UDC 658-044.922:330.342
DOI: 10.15587/1729-4061.2025.333006

ASSESSING THE EFFECTIVENESS OF INNOVATIVE TRANSFORMATIONS OF SOCIO-ECONOMIC SYSTEMS AND ENTERPRISE DEVELOPMENT WITHIN INDUSTRY 5.0

Nataliia Kashchena
Corresponding author
Doctor of Economic Sciences, Professor*
E-mail: natakaschena@gmail.com
Hanna Chmil
Doctor of Economic Sciences, Professor
Department of Marketing, Reputation Management and Customer Experience**
Oksana Chumak
Doctor of Economic Sciences, Professor
Department of Economics and Business Technologies***
Iryna Nesterenko
Department of Economics***
Arkadii Mykytas
Doctor of Economic Sciences, Associate Professor
Department of Finance, Banking and Insurance**
Yevhenii Chmil*
*Department of Accounting, Auditing and Taxation**
**State Biotechnological University
Alchevskykh str., 44, Kharkiv, Ukraine, 61002
***State University «Kyiv Aviation Institute»
Lyubomyr Huzar ave., 1, Kyiv, Ukraine, 03058

The object of this study is the financial and economic processes of the enterprise's functioning under the conditions of innovative transformations of socio-economic systems.

The problem is to provide high-quality analytical support for making management decisions through updating the methodological tools that reflect the complexity of the relationships between innovative transformations, environmental and social standards, and financial indicators.

The study was conducted using data on 32 food retail enterprises in the city of Kharkiv and the Kharkiv oblast (Ukraine) over 2023–2024.

A scientific and methodological approach to assessing the profitability of an enterprise's capital has been devised, taking into account the specificity of innovative transformations of its socio-economic system under the conditions of Industry 5.0. Based on the principal components method, key determinants (innovative activity, financing of activities, cost of activities, operational efficiency) have been identified that affect the effectiveness of innovative transformations and explain 77.81% of the variance in the profitability of capital. Economic and mathematical models of the dependence of the return on capital on microenvironmental factors were built. It was found that the return on capital increases by 1.0692% due to innovative activity, financing of activities and operational efficiency, but decreases by 0.58% due to increased costs.

The practical value of the proposed scientific and methodological approach relates to the possibility of using models to identify reserves for increasing financial performance and forming recommendations for overcoming negative trends that prevent the achievement of target parameters of sustainable development of enterprises under the conditions of Industry 5.0

Keywords: Industry 5.0, enterprise, management, innovation, transformation, assessment, efficiency, capital, profitability, modeling

Received 03.04.2025
Received in revised form 22.05.2025
Accepted 16.06.2025
Published 30.06.2025

How to Cite: *Kashchena, N., Chmil, H., Chumak, O., Nesterenko, I., Mykytas, A., Chmil, Ye. (2025). Assessing the effectiveness of innovative transformations of socio-economic systems and enterprise development within Industry 5.0. Eastern-European Journal of Enterprise Technologies, 3 (13 (135)), 35–46. https://doi.org/10.15587/1729-4061.2025.333006*

1. Introduction

Industry 5.0 marks a new phase in the development of socio-economic systems, characterized by the harmonious interaction of humans and high-tech solutions to ensure sustainable, inclusive, and value-oriented growth. Digital, environmental, and social components are increasingly integrated into the business processes of enterprises, which are key prerequisites for their balanced and long-term innovative development under conditions of dynamic change. The transition to flexible, sustainable, and inclusive models of adaptation to global challenges, in particular the technological singularity and the spread of bio-integrated solutions in production and management practices, reflects the transformation of socio-economic systems of enterprises.

The effectiveness of innovative transformations in the modern business environment largely depends on the ability of enterprises to strategically foresee and respond promptly to external and internal challenges. The implementation of a flexible management model based on the principles of endogenous growth and intersystem integration of digital, environmental, and social innovations is a necessary condition for increasing innovation potential. This approach contributes to strengthening financial sustainability, social responsibility, and the ability to achieve sustainable development in the context of Industry 5.0.

Environmentally-oriented innovations in the production and economic activities of enterprises enhance the overall social, environmental, and economic effect. This is of strategic importance and affects key performance indicators, in particular the profitability of using own and borrowed capital. Growing economic turbulence and increasing environmental requirements emphasize the need to improve analytical support for management decisions to assess the effectiveness of transformational changes and enterprise development.

In the context of Industry 5.0, the need to devise a scientific and methodological approach to assessing the profitability of capital, taking into account the specificity of innovative and environmentally-oriented transformations, is becoming more urgent. This approach should integrate financial, environmental, and operational indicators into a single analytical system that ensures informed decision-making and promotes sustainable business growth. The methodological basis is a combination of classical financial ratios with sustainable development indicators, which makes it possible to assess the current efficiency of capital use and form strategic guidelines for its improvement.

The relevance of research on assessing the effectiveness of innovative transformations of socio-economic systems and enterprise development in the context of Industry 5.0 is due to the need for theoretical understanding and practical support for business adaptation to new challenges. Scientific developments in this area are important as they create the basis for the formation of sustainable development strategies that combine economic efficiency with social and environmental responsibility. The practical value of such research is to provide enterprises with analytical tools to assess and improve the return on capital, which contributes to their competitiveness and long-term sustainability in the face of global change.

2. Literature review and problem statement

Numerous scientific studies on the Industry 5.0 paradigm demonstrate the growing interest in a human-centric approach that involves integration [1]. At the same time, there is a lack of operationalization of management mechanisms for its implementation. In this context, work [2] deserves attention, in which a comprehensive analysis of the financial, managerial, and inclusive aspects of the implementation of Industry 5.0 is carried out. Despite highlighting the need for multi-level support, the issues of forming a financial and institutional infrastructure remain outside the scope of the study.

The discourse is deepened in work [3], which emphasizes the importance of ethical guidelines for building human-oriented business models. However, the emphasis on the normative-value approach is accompanied by the lack of analysis of practical mechanisms for implementing value principles in the activities of enterprises. Study [4] addresses the consideration of practical challenges of implementing the new paradigm, where the risks of digitalization are identified. At the same time, there is a lack of a systemic vision of the interdependence of technical barriers and the human factor. A logical continuation is work [5], which emphasizes the importance of combining automation with the leading role of humans in management. Although this is in line with the principles of sustainable development, the study does not specify indicators of production efficiency or social effectiveness.

In turn, work [6] emphasizes the need to adapt robotic systems to the needs of employees but leaves out the issue of the cost of such solutions. In light of the strategic focus on environmental sustainability and operational excellence, the experience of [7], which proposes the integration of Industry 5.0 technologies into the Green Lean Six Sigma cycle, becomes important. Despite the innovative nature of the approach, the study is mainly theoretical in nature and requires empirical confirmation through thematic cases and pilot implementations.

Similarly, work [8] reveals the potential for synergy between Industry 5.0 and "green" supply chain management. However, the cross-sectoral complexity and lack of applied methodologies make it difficult to form typical implementation scenarios. These limitations highlight the need for an interdisciplinary approach that combines qualitative and quantitative methods of analysis. This approach is implemented in study [9], which presents new management practices based on artificial intelligence, IoT, and blockchain technologies. At the same time, the lack of comprehensive tools for assessing the effectiveness of transformation processes narrows the practical applicability of the results obtained.

