". In this equation, we have introduced a new indicator – the resource innovation coefficient K_{in}^F, which is defined as follows:

$$K_{in}^F = \frac{f_2}{f_1} - 1, \tag{1.7}$$

where $f_1 -$ return on investment calculated for operating FA; $f_2 -$ return on investment for new (innovative) FA.

If both capital providers are the same, the resource innovation coefficient is zero, and the growth rate of production will coincide with the growth rate of the FA. Therefore, the obtained dependence can be presented using the resource innovation coefficient and in the following form:

$$\eta_P = \eta_F + K_{in}^F \, K_{on}, \tag{1.8}$$

where $K_{in}^F -$ the resource innovation coefficient.

In its economic sense, the resource innovation coefficient K_{in}^F characterizes the change in the return on assets in the process of updating the equipment.

The given resource innovation coefficient is greater than zero if the return on assets of new equipment is greater than the similar indicator for existing equipment. In this variant of updating, the growth rate of production exceeds the growth rate of FA. Otherwise, when $f_2 < f_1$, the innovation component in the equation is negative and the growth rate of production will be less than the growth rate of FA.

In practice, in conditions of constant development of the production potential of enterprises, continuous renewal and replacement of the active part of fixed assets is carried out. At a certain time interval, equipment of at least 2 technical levels operates simultaneously in different proportions. Initially, the operating equipment prevails, and at the end of the replacement interval, the share of new equipment dominates. Depending on the intensity of the update, the period of complete replacement of equipment will be different. Such variability involves the formulation of optimization problems that relate to the choice of the most effective directions of technical development of production. In order to formulate optimization problems, it is necessary to determine the optimization criterion and restrictions that must be taken into account when choosing options for updating fixed assets. This process is dynamic and its management must take into account certain regularities characteristic of intensive production development. If there are appropriate dependencies between the growth rates of fixed assets and the factors that determine them, then it is possible to consider the problems of optimal selection of controlled parameters, for example, such as the service life of fixed assets, the relative share of accumulation, etc. To model the renewal of fixed assets at a particular enterprise, it is necessary, first of all, to take into account its initial economic state and the investment opportunities for changing this state. After that, it is necessary to solve the problem of choosing a trajectory for the transition to another state of the enterprise's production system. Let us consider the essence of optimizing the dynamics of updating fixed assets using the following example.

Let us assume that the production system consists of a set of equipment of the same type, which can be replaced by new equipment of higher productivity. At the initial point in time, the cost of fixed assets, the number of employees, and production volumes are known. At the expense of depreciation and profit, an accumulation fund is formed, which is directed to the purchase of new equipment. To simplify the considerations, we will assume that during the renewal process, during the interval of replacing existing equipment with new ones, the number of employees remains constant. Having investment funds at the initial point in time, we will purchase a certain amount of new equipment. Under conditions of a stable number of employees, it is possible to unambiguously determine the amount of equipment that is being retired. By means of balance sheet calculations, the increase in funds and production volumes is also found. Thus, for the adjacent period of time, a new state of the production system is found and, accordingly, new indicators are found – production volumes, cost of fixed assets, investment funds, and increases in production and fixed assets. For a given accumulation rate, this process can be modeled and analyzed throughout the entire interval of replacing existing equipment with new ones. This process is multivariate. It has several controllable parameters. First of all, these include the share (rate) of accumulation. To accelerate the replacement of equipment, the amount of funds for the purchase of new equipment should be increased. Thus, as a result of reducing or increasing the share of accumulation, a correspondingly lower or higher intensity of the renewal of fixed assets is achieved, that is, the duration of complete replacement is reduced or increased. The dynamics of production volumes also changes, which is determined by the productivity of new equipment under the condition of a given number of employees. In turn, when regulating the intensity of the renewal of fixed assets, the demand for products or other restrictions on its production should be taken into account. Labor resources, along with investment funds, are the second important parameter that regulates the dynamics of the development of the production system. Thus, other things being equal, more intensive renewal of fixed assets should be used to release employees.

The possibility of using new equipment for replacement, which is different in cost and productivity, i.e. has different K_{in}^{F}, causes significant variability in the process of updating the FA and, accordingly, the technical development of production. This has an impact on the resource provision of the update, on the growth rates of fixed assets and production volumes, the release of workers, etc.

