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ECONOMIC-MATHEMATICAL MODEL OF CLUSTER-ORIENTED INNOVATIVE DEVELOPMENT IN THE UKRAINIAN AGRICULTURAL SECTOR

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ЕКОНОМІКО-МАТЕМАТИЧНА МОДЕЛЬ ІННОВАЦІЙНОГО РОЗВИТКУ АГРАРНОГО СЕКТОРУ УКРАЇНИ НА ОСНОВІ КЛАСТЕРНОГО ПІДХОДУ

Contemporary transformational processes in Ukraine's agricultural sector have increased the need for scientifically grounded mechanisms to support innovative development, ensuring the sustainable competitiveness of national agriculture amid global challenges. One of the most effective tools to address this task is the implementation of a cluster approach, which facilitates the formation of spatial and economic associations among agricultural entities, stimulates innovative cooperation, accelerates the diffusion of innovations, and enhances the efficiency of resource utilization. At the same time, scientifically grounded managerial decisions regarding the development of agricultural clusters require precise and reliable methods for quantitatively assessing the relationships among economic, production, innovation, and social indicators. Accordingly, the aim of this study is to develop and substantiate an economic-mathematical model of innovative development in Ukraine's agricultural sector based on the cluster approach, employing correlation-regression methods. These methods allow for the identification of key influencing factors, the evaluation of the strength and direction of interconnections among them, and the creation of an analytical foundation for forecasting the effectiveness of innovation processes within agricultural clusters. The study emphasizes that economic-mathematical modeling of innovative development based on the cluster approach is a highly complex scientific task, as it requires constructing models that not only systematically evaluate the impact of key factors on total innovation investments but also account for the specific conditions of individual clusters. The results indicate that the most effective solution for this task is a correlation-regression model, which assesses the influence of key factors on the dependent variable while allowing analytical adaptation to local conditions without compromising overall scientific rigor. This model identifies critically important influencing factors and enables the simulation of various development scenarios, supporting the substantiation of political and economic decisions in the agricultural sector.

Сучасні трансформаційні процеси в аграрному секторі України зумовлюють підвищену потребу в розробленні науково обґрунтованих механізмів підтримки інноваційного розвитку, здатних забезпечити стійку конкурентоспроможність національного сільського господарства в умовах глобальних викликів. Одним із найбільш ефективних інструментів, що наразі застосовуються для вирішення такої задачі є впровадження кластерного підходу, який сприяє формуванню просторових та економічних об'єднань суб'єктів аграрної діяльності, оскільки вони стимулюють інноваційну кооперацію, прискорюють дифузію інновацій і підвищують ефективність використання ресурсного потенціалу. Разом із тим, для наукового обґрунтування управлінських рішень щодо розвитку аграрних кластерів необхідні точні та надійні методи кількісної оцінки зв'язків між економічними, виробничими, інноваційними та соціальними показниками. Відтак, метою статті є розробка та обґрунтування економіко-математичної моделі інноваційного розвитку аграрного сектору України на основі кластерного підходу із застосуванням кореляційно-регресійних методів, що дозволяють ідентифікувати ключові фактори впливу, оцінити силу та напрям взаємозв'язків між ними та сформувати аналітичну базу для прогнозування результативності інноваційних процесів у аграрних кластерах. У межах дослідження звернено увагу на той факт, що економіко-математичне моделювання інноваційного розвитку на основі кластерного підходу є надскладною науковою задачею, адже потребує побудови моделей, що здатні не лише системно оцінювати вплив ключових факторів на сукупні інвестиції в інновації, але й відзеркалювати специфічні умови в яких функціонує кожен окремий кластер. За результатами дослідження доведено, що найбільш оптимальною для вирішення окресленої задачі є кореляційно-регресійна модель, яка надає змогу оцінювати вплив ключових факторів на залежну змінну вже в процесі її формування, проходячи аналітичну адаптацію до локальних умов без втрати загальної наукової строгості. Так, модель ідентифікує критично важливі фактори впливу та дає можливість моделювати різні сценарії розвитку та обґрунтовувати політичні та економічні рішення у аграрному секторі.