In this context, the emphasis of study [10] on the need to design a system for assessing the integration potential of social, economic, and technological components is appropriate. However, the implementation of such systems is constrained by technical complexity, lack of qualified personnel, and high cost, which limits the capabilities of enterprises. This, in turn, determines the need for in-depth theoretical understanding of transformation processes, which is the subject of work [11]. It analyzes the parameters and conditions of transformation of socio-economic systems, expanding the understanding of the patterns of change. However, there is a lack of methodological solutions for institutionalizing the revealed patterns.

In this context, the principle of determinism is actualized as a basic category of economic science, which is considered both in classical studies [12] and in modern discourse [13]. At the same time, no specific factors have been identified that influence the transformation trajectories of enterprises.

All this allows us to state that it is advisable to conduct a study on the development of methodological and applied aspects in assessing and ensuring the effectiveness of innovative transformations of socio-economic systems of enterprises in the context of Industry 5.0.

3. The aim and objectives of the study

The purpose of our study is to devise a scientific and methodological approach to assessing the profitability of an enterprise's capital to ensure sustainable development in the context of innovative transformations of the socio-economic system in the Industry 5.0 paradigm. This will make it possible to increase the financial performance and competitiveness of enterprises by integrating innovative factors into the management system.

To achieve the goal, the following tasks have been defined:

– to identify the key determinants of innovative transformations of the socio-economic systems of the enterprise in the context of Industry 5.0;

– to devise a technology for assessing the effectiveness of innovative transformations of socio-economic systems and enterprise development;

– to build an economic and mathematical model of the dependence of the profitability of capital on microenvironmental factors caused by innovative transformations.

4. The study materials and methods

The object of our study is the financial and economic processes of the enterprise's functioning under the conditions of innovative and environmentally-oriented transformations of the socio-economic system.

The subject of the study is the process of economic and mathematical modeling of the dependence of the profitability of the enterprise's capital on the factors of the microenvironment caused by the transformational changes of its socio-economic system under the conditions of Industry 5.0.

The basic hypothesis of the study assumes that the profitability of the enterprise's capital as an integral indicator of financial performance could be significantly increased by improving the approaches to its assessment. At the same time, it is advisable to take into account the influence of the determinants of the microenvironment that are formed as a result of innovative and environmentally-oriented transformations of the socio-economic system of the enterprise under the conditions of Industry 5.0. This makes it possible to increase the profitability of capital, ensure the stability of the enterprise, and strengthen its competitive position.

Assumptions in the study:

– the effectiveness of innovative transformations can be modeled in the form of economic and mathematical dependences of the profitability of capital based on microenvironment factors;

– there are reserves for increasing the profitability of capital, which can be identified and used in the management system;

– the innovative orientation of resource management directly affects the financial stability and strategic competitiveness of the enterprise.

Simplification in the study:

– it is assumed that all the main dependences between factors and profitability can be adequately described by component analysis;

– indirect factors of the external environment, not directly related to the microenvironment, are not taken into account in building models.

The methodological basis of the study involves the use of an integrated approach to analyzing the effectiveness of innovative transformations of socio-economic systems and the development of trade enterprises. The study devised and implemented an appropriate technology that integrates the principal component method and the module-structured identification of key determinants of innovative transformations to model their impact on the enterprise's return on capital.

Component analysis of the efficiency of capital use of enterprises was carried out on the basis of accounting and statistical reporting indicators from 32 enterprises engaged in retail trade in food products in the city of Kharkiv and the Kharkiv oblast in 2023–2024. The objects of the study differ in organizational and legal forms, scale of activity and stages of the life cycle, but are characterized by similar operating conditions and the influence of micro- and meso-level factors. The sample was formed in compliance with the requirements for volume and homogeneity, which ensures its representativeness for the study. The population includes only enterprises that meet a number of criteria: profitable activities, absence of leased fixed assets, potential for the development of diversified areas, as well as compliance with financial independence standards. The calculation of the main components and the implementation of the analytical algorithm were carried out using the STATISTICA software package (TIBCO Software Inc., USA).

5. Results of assessing the impact of innovative transformations on the profitability of capital

5. 1. Identification of key determinants of transformations of socio-economic systems of an enterprise in the context of Industry 5.0

Industry 5.0 involves combining technological innovations with social and environmental priorities to form an intelligent economy that strives for a harmonious combination of domains based on human intelligence and emotional context [14].

Modernization processes of socio-economic systems of enterprises in the context of Industry 5.0 are aimed at combining technological innovations with a green course and a double transition. This involves simultaneous digital and ecological transformation, strengthening the resilience of value chains, adaptation to challenges, and the implementation of ESG principles to achieve sustainable development goals [15].

The transition to ESG principles and Industry 5.0 are becoming key drivers of innovative transformations of modern socio-economic systems of enterprises. They define new approaches to enterprise management, the implementation of the latest digital technologies (artificial intelligence, robotics, Internet of Things), and the formation of values for stakeholders [16].

The main aspects of influence at this stage are human-centricity (combining automation with human creativity, adapting technologies to the needs of employees); technological breakthroughs (implementation of flexible production processes. In addition, the influence of "smart" factories and personalized production); innovative business models (development of the platform economy and service approach to customers); resource saving (optimization of energy use, waste reduction and increased environmental efficiency) [17].

ESG principles affect all aspects of the functioning of enterprises, integrating environmental, social, and management components into the development strategy. The combination of the advantages of Industry 5.0 and ESG standards creates unique opportunities for innovative transformations of the socio-economic system of the enterprise, namely, the use of 5.0 technologies makes it possible to ensure the efficiency of processes with minimal environmental impact. ESG principles contribute to increasing stakeholder trust and create the basis for long-term business sustainability; enterprises that integrate these approaches gain competitive advantages in the market and adapt to modern globalization requirements [18].

The basis of the determinant development of enterprises under the conditions of global uncertainty, caused by the influence of risks of various etiologies, is a deep transformation of socio-economic systems, which is formed under the influence of doctrinal changes that determine the postulates of the Industry 5.0 paradigm [19]. This paradigm integrates a human-centric approach with advanced technologies and environmental innovations, which leads to a systemic modification of the economic structure and contributes to the formation of innovative business models focused on multifactor efficiency [20]. According to the concept of sustainable development, such a transformation generates a synergistic effect, implemented in the form of combinatorial advantages of an economic, environmental, social, and corporate nature. That makes it possible for enterprises to ensure strategic adaptability, increase the level of sustainability, and maintain competitive positions under the conditions of dynamic challenges of modern economic reality [21].

The synergy of determinants of innovative transformations of the socio-economic system of an enterprise reflects a complex system of relationships between key development factors under the conditions of the digital-ecological paradigm (Fig. 1).

Innovative transformations are considered as a multi-vector process that encompasses digital, technological, social, environmental, and financial components, united by the common goal of sustainable development [22]. Digital and technological transformation forms the core of changes, ensuring the implementation of digital platforms, automated systems and intelligent solutions that increase management efficiency. The development of human capital is critically important, which involves the growth of professional competence, innovation culture, and adaptability of employees to new conditions [23].

Corporate social responsibility is implemented through the implementation of ESG principles, which strengthen the relationship between business and society and ensure long-term sustainability [24]. The condition for effective functioning is the formation of adaptive cluster business ecosystems that promote the synergy of knowledge, innovation, and resources. An important factor is institutional and financial support, which determines the ability of an enterprise to implement innovative strategies under conditions of increasing risks. The systemic interaction of these elements ensures the stability of the socio-economic system of the enterprise and its ability to self-renewal based on innovations. This approach forms the theoretical basis for the development of effective management solutions in the field of innovative transformation [25–27].