Let us illustrate the approach to modeling the process of updating fixed assets using the resource innovation coefficient K_{in}^{F} (Table 1). Let us assume that at the beginning of the update the production system consists of 10 units of the same type of equipment. Each unit of existing equipment has a cost of 7 c.u., and productivity is –4 (units). Each unit of new equipment has a cost of 30 c.u. and productivity is 8 (units).

Thus, the resource innovation coefficient of existing equipment is K_{in}^{F} = -0.53, i.e. has a negative value.

Funds for investments (capital investments) in equipment upgrades are generated through depreciation deductions at the rate of 10 % and 20 % of the cost of products.

In Table 1, the indicator “new equipment” is given in the dimension, which means its quantity in physical terms.

Table 1

Technical development of production potential at $K_{in}^{F} = -0.53$

Indicators	Years of equipment replacement				
	1	2	3	…	10
Products	40.00	42.00	44.21	...	67.54
Fixed assets	70.00	81.50	94.19	…	228.37
Investment funds	15.00	16.55	18.26	…	36.35
New equipment	00.50	00.55	00.61	…	01.21
Production growth	02.00	02.21	02.43	…	04.85
FA growth	11.50	12.69	14.00	…	27.87

Source: own calculations.

Let us determine the growth rates of production volumes, which are constant throughout the replacement interval, using formula (1.8):

$$\eta_P = \eta_F + K_{in}^{F} K_{on}.$$

To do this, we calculate its components. If the volume of investment is known, then K_{on} and η_F are easily determined. Thus, in the time interval [1; 2] we have:

$$K_{on} = \frac{15}{70} = 0.214;$$

$$\eta_F = \frac{81.5}{70} = 1.164.$$

Then, from the ratio (1.8), we determine the growth rate of production volumes:

$$\eta_P = 1.164 - 0.53 \times 0.214 = 1.05.$$

Comparison with tabular data shows that the results of calculations using the theoretical formula and the direct method are equivalent.

Analysis of tabular data shows that in the process of development of production potential at the beginning of replacement, the growth rates of output volumes are 5 percent, fixed assets 16.4 percent, investment funds – 10.3 percent. Thus, the growth rates of fixed assets are higher than the growth rates of output volumes, and the growth rates of investment funds are between these two growth rates. At the end of the period of replacement of existing equipment with new equipment, the growth rates of output volumes are 68.9 %, they are significantly exceeded by the growth rates of fixed assets and investment funds (226.2 % and 142.3 %, respectively).

Thus, a negative value of the resource innovation coefficient (which means a decrease in the return on assets) significantly reduces the growth rate of production volumes and they will be even lower than the growth rate of the FA. This is a negative dynamic. But such a technique can be effective in relation to other indicators – profit, labor productivity, etc. In the case of a trend of decreasing capital return, it is advisable to increase the service life of the FA. This will reduce the renewal coefficient and, accordingly, increase the growth rate of production.

For comparison, let us consider another example of innovative updating of the equipment resource innovation coefficient K_{in}^F which is 0.089, i.e. is a positive value (Table 2). The initial conditions are identical, i.e. at the beginning of the update the production system consists of 10 units of equipment, each unit of which has a cost of 7 (c.u.), and productivity –4 (units). New equipment, which is used to replace the existing one, has a cost of 45 c.u. and productivity 28 (units).

Table 2

Technical development of production potential at $K_{in}^F = 0.089$

Indicators	Years of equipment replacement				
	1	2	3	…	10
Products	40	47.92	57.52	...	200.08
Fixed assets	70	82.54	97.74	…	323.46
Investment funds	15	17.84	21.278	…	72.362
New equipment	0.33	00.4	00.47	…	01.61
Production growth	7.92	09.6	11.28	…	32.4
FA growth	12.54	15.2	17.86	…	51.3

Source: own calculations.