Key words: influencing factors; model; agricultural cluster; agricultural sector; development scenarios.

Ключові слова: фактори впливу; модель; аграрний кластер; аграрний сектор; сценарії розвитку.

PROBLEM STATEMENT

Modern transformational processes in Ukraine's agricultural sector have increased the need for scientifically grounded mechanisms to support innovative development, capable of ensuring the sustainable competitiveness of national agriculture in the face of global challenges. One of the most effective tools currently employed to address this task is the cluster approach, which fosters the formation of spatial and economic associations of agricultural actors by stimulating innovative cooperation, accelerating the diffusion of innovations, and enhancing the efficiency of resource utilization.

At the same time, scientifically grounded managerial decisions regarding the development of agricultural clusters require precise and reliable methods for quantitatively assessing the relationships between economic, production, innovation, and social indicators. In this context, correlation and regression methods play a key role, as they allow for determining the strength and direction of relationships between innovation activity factors, assessing their impact on the performance of agricultural enterprises, and constructing predictive models for the development of cluster structures.

The application of an economic-mathematical framework based on correlation-regression models provides opportunities for a comprehensive analysis and optimization-oriented adjustment of the spatial and sectoral characteristics of innovation processes, the formation of optimal interaction structures among cluster participants, and the evaluation of the effectiveness of innovation policies in the agricultural sector. This, in turn, opens prospects for the development of flexible strategic planning models capable of adapting to the dynamics of both the external environment and internal resource constraints.

In this regard, the development of an economic-mathematical model for the innovative development of Ukraine's agricultural sector, based on the cluster approach and grounded in the application of correlation-regression models to identify key factors and patterns of innovation processes, becomes particularly relevant.

ANALYSIS OF RESEARCH AND PUBLICATIONS

Problems of economic-mathematical modeling of the innovative development of Ukraine's agricultural sector based on the cluster approach

Table 1. Systematization and analysis of the content and key properties of the main data analysis methods

Data analysis methods	Essence of the model	Possibility of establishing a causal relationship	Predictive capabilities	Overall flexibility
Correlation and regression analysis	Evaluates the strength and direction of the influence of factors $X_1…X_n$ on the outcome variable Y	Yes (within the model, after statistical significance tests)	Yes (forecast scenarios can be built)	Very high
Analysis of variance (ANOVA)	Comparison of means between groups	No (only differences between means)	Low	Low
Cluster analysis	Grouping of objects based on similarity	No (no causality)	None	Medium (for structuring)
Factor analysis	Identifies latent factors that explain data variation	No	None	Medium
Principal component analysis (PCA)	Dimensionality reduction, formation of components	No	None (not a predictive method)	Medium
Discriminant analysis	Constructing functions for group classification	Partially, but for classification purposes	Low (for classification, not prediction)	Low
Multidimensional scaling (MDS)	Visualization of distances/similarities between objects	No	None	Low

Source: created by the authors based on [4; 8].

have been examined in considerable detail by such scholars as Litvinov D., Shalenyi V. [3], Derlukiewicz N., Mempel-Sniezyk A., Mankowska D., Dyjakon A., Minta S., and Pilawka T. [1]. In particular, these researchers focused on analyzing existing methods of economic-mathematical modeling, their suitability for describing structural transformations in clustered agri-food systems, and the potential of clusters to enhance the innovative activity of enterprises.

Furthermore, Mazhara H. and Grekul A. [5] emphasize that modeling innovative development in agricultural clusters requires accounting for a wide range of factors-from financial and technological to organizational and network-related. However, most approaches rely either on aggregated macro-models, which do not adequately capture the specifics of local production systems, or on qualitative expert evaluations, which limit the potential for quantitative forecasting.