Thus, Industry 5.0 and ESG principles become not only factors of innovative transformations but also key elements of the strategy of sustainable development of enterprises. This trend determines the need for an integrated approach to the formation of a new quality of enterprise management, based on synergy between the identified key determinants of innovative transformations.

Fig. 1. Synergy profile of determinants of innovative transformations of socio-economic systems of enterprises in the context of Industry 5.0

5. 2. Technology for assessing the effectiveness of innovative transformations of socio-economic systems and enterprise development

In the context of implementing innovative transformations in the socio-economic systems of enterprises, the technology for assessing their effectiveness becomes particularly relevant, which allows for a comprehensive analysis of the financial performance of transformational changes and determining their impact on sustainable development. The key integral indicator that reflects the effectiveness of changes in the business environment of the enterprise is the return on capital. The strategic guidelines of Industry 5.0 are focused on a harmonious combination of digital, environmentally friendly innovations, human capital, resource sustainability and adaptive interaction, requiring an assessment of the impact of these factors on the return on capital. This is possible by forming an appropriate evidence base for making effective management decisions and ensuring sustainable development of the enterprise.

The technology for assessing the effectiveness of transformational changes in the socio-economic system of the enterprise, devised and shown in Fig. 2, represents a comprehensive analytical procedure involving the principal component method.

The principal components method involves the formation of new generalized variables that make it possible to reduce the dimensionality of examination without losing information. Its essence is to determine the most informative components (factors) $Fj,\ j = \overline{1,k}$ based on the set of features $X_i,\ i = \overline{1,n}$

$$\{X_1, X_2, X_3, ..., Xn\} \to \{F_1, F_2, F_3, ..., F_k\}.$$

The principal components are defined as linear combinations of the initial factors that have the largest eigenvalues in the covariance matrix and create a new coordinate system in which stable patterns are revealed. Based on the obtained correlation matrix, regression models are constructed that link microenvironmental factors with indicators of return on capital. These models make it possible to form economic conclusions and recommendations to increase the efficiency of innovative transformations.

Structurally, the proposed technology includes two modules. The first is the identification of determinants of innovative transformations of the socio-economic system of the enterprise under the conditions of Industry 5.0, focused on harmonizing technological development and human needs. The second is a direct analysis of the efficiency of the use of capital by the enterprise through the determination of factors of changes in the microenvironment under the influence of innovative transformations, modeling of relationships, quantitative assessment of the causes of changes in the profitability of capital and the formation of conclusions for making management decisions.

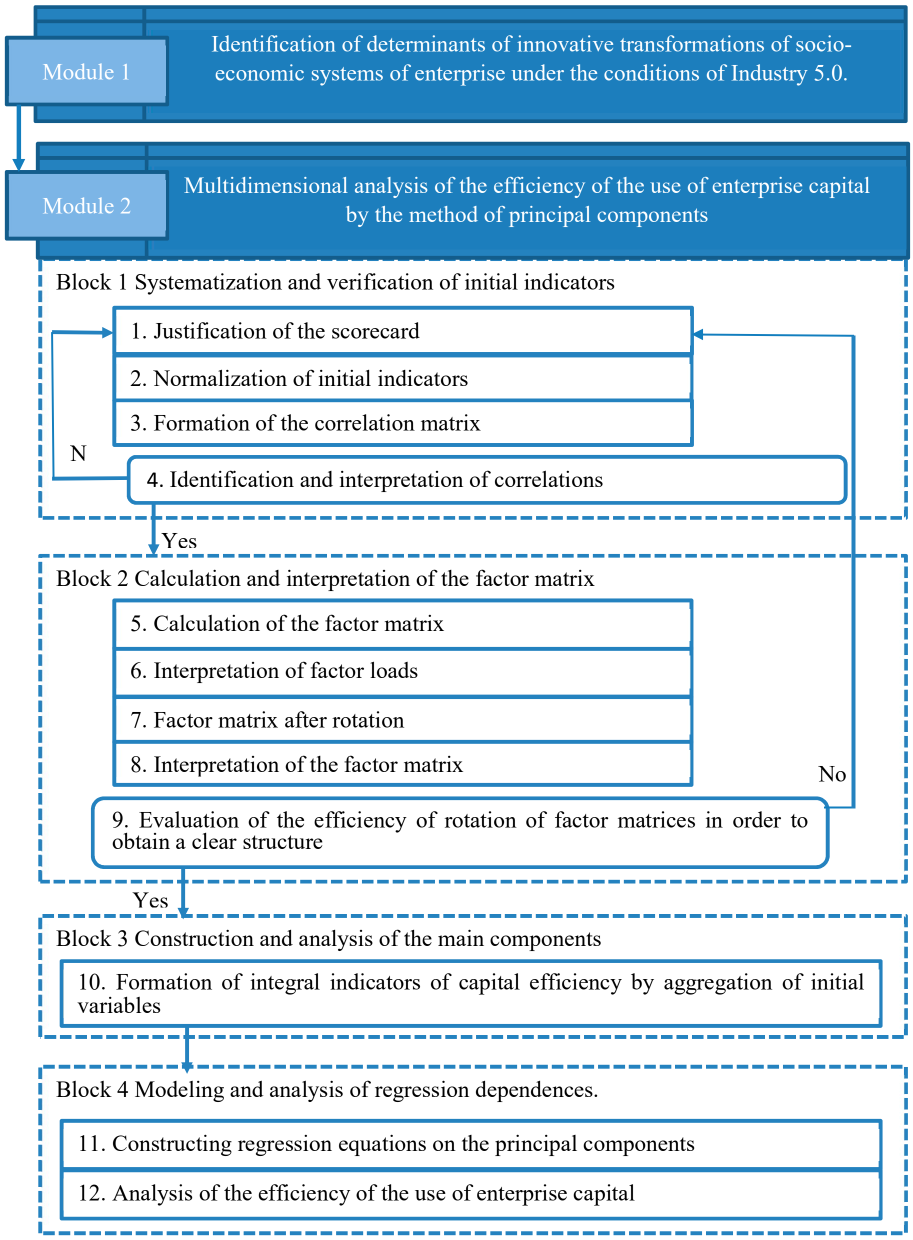

Fig. 2. Technology for assessing the effectiveness of innovative transformations of socio-economic systems and enterprise development

Within the framework of the second module "Analysis of the efficiency of the use of capital by the principal component method", an integrated system of analytical procedures is implemented, structured into four methodological modules:

– the first module covers the stages of identifying relevant input economic and statistical indicators and their preliminary parameterization. To ensure metric compatibility, the information matrix is standardized. The study of the intensity and direction of relationships between variables is implemented using correlation analysis;

– the second module involves the formation of a matrix of factor loadings with its subsequent structural interpretation, as well as determining the proportion of cumulative variance explained by each principal component. The varimax rotation procedure is used to achieve orthogonality of latent factors, interpretation of transformed loadings and comparative analysis of alternative factor structures;

– the third module is focused on the construction of integral principal components using an adjusted factor matrix. Quantitative operationalization of components is carried out through the aggregation of standardized variables taking into account the weight coefficients of factor loadings;

– the fourth module covers the construction of a parametric regression model using principal components as independent variables for further factor modeling of the efficiency of capital use of the enterprise.

The proposed technology for assessing the efficiency of innovative transformations of socio-economic systems of enterprises is an integrated analytical tool that combines the principal components method and regression modeling for a deep analysis of changes in the business environment of enterprises.