As the analysis of tabular data shows, at the beginning of the renewal process, the growth rates of production volumes are 19.8 percent (and remain constant), fixed assets –17.9 percent, and investment funds – 18.9 percent. In general, it can be stated that in the second variant of technical development of production potential, the growth rates of all indicators are higher. Thus, in the considered time interval, the growth of production volumes occurred more than 5 times. At the same time, the cost of fixed assets increased by 4.62 times, and the amount of investment – by 4.82 times. Thus, we considered two options for replacing existing equipment with new ones, which differ in capital efficiency and, accordingly, have different resource innovation coefficients. Analysis of the obtained results showed that in the second variant of renewal, the growth rates of production volumes are ahead of the growth rates of fixed assets and the growth rates of capital investments. That is, qualitatively better results were obtained. This confirms the conclusion that the option of updating existing fixed assets with new ones with a higher resource innovation coefficient is more priority.

In addition to the funds for the purchase of new equipment, the process of updating the fixed assets may require additional costs for the use of new premises, their reconstruction, new construction, etc. in the case of expansion of production or its reconstruction.

Quantitative determination of the patterns of dynamics of innovative development of production should be considered a promising area of research that has significant theoretical and practical significance. An important result of the study is that generally accepted technical and economic indicators should be expanded quantitatively with similar indicators that characterize the change in other resource costs as a result of updating fixed assets. This study provides an example of such an indicator that characterizes the change in return on assets.

Conclusions

The study of the process of updating fixed assets allows us to draw a number of important conclusions regarding the dynamics of their reproduction, economic patterns and the impact on the efficiency of production activities. Thus, the analysis of the model of the dynamics of updating fixed assets shows that the growth rate of production is determined not only by the rate of renewal of funds, but also by the resource innovation coefficient. This means that the introduction of more productive equipment allows us to accelerate economic growth, even with limited growth rates of fixed assets.

The value of the resource innovation coefficient K_{in}^{F} plays an important role in determining the efficiency of investing in new equipment. A positive value of this indicator indicates an increase in the return on investment of new equipment, which contributes to an increase in production productivity. In the case of a negative value of K_{in}^{F}, the growth rate of production may be lower than the rate of renewal of fixed assets, which requires optimization of investment decisions.

The process of updating fixed assets is multivariate and dynamic. The efficiency of technical development of production depends on the choice of optimal parameters of renewal, in particular the service life of equipment, the rate of accumulation and the investment capabilities of the enterprise. The appropriate balance between these parameters allows minimizing the costs of renewal and ensuring sustainable productivity growth.

The intensity of renewal of fixed assets depends on the financial capabilities of the enterprise, in particular on the level of depreciation deductions and the share of profit directed to reinvestment. A higher accumulation rate contributes to faster replacement of equipment and increased efficiency of the production system.

Therefore, effective management of renewal of fixed assets is an important factor in increasing productivity, ensuring sustainable economic development of the enterprise and its long-term competitiveness.

Prospects for further research

Further research should be focused on quantitatively determining the patterns of the dynamics of innovative development of production, which is of important theoretical and practical importance. In particular, a promising direction is the expansion of generally accepted technical and economic indicators by including in them quantitative characteristics of changes in other resource costs due to the renewal of fixed assets. The article provides an example of such an indicator, which reflects the change in return on assets. Determining similar indicators for other resource factors requires further research, which will allow for a more accurate assessment of the growth rates of production costs, profits, labor productivity, etc.

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МЕТОДОЛОГІЧНІ АСПЕКТИ АНАЛІЗУВАННЯ ТА ОПТИМІЗАЦІЇ ПРОЦЕСІВ ІННОВАЦІЙНОГО ОНОВЛЕННЯ ОСНОВНИХ ВИРОБНИЧИХ ЗАСОБІВ ПІДПРИЄМСТВ

У роботі розглянуто процес оновлення основних виробничих засобів як важливу складову інвестиційної діяльності підприємства. Запропоновано математичну модель динаміки заміни обладнання з урахуванням темпів зростання вартості основних засобів та їх експлуатаційного терміну. Подано схему динаміки оновлення обладнання, яка дає змогу оцінити зміни у віковій структурі та пропорціях основних засобів, а також аналізувати вплив інноваційних факторів на темпи зростання продукції. Запропоновано метод оптимізації інвестиційної діяльності з урахуванням показника, який характеризує зміну фондовіддачі у ході технічного оновлення виробництва. Отримані результати можна використати для планування інвестиційних стратегій підприємств з метою підвищення ефективності виробництва.

Ключові слова: основні виробничі засоби, фондовіддача, оновлення, інновації, темпи зростання, коефіцієнт ресурсної інноваційності.