5. 3. Modeling the dependence of capital profitability on microenvironment factors

The safe functioning, restoration of economic activity, and sustainable economic development of commercial enterprises in a turbulent business environment are determined by innovative transformations and require effective management of the enterprise's capital. This is achieved primarily through updating the methodological tools for analytical support of managerial influences on its economic potential, which is based on a synergistic combination of determinants of innovative transformations of socio-economic systems of enterprises.

To study the dependence of profitability of the enterprise's capital (Y) on microenvironmental factors caused by innovative transformations, a system of indicators was formed that covers the innovative intensity, composition, structure, efficiency of use of the financial and economic potential of a trading enterprise, and the cost of activity. This system includes the coefficients of equity (X_1), debt (X_2), current liquidity (X_3) and the provision of inventories with own working capital (X_4). In addition, the level of costs for the purchase, storage, and sale of goods (X_6) and the share of administrative costs (X_5), logistics costs (X_7), and digital innovations (X_8) in these costs. Indicators of innovative transformations are the level of automation of business processes (X_9), the share of income from online sales (X_{10}). Indicators of labor security and efficiency of use of fixed assets are the coefficient of productivity of the active part of fixed assets (X_{11}), the level of technical equipment of the enterprise's personnel (X_{12}). Indicators of the structure and efficiency of the use of labor resources – the share of operational personnel (X_{13}), sales volume per employee (X_{14}). Indicators of turnover and spatial efficiency – inventory turnover ratio (X_{15}) and revenue per 1 m^2 (X_{16}).

The primary information collected from the sample of enterprises was checked for accuracy, homogeneity, and compliance with the normal distribution of the effective and factor indicators. Analysis of the variation series revealed that the level of variation does not exceed 33%, which makes it possible to conclude that the formed population is homogeneous [28]. The asymmetry and kurtosis indicators are within the permissible values, which indicates compliance with the laws of normal distribution in the original data. Therefore, the sample is characterized by proper representativeness and a sufficient level of reflection of the properties of the general population of trade enterprises.

In order to unify the dimensionality and ensure the comparability of the original data, their standardization was carried out, which was performed according to the following formula

$$Z_{ij} = \frac{x_{ij} - \overline{X_j}}{\sigma_j}, \quad (1)$$

where $\overline{X_j}$ is the mean value of the j-th variable;

σ_j – mean square deviation of the corresponding variable.

The standardized values of the initial data were used to construct a matrix of correlation coefficients. Its analysis confirmed the presence of statistically significant relationships between the variables included in the model, which indicates the existence of common factors that determine their variability.

The significance of the correlation matrix was checked using the Wilks test, calculated with the number of degrees of freedom $\nu = p(p-1)/2$ [287]

$$\chi^2 = -\left[n - \frac{1}{6}(2p+5)\right]\ln|R|, \quad (2)$$

where n is the number of elements of the population;

p is the number of variables under study;

$|R|$ is the determinant of the correlation matrix.

The actual value of the χ^2 criterion was 1133.2, which exceeds the tabular value ($\chi^0_{0.5}(120) = 83{,}85$); therefore, there are grounds to accept the hypothesis of the significance of the correlation matrix.

The eigenvalues of the correlation matrix, representing the variances of the corresponding principal components, demonstrate the contribution of each of them to the total variance. The maximum number of possible principal components (F) corresponds to the number of indicators selected for analysis (X).

To determine the appropriate number of principal components, the Kaiser criterion was applied, according to which only those components whose eigenvalues exceed unity ($\lambda_j > 1$) are recognized as significant. This means that each remaining component must explain the variance of at least one primary variable. The results of our calculations showed that the eigenvalues of the first four components exceed the critical value, so these components were reasonably included in further analysis (Table 1).

Calculation of factor loadings of the features (Table 2) showed that only the first four components provide a significant share in explaining the total variance: 49.87%, 12.98%, 9.39%, and 7.12%, respectively.

The total explanatory power of these components is 79.37%, which indicates a high degree of adequacy of the constructed factor model. The first main component represents a generalized integral factor that characterizes the efficiency of using the enterprise's resource potential. The first main component reveals a high level of correlation saturation with such variables as the level of automation of business processes, the share of income from online sales and the level of technical equipment of personnel. The share of this component in the total variance is 48.88%, which indicates its dominant role in forming the integral indicator of the enterprise's digital and technological transformation. The second component forms 12.98% of the total variance and reveals a strong association with the ratio of inventory coverage with own working capital as a key indicator of the efficiency of working capital management and the financial stability of the enterprise. The third component with a share of 9.39% reflects the level of costs for the purchase, storage and sale of goods and the share of costs for digital innovations in the total costs of the enterprise. The fourth component explains 7.12% of the variation and is characterized by high weight values of the productivity coefficient of the active part of fixed assets, sales volume per employee, inventory turnover coefficient, and revenue per 1 m^2.

Table 1

Statistical characteristics of principal components

Main components	Eigenvalues, λ	Fraction of total variance, %	Cumulative eigenvalues	Cumulative variance, %
F_1	7.979	49.874	7.979	49.874
F_2	2.077	12.981	10.057	62.855
F_3	1.502	9.391	11.560	72.247
F_4	1.139	7.122	12.699	79.370
F_5	0.841	5.254	13.540	84.624
F_7	0.697	4.353	14.236	89.978
F_8	0.542	3.385	14.678	92.363
F_9	0.440	2.745	15.118	95.108
F_{10}	0.305	1.906	15.423	97.010
F_{11}	0.271	1.698	15.733	98.945
F_{12}	0.230	1.440	15.964	100.923
F_{13}	0.127	0.792	16.091	101.922
F_{14}	0.101	0.630	16.194	102.941
F_{15}	0.040	0.247	16.234	103.989
F_{16}	0.023	0.148	16.258	105.068

Table 2

Factor loadings of features

Feature	Principal components			
	F_1	F_2	F_3	F_4
Z_1	–0.6348	0.1163	0.1260	–0.0780
Z_2	–0.9326	0.1208	–0.1097	–0.2498
Z_3	–0.9286	0.1348	–0.0373	–0.2396
Z_4	–0.8488	0.1348	0.0768	–0.2165
Z_5	–0.7449	0.1450	–0.3842	–0.0413
Z_6	0.4552	–0.0231	0.6586	–0.1936
Z_7	–0.6946	–0.0736	0.2961	–0.5697
Z_8	–0.6368	0.2352	–0.4135	0.2483
Z_9	0.6445	–0.0440	–0.0738	–0.5783
Z_{10}	0.4630	–0.5167	–0.5802	–0.1722
Z_{11}	0.9073	–0.1122	0.1669	–0.0334
Z_{12}	0.3154	–0.6592	–0.4142	–0.3279
Z_{13}	–0.7822	–0.5426	0.2053	0.1400
Z_{14}	0.7934	–0.0452	0.0567	0.0366
Z_{15}	–0.7803	–0.5797	0.1541	0.1110
Z_{16}	–0.4808	–0.7894	0.2163	0.2413
Eigenvalues, λ	7.9800	2.0770	1.5026	1.1396
Fraction of total variance, coefficient	0.4988	0.1298	0.0939	0.0712

Principal components are generalized, latent factors whose values can only be estimated indirectly. This is done by constructing appropriate linear combinations with primary features using a mathematical model that describes the relationship between these features and components (3) [29, 30]

$$Z_j = a_{j1}F_1 + a_{j2}F_2 + \ldots + a_{jk}F_k + d_j u_j, \quad (3)$$

where Z_j – unified values of the j-th feature with unit variance;

$a_{j1}, a_{j2}, \ldots, a_{jk}$ – coefficients of influence of the k-th component on the j-th feature;

$F_1, F_2, \ldots, F_k$ – common factors influencing all features;

u_j – unique factor for feature Zj;

d_j – coefficient of influence of a unique factor on feature Z_j.

Linear equations describing the dependence of factors Z_j on principal components F are given in Table 2.

Table 2

Linear equations of dependent factors Z_j and principal components F (calculated by Authors)

Feature	Linear equations
Z_1	$Z_1 = -0.6348F_1 + 0.1163F_2 + 0.1259F_3 - 0.0780F_4$
Z_2	$Z_2 = -0.9326F_1 + 0.1206F_2 - 0.1097F_3 - 0.2498F_4$
Z_3	$Z_3 = -0.9286F_1 + 0.1349F_2 - 0.0373F_3 - 0.2396F_4$
Z_4	$Z_4 = -0.8489F_1 + 0.1349F_2 + 0.0768F_3 - 0.2165F_4$
Z_5	$Z_5 = -0.7449F_1 + 0.1452F_2 - 0.3843F_3 - 0.0413F_4$
Z_6	$Z_6 = 0.4552F_1 - 0.0231F_2 + 0.6586F_3 - 0.1937F_4$
Z_7	$Z_7 = -0.6946F_1 - 0.0736F_2 + 0.2961F_3 - 0.5697F_4$
Z_8	$Z_8 = -0.6368F_1 + 0.2352F_2 - 0.4132F_3 + 0.2483F_4$
Z_9	$Z_9 = 0.6445F_1 - 0.0439F_2 - 0.0739F_3 - 0.5783F_4.$
Z_{10}	$Z_{10} = 0.4629F_1 - 0.5167F_2 - 0.5801F_3 - 0.1721F_4$
Z_{11}	$Z_{11} = 0.9073F_1 - 0.\ 1122F_2 + 0.1669F_3 - 0.0334F_4$
Z_{12}	$Z_{12} = 0.3154F_1 - 0.6592F_2 - 0.4142F_3 - 0.3279F_4$
Z_{13}	$Z_{13} = -0.7822F_1 - 0.5426F_2 + 0.2053F_3 + 0.1401F_4$
Z_{14}	$Z_{14} = 0.7934F_1 - 0.0452F_2 + 0.0567F_3 + 0.0366F_4$
Z_{15}	$Z_{15} = -0.7803F_1 - 0.5797F_2 + 0.1541F_3 + 0.1119F_4$
Z_{16}	$Z_{16} = -0.4808F_1 - 0.7894F_2 + 0.2163F_3 + 0.2413F_4$

The selected principal components are difficult for meaningful economic interpretation due to the presence of a corresponding factor structure, which is characterized by cross-loadings of components on individual characteristics. The interpretation of the obtained factors was simplified by applying rotation. As a result, new values of factor loadings, eigenvalues, and the proportion of variance determined by individual components were obtained (Table 3).

At the same time, the overall factorization level has not changed and is 79.37%. The results of the factor loading calculations are given in Table 4.

Analysis of the structure of the first principal component (F_1) reveals that the leading indicators for its interpretation are variables with factor loadings greater than or very close to 0.7. These variables are the level of automation of business processes, the share of income from online sales, and the level of technical equipment of personnel. Based on this, it is advisable to identify this component as a factor of "innovative activity of the enterprise". Its contribution to the total variance is 18.97%. The high level of correlation between the variables characterizing the equity ratio, the current liquidity ratio, the ratio of the provision of inventories with own working capital with the factor axis of the second component (F_2) makes it possible to interpret it as a factor of "financing of the enterprise's activities". This group of indicators explains 18% of the total variance of the return on capital indicator. The third principal component (F_3) demonstrates a close inverse relationship with the indicators of the level of costs for the purchase, storage, and sale of goods, and the share of costs for digital innovations in the total costs of the enterprise. Their increase causes a decrease in the value of this component, and therefore a decrease in the profitability of capital. In view of this, the third component, which explains 13.34% of the total variance, can be characterized as a factor of "costliness of the enterprise's activities". The fourth component (F_4) has the largest eigenvalue – 4.39, which is 27.47% of the total variance. It is closely correlated with such indicators as the productivity ratio of the active part of fixed assets, sales volume per employee, revenue per 1 m^2, inventory turnover ratio. This gives grounds to identify it as a factor of "operational efficiency of the enterprise".

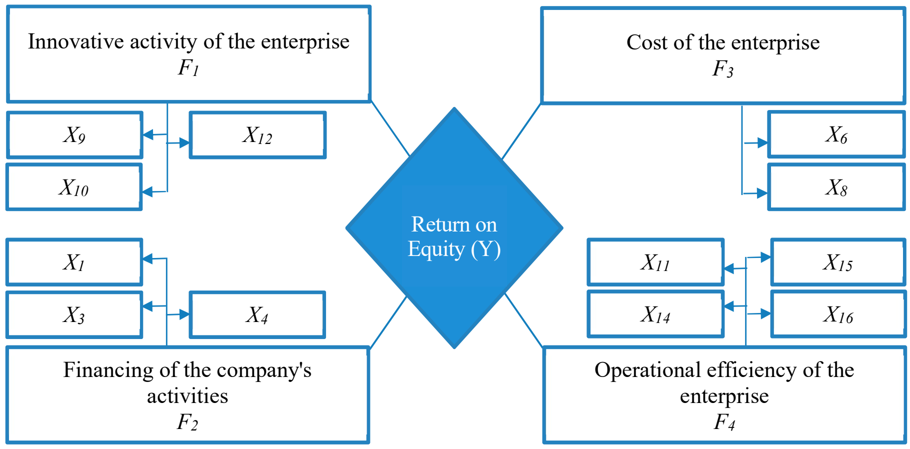

Fig. 3. Relationship between the principal components and indicators that influence the dynamics of return on capital of trading enterprises (developed by Authors)

Table 3

Factor loadings of features after rotation

Feature	Principal components			
	F_1	F_2	F_3	F_4
Z_1	0.2150	0.1998	0.2816	0.5224
Z_2	0.4813	0.1992	0.1510	0.8153
Z_3	0.4307	0.2107	0.2043	0.8171
Z_4	0.3124	0.2157	0.2580	0.7621
Z_5	0.6775	0.0978	0.0578	0.5034
Z_6	–0.8042	–0.0725	0.1394	–0.0867
Z_7	–0.1008	0.2366	0.0428	0.9122
Z_8	0.7690	0.0802	0.2054	0.2312
Z_9	–0.4866	–0.4892	–0.5277	–0.0521
Z_{10}	0.0482	–0.0375	–0.8549	–0.3364
Z_{11}	–0.6143	–0.2838	–0.2428	–0.5897
Z_{12}	–0.0885	0.1257	–0.8808	–0.1176
Z_{13}	0.1827	0.8729	0.0743	0.4089
Z_{14}	–0.4351	–0.2892	–0.1992	–0.5687
Z_{15}	0.2031	0.8753	0.0082	0.4167
Z_{16}	0.0137	0.9682	–0.1042	0.1048
Eigenvalues, λ	3.0949	3.0724	2.1346	4.3973
Fraction of total variance, coefficient	0.1934	0.1921	0.1334	0.2748

The composition of the principal components that affect the efficiency of capital use of the enterprise is shown in Fig. 3.

The principal components F_k are uncorrelated dimensionless variables that are a linear combination of k-variables

$$F_k = \frac{1}{\lambda_j}\left(a_{k1}Z_1 + a_{k2}Z_2 + \ldots + a_{kj}Z_j\right). \quad (4)$$

The dependences between the values of the principal components and the values of the studied indicators are given in the form of linear combinations in Table 5.

Correlation coefficients characterizing the relationship between factors that affect the profitability of a trading enterprise are given in Table 6.

Table 4

Factors determining the return on capital of the studied set of trading enterprises

Principal components	Value of factor loads	Indicator	ID
F_1	0.6775	Level of automation of business processes	Innovative activity of the enterprise
	–0.8042	Share of income from online sales	
	0.7690	Level of technical equipment of the company's personnel	
F_2	0.8729	Equity ratio	Financing of enterprise activities
	0.8753	Current liquidity ratio	
	0.9682	Ratio of provision of inventories with own working capital	
F_3	–0.8549	Level of costs for the purchase, storage, and sale of goods	Cost effectiveness of the enterprise's activities
	–0.8808	Share of costs for digital innovations in the total costs of the company	
F_4	0.8153	Sales volume per employee	Operational efficiency of the enterprise
	0.8171	Inventory turnover ratio	
	0.7621	Revenue per 1 m^2	
	0.9122	Ratio of productivity of the active part of fixed assets	

Table 5

Linear combinations of the main factors for the efficiency of equity use by the enterprise

Designation	Components of principal components
F_1	$0.2461Z_5 - 0.4345Z_6 + 0.3578Z_8$
F_2	$0.333Z_{13} + 0.3283Z_{15} + 0.4453Z_{16}$
F_3	$-0.468Z_{10} - 0.5086Z_{12}$
F_4	$0.2353Z_2 + 0.2362Z_3 + 0.2654Z_4 + 0.444Z_7$

Table 6

Correlation matrix of principal components of the impact on the return on equity in the set of studied trading enterprises

Factor	Y	F_1	F_2	F_3	F_4
Y	1	0.69017	0.62350	–0.50862	0.71323
F_1	0.69017	1	0.38255	–0.21689	0.54330
F_2	0.62350	0.38255	1	–0.12619	0.55680
F_3	–0.50862	–0.21689	–12619	1	–41695
F_4	0.71323	0.54330	0.55680	–0.41695	1

Analysis of the correlation coefficient matrix reveals the presence of a moderate inverse relationship between the profitability of the enterprise's capital and the component "Enterprise's operating costs" ($r = -0.5086$). At the same time, a pronounced direct relationship between the profitability of the enterprise's capital and other isolated components was established.

The orthogonality of the principal components makes it possible to build a regression equation based on them, in which the coefficient estimates do not depend on each other, which favorably distinguishes it from the regression equation built on the initial data, independent variables that are correlated with each other. The regression model built on the basis of the principal components looks as follows

$$y = a_0 + a_1F_1 + a_2F_2 + \ldots + a_kF_k, \quad (5)$$

where y is the modeled indicator;

a_k is the weighting factor for the k-th principal component;

F_k is the k-th principal component.

Thus, whereas previously the change in the efficiency of capital use of trade enterprises was influenced by 16 features, now this influence can be judged by four new, but generalized characteristics – principal components. The established four principal components were used as generalized factors for approximating economic indicators using a linear regression model. The obtained principal components were used as independent variables to construct the following regression equation (6)

$$Y' = -\text{[illegible]}\,F_1 + \text{[illegible]}1F_2 - \\ -0.3354F_3 + 0.1918F_4. \quad (6)$$

The statistical evaluation of the obtained regression equation was carried out using the coefficients of multiple correlation (R) and determination (R^2), Fisher's exact test (F-test), as well as the average error of approximation. The value of the actual F-test, which is 43.78, significantly exceeds its tabular value (2.53), which indicates a high statistical significance and reliability of the established relationship between the profitability of the enterprise's capital and the studied principal components.

The average approximation error, which is 8.08%, gives grounds to assert a satisfactory accuracy of the model in describing the identified dependences. The high level of closeness of the relationship between the profitability of the enterprise's capital and the set of principal components is confirmed by the value of the multiple correlation coefficient $R = 0.88$, which corresponds to determination $R^2 = 0.758$. This means that 75.8% of the variation in the return on capital is explained by changes in the studied factors, while the remaining 24.2% is due to the action of other factors not taken into account in the model.

The resulting indicator in the formed regression equation is the standardized value of the enterprise's return on capital, therefore its reverse transformation to the original economic variable Y was carried out. This transformation was based on data on the average value of the return on capital and its standard deviation. As a result, an economic and mathematical model was built in the form of a regression equation (7)

$$Y = 8.17 + 0.7912F_1 + 0.5460F_2 - \\ -0.5779F_3 + 0.3305F_4. \quad (7)$$

According to the presented model, the profitability of the enterprise's capital increased on average by 1.0692% due to the influence of groups of factors characterizing the enterprise's innovative activity (F_1), financing of its activities (F_2), and operational efficiency (F_4). At the same time, the increase in the cost of the enterprise's activities (F_3) reduces its profitability by 0.58% but has reserves for its increase. Taking into account the composition of the identified principal components, a multifactor regression equation was derived, which reflects the dependence of the profitability of the enterprise's capital on the set of indicators of the microenvironment of its activities. These indicators are the result of innovative transformations of the socio-economic system of the enterprise, which occur under the influence of digital changes and structural and functional shifts in the internal environment. The resulting regression equation takes the following analytical form (4)

$$Y = 8.17 + 0.1902X_5 - 0.3358X_6 + \\ +0.2766X_8 + 0.1781X_{13} + 0.1754X_{15} + \\ +0.2332X_{16} - 0.2647X_{10} - 0.2872X_{12} + \\ +0.0759X_2 + 0.0762X_3 + 0.0728X_4 + 0.1434X_7. \quad (4)$$

The derived regression equation (4) was used to assess the potential for increasing the return on capital of enterprises in the trade sector through the implementation of innovative transformations and to substantiate possible directions for their practical implementation.

Based on the modeling results, it was established that increasing the efficiency of innovative transformations of the studied enterprises can be achieved by increasing the return on capital of enterprises (Table 7).

Table 7

Calculation of reserves to increase the profitability of capital of enterprises

Principal component	Factor feature	Growth reserve of the j-th characteristic of the enterprise		Weight coefficient at the j-th feature	Value of the enterprise's reserve, %	
		1	2		1	2
F_1	X_5	0.7854	0.5814	0.1902	0.1463	0,1084
	X_6	4.2432	7.7214	–0.3227	–1.3423	–2,4430
	X_8	–1.163	–3.3762	0.2766	–0.3029	–0,8795
F_2	X_{13}	–0.1418	0.099	0.1782	–0.0248	0,0174
	X_{15}	–0.3366	0.3713	0.1754	–0.0578	0,0639
	X_{16}	–0.1306	0.1499	0.2370	–0.0305	0,035
F_3	X_{10}	12.0166	–4.9480	–0.2648	–3.1197	1,2846
	X_{12}	–1.1934	–0.3468	–0.2872	0.3361	0,0976
F_4	X_2	6.885	–26.3364	0.076	0.5130	–1,9624
	X_3	3.4476	–1.4484	0.0763	0.2579	–0,1083
	X_4	1.7340	–2.8560	0.0729	0.1240	–0,2040
	X_7	5.9130	2.3491	0.1432	0.8315	0,3303
Total		×	×	×	–2.7367	–3.7958

The data in Table 7 show that in order to increase the profitability of the capital of Enterprise 1 by 2.7367%, it is necessary to improve the level of technical equipment of the enterprise's personnel, increase the provision of stocks with its own working capital. It is also advisable to improve current solvency and reduce the share of administrative expenses in the costs of purchasing, storing, and selling goods. An increase in the profitability of the capital of Enterprise 2 by 3.7958% is possible by increasing the maneuverability of using its own financial resources, improving current solvency indicators, reducing depreciation of fixed assets, and reducing the cost of operating activities. These factors are key points of influence in the implementation of sustainable development measures aimed at strengthening the financial stability of enterprises in the context of the digital transformation of the economy.

6. Discussion of the impact of innovative transformations on the profitability of capital

The uniqueness of the proposed technology relates to the multi-level approach to processing economic and statistical data, which makes it possible to reduce the dimensionality of examination without losing meaningful information. It also makes it possible to identify stable patterns between microenvironmental factors and financial performance indicators; to build quantitatively substantiated regression models of profitability of capital using principal components as generalized indicators of innovative changes. In addition, the structured modularity of the technology ensures its flexibility and the ability to adapt to the specificity of individual enterprises or industries. Taking into account Industry 5.0 factors (digitalization; environmental orientation; human capital; adaptability) increases the relevance of the approach under the conditions of modern transformation of the business environment. This technology has high applied potential for modeling the dependence of profitability of capital on microenvironmental factors. It makes it possible to make informed management decisions and is an effective tool for ensuring the sustainable development of enterprises in the face of dynamic economic changes and the transition to the Industry 5.0 model.

Our research confirms the hypothesis that under the conditions of Industry 5.0. and strengthening of ESG principles, the potential for increasing the profitability of the enterprise's capital is determined by microenvironmental factors formed as a result of innovative and environmentally-oriented transformations. Unlike work [1], which emphasizes the theoretical aspects of Lean Six Sigma in Industry 5.0 without empirical models, the proposed approach provides a quantitative assessment of the impact of transformations on the profitability of capital through component analysis (Tables 1–5). Compared with [2], which analyzes the prospects of Industry 5.0 without specific financial indicators, our result makes it possible to assess the impact of the microenvironment on the profitability of equation (4). The advantages are achieved through the integration of ESG principles and digital technologies, which provide synergy between process efficiency and sustainable development.

The identified problem of the need to update the methodological tools for analytical support of management decisions was fully resolved through the development of assessment technology (Fig. 1) and model (4). The integration of financial, environmental, and social indicators into a single analytical system (Tables 3–5) provides an evidence base for management decisions, increasing the profitability of capital and the sustainability of enterprises. This fills the niche associated with the lack of operationalization of management mechanisms of Industry 5.0, indicated in [2, 3].

Our results, given in Tables 1–5, Fig. 2, 3, and by equations (2) to (4), are attributed to the complex impact of innovative transformations in the Industry 5.0 paradigm. The devised evaluation technology, based on the principal components method, makes it possible to integrate digital, environmental, and social factors (Fig. 2). This provides a systematic analysis of the impact of the microenvironment on the profitability of capital. The configuration of the synergy of microenvironment factors (Fig. 3) shows that innovative activity (F_1, 18.97%), financing of activities (F_2, 18%), cost of activities (F_3, 13.34%), and operational efficiency (F_4, 27.47%) are key factors (Table 3). The construction of an economic and mathematical model of the dependence of equity profitability on microenvironment factors caused by transformational changes was implemented through equation (4). It quantitatively assesses the dependence of return on capital ($R^2 = 0.758$) on the identified components, confirming an increase in profitability by 1.0692% due to F_1, F_2, F_4 and a decrease by 0.58% due to F_3 (Table 5).

Limitations include the exclusion of indirect macroeconomic factors, which may affect the accuracy of the model in the context of global changes. The results are adequate for food retail enterprises in the regional context (Kharkiv, 2023–2024). The application of the model in other industries or regions requires adaptation taking into account the specificity of the microenvironment.

The disadvantage is the insufficient integration of intelligent information and analytical platforms, which limits the efficiency of identifying efficiency reserves. This may complicate rapid response to dynamic changes under the conditions of Industry 5.0.

The proposed approach has practical value for enterprise management as it contributes to the formation of adaptive management decisions in the dynamic business environment of Industry 5.0. It provides an assessment of the efficiency of capital use and creates the basis for sustainable development strategies aimed at increasing competitiveness and financial sustainability.

Further research should include macroeconomic variables and dynamic models with time lags to improve forecasting accuracy. Development of machine learning-based capital structure optimization methods could facilitate decision adaptability. This is necessary to ensure that net profit is maximized while the cost of capital is minimized in the face of global economic turbulence.

7. Conclusions

1. Key determinants of innovative transformations of the enterprise microenvironment have been identified, in particular, innovative activity, financing of activities, cost of activities, and operational efficiency. These factors explain a significant part of the variation in return on capital, which makes it possible to empirically assess the impact of digitalization and ESG principles on financial performance. Our results emphasize the importance of structuring the microenvironment for effective management.

2. A technology for assessing the effectiveness of innovative transformations of socio-economic systems and enterprise development has been devised, based on the principal components method. The technology integrates digital, environmental, and social indicators for a comprehensive analysis of the impact of the microenvironment on the enterprise's activities. The designed methodological toolkit makes it possible to identify key factors affecting the return on capital. Our approach provides diagnostics of changes in the internal environment of the enterprise, taking into account the synergy of technological and social factors. The proposed solution increases the adaptability of management to the challenges of Industry 5.0 and promotes sustainable development in the digital economy.

3. An economic and mathematical model of dependence of the return on capital on microenvironmental factors caused by innovative transformations of the socio-economic system of the enterprise has been constructed.

The model is built on the basis of a representative sample of enterprises, formed taking into account the requirements for volume, homogeneity, and statistical reliability. Return on capital is defined as the dependent variable, and innovative activity, financing, cost, and operational efficiency are defined as independent variables. According to the results of regression analysis, it was found that innovative activity, financing, and operational efficiency increase the return on capital by 1.0692%. Cost of activity has a negative impact and reduces the return on capital by 0.58%, which requires cost control to maintain financial stability. The return on capital is most strongly affected by operational efficiency, followed by innovative activity and financing. The model built makes it possible to quantitatively assess the impact of microenvironmental factors and identify reserves for increasing the performance of enterprises. Our model has passed statistical verification; it is reliable and can be used in the enterprise's innovative transformation management system.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Rahardjo, B., Wang, F.-K., Lo, S.-C., Chu, T.-H. (2023). A Sustainable Innovation Framework Based on Lean Six Sigma and Industry 5.0. Arabian Journal for Science and Engineering, 49 (5), 7625–7642. https://doi.org/10.1007/s13369-023-08565-3
2. Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D., Wang, L. (2022). Industry 5.0: Prospect and retrospect. Journal of Manufacturing Systems, 65, 279–295. https://doi.org/10.1016/j.jmsy.2022.09.017
3. Adel, A. (2022). Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas. Journal of Cloud Computing, 11 (1). https://doi.org/10.1186/s13677-022-00314-5
4. Sharma, R., Nibedita, B., Gupta, H. (2025). Innovating tomorrow: Industry 5.0's role in shaping the workforce and socio-economic development in the sustainable energy transition era. Journal of Environmental Management, 381, 125170. https://doi.org/10.1016/j.jenvman.2025.125170
5. Emma-Ikata, D., Doyle-Kent, M. (2022). Industry 5.0 Readiness – "Optimization of the Relationship between Humans and Robots in Manufacturing Companies in Southeast of Ireland." IFAC-PapersOnLine, 55 (39), 419–424. https://doi.org/10.1016/j.ifacol.2022.12.071
6. Jonker, J., Faber, N. (2021). Organizing for Sustainability. Springer International Publishing. https://doi.org/10.1007/978-3-030-78157-6
7. Boumsisse, I., Benhadou, M., Haddout, A. (2024). Exploring the Potential Synergies between Industry 5.0 and Green Lean Six Sigma for Sustainable Performance: A New Dimension of Operational Excellence. Evolutionary Studies In Imaginative Culture, 1242–1259. https://doi.org/10.70082/esiculture.vi.1442
8. Amin, M. A., Chakraborty, A., Baldacci, R. (2025). Industry 5.0 and green supply chain management synergy for sustainable development in Bangladeshi RMG industries. Cleaner Logistics and Supply Chain, 14, 100208. https://doi.org/10.1016/j.clscn.2025.100208
9. Papacharalampopoulos, A., Karagianni, O. M., Stavropoulos, P., Ziarsolo, U., Totterdill, P., Exton, R. et al. (2025). On a heuristic evaluation system for Industry 5.0 with respect to interventions: the case of training in businesses. Procedia CIRP, 132, 122–128. https://doi.org/10.1016/j.procir.2025.01.021
10. Hein-Pensel, F., Winkler, H., Brückner, A., Wölke, M., Jabs, I., Mayan, I. J. et al. (2023). Maturity assessment for Industry 5.0: A review of existing maturity models. Journal of Manufacturing Systems, 66, 200–210. https://doi.org/10.1016/j.jmsy.2022.12.009
11. Holgersson, U. (2016). Economic Determinism. The Wiley Blackwell Encyclopedia of Gender and Sexuality Studies, 1–2. Portico. https://doi.org/10.1002/9781118663219.wbegss264
12. Sindhwani, R., Afridi, S., Kumar, A., Banaitis, A., Luthra, S., Singh, P. L. (2022). Can industry 5.0 revolutionize the wave of resilience and social value creation? A multi-criteria framework to analyze enablers. Technology in Society, 68, 101887. https://doi.org/10.1016/j.techsoc.2022.101887
13. Dwivedi, A., Agrawal, D., Jha, A., Mathiyazhagan, K. (2023). Studying the interactions among Industry 5.0 and circular supply chain: Towards attaining sustainable development. Computers & Industrial Engineering, 176, 108927. https://doi.org/10.1016/j.cie.2022.108927
14. Davydova, O., Kashchena, N., Staverska, T., Chmil, H. (2020). Sustainable development of enterprises with digitalization of the economic management. International Journal of Advanced Science and Technology, 29 (8s), 2370–2378. Available at: https://repository.hneu.edu.ua/handle/123456789/23535
15. Maddikunta, P. K. R., Pham, Q.-V., B, P., Deepa, N., Dev, K., Gadekallu, T. R. et al. (2022). Industry 5.0: A survey on enabling technologies and potential applications. Journal of Industrial Information Integration, 26, 100257. https://doi.org/10.1016/j.jii.2021.100257

16. Nesterenko, I., Kashchena, N., Chmil, H., Chumak, O., Shtyk, Y., Nesterenko, O., Kovalevska, N. (2024). Devising a methodological approach to identifying the economic potential of production costs for eco-innovative products. Eastern-European Journal of Enterprise Technologies, 3 (13 (129)), 6–15. https://doi.org/10.15587/1729-4061.2024.304805
17. Stupnytskyi, V., Filipishyna, L., Chumak, O., Gonchar, V., Komandrovska, V., Iefimova, G. (2023). Environmental compliance and business strategies practices of entrepreneurial ventures. E3S Web of Conferences, 408, 01025. https://doi.org/10.1051/e3sconf/202340801025
18. Lysak, H., Morozova, H., Gorokh, O., Maliy, O., Nesterenko, I. (2022). The System of Financial Control in the Management of a Small Business Enterprise: Methods and Tools of Implementation. Review of Economics and Finance, 20, 1034–1041. https://doi.org/10.55365/1923.x2022.20.115
19. Kolosok, S., Lyeonov, S., Voronenko, I., Goncharenko, O., Maksymova, J., Chumak, O. (2022). Sustainable Business Models and IT Innovation: The Case of the REMIT. Journal of Information Technology Management, 14, 147–156. https://doi.org/10.22059/jitm.2022.88894
20. Kashchena, N., Nesterenko, I., Chmil, H., Kovalevska, N., Velieva, V., Lytsenko, O. (2023). Digitalization of Biocluster Management on Basis of Balanced Scorecard. Journal of Information Technology Management, 15 (4), 80–96. https://doi.org/10.22059/jitm.2023.94711
21. Koval, V., Laktionova, O., Rogoza, N., Chumak, O., Komandrovska, V., Berdar, M. (2023). The impact of fiscal policy on environmental management in ensuring sustainable economies. IOP Conference Series: Earth and Environmental Science, 1126 (1), 012016. https://doi.org/10.1088/1755-1315/1126/1/012016
22. Duineveld, S., Hambel, C., Lessmann, K. (2025). Green investors and the return on capital in general equilibrium. Economics Letters, 247, 112149. https://doi.org/10.1016/j.econlet.2024.112149
23. Kashchena, N., Chmil, H., Nesterenko, I., Lutsenko, O., Kovalevska, N. (2024). Diagnostics as a Tool for Managing Behavior and Economic Activity of Retailers in the Conditions of Digital Business Transformation. Data-Centric Business and Applications, 149–173. https://doi.org/10.1007/978-3-031-53984-8_7
24. Dempsey, S. J., Sheng, H. (2023). Dividend change announcements, ROE, and the cost of equity capital. International Review of Financial Analysis, 86, 102506. https://doi.org/10.1016/j.irfa.2023.102506
25. Savytska, N., Chmil, H., Hrabylnikova, O., Pushkina, O., Vakulich, M. (2019). Behavioral models for ensuring the security of functioning and organizational sustainability of the enterprise. Journal of Security and Sustainability Issues, 9 (1), 63–76. https://doi.org/10.9770/jssi.2019.9.1(6)
26. Gertler, P., Green, B., Wolfram, C. (2024). Digital Collateral. The Quarterly Journal of Economics, 139 (3), 1713–1766. https://doi.org/10.1093/qje/qjae003
27. Grossman, G. M., Helpman, E., Sabal, A. (2024). Optimal Resilience in Multitier Supply Chains. The Quarterly Journal of Economics, 139 (4), 2377–2425. https://doi.org/10.1093/qje/qjae024
28. Jaber, M. Y., Peltokorpi, J. (2024). Economic order/production quantity (EOQ/EPQ) models with product recovery: A review of mathematical modeling (1967–2022). Applied Mathematical Modelling, 129, 655–672. https://doi.org/10.1016/j.apm.2024.02.022
29. Kaufmann, M., Andre, P., Kőszegi, B. (2024). Understanding Markets with Socially Responsible Consumers. The Quarterly Journal of Economics, 139 (3), 1989–2035. https://doi.org/10.1093/qje/qjae009
30. Bazan, E., Jaber, M. Y., Zanoni, S. (2016). A review of mathematical inventory models for reverse logistics and the future of its modeling: An environmental perspective. Applied Mathematical Modelling, 40 (5-6), 4151–4178. https://doi.org/10.1016/j.apm.2015.11.027