FORMULATION OF THE ARTICLE'S OBJECTIVES

Therefore, the purpose of this article is to develop and substantiate an economic-mathematical model of innovative development in Ukraine's agricultural sector based on the cluster approach, employing correlation-regression methods that allow for the identification of key influencing factors, the assessment of the strength and direction of their relationships, and the creation of an analytical foundation for forecasting the effectiveness of innovation processes within agricultural clusters.

THE PAPER MAIN BODY

Modern researchers (in particular, Mazhara H., Grekul A. [5], Litvinov D., and Shaleny V. [3]) emphasize that an economic-mathematical model is a mathematical expression, equation, or system of equations constructed on the basis of real data and validated using statistical and other analytical methods. Such methods include analysis of variance, cluster analysis, factor analysis, principal component analysis, discriminant analysis, and multidimensional scaling. A systematization and analysis of the content and key properties of the main data analysis methods is presented in Table 1.

It should be noted that the content of the methods outlined in the table should be as flexible as possible, so that the model constructed using them reflects objective economic relationships that are interpretable and suitable for forecasting. Accordingly, within the scope of this study, such a method is the multifactor regression equation, which:

— reproduces actual interrelations between indicators based on empirical data;

— allows for the assessment and interpretation of the influence of factors X_1, X_2, and X_3 on the outcome variable Y;

— possesses predictive properties, enabling the evaluation of possible scenarios for the innovative development of agricultural clusters.

Thus, not every expression or equation can be considered an economic-mathematical model. Only those derived from statistically validated relationships, which adequately describe the studied economic processes and possess explanatory and predictive power, can be qualified as a full-fledged economic-mathematical model.

A problematic aspect of the study is that the modeling of the innovative development of Ukraine's agricultural sector was carried out not

Table 2. Factors that may potentially serve as a basis for constructing a model of innovative development of Ukraine's agricultural sector

Group of factors	Factors that may potentially be included in the model
Economic	Investment volume in the cluster (foreign direct investment, domestic investment in equipment and infrastructure modernization)
	Availability of financial resources (loans for agricultural producers; government support programs; availability of agricultural banking products)
	Level of infrastructure development (logistics infrastructure, energy and digital infrastructure)
Technological	Technological level of enterprises (equipment level; automation and digitalization of production processes)
	Implementation of digital solutions (precision farming; GPS monitoring; drones, sensors, satellite data; digital farm management systems)
	R&D activity within the cluster (presence of innovation centers; expenditures on research and development; number of patents and innovative projects)
Human capital and personnel	Qualification of employees and managers (level of education and professional training; ability to work with modern technologies)
	Presence of educational and research institutions in the cluster (agricultural universities, colleges; research institutes; training centers)
	Management culture and entrepreneurial activity (willingness to implement innovations; efficiency of farm management)
Institutional and regulatory	Stability and predictability of government policy (land reform; export/import regulation; tax policy)
	Presence of institutions supporting agricultural innovations (advisory services; business incubators; agricultural innovation hubs)
	Degree of cluster governance development (presence of cluster associations; quality of coordination between enterprises, authorities, and research institutions)
Market	Access to domestic and international markets (logistics, certification, quality standards)
	Competitive pressure within the cluster (competition stimulates modernization and investment in innovations)
	Demand for high value-added products (development of processing, organic production, export niches)

Source: created by the authors based on [1—2; 6—7].

at the level of the entire industry, but at the level of individual clusters, identified according to three criteria: geographic (cluster formations within specific districts or regions), functional (specialization — grains, dairy, livestock, etc.), and network-based (the structure of interconnections between suppliers, processors, and markets), in order to determine the extent to which these formations contribute to its innovative development. Naturally, due to the locality of the clusters, the diversity of their functional specialization, and the variability of network connections, the model will have practical value.

Accordingly, within the framework of the outlined study, correlation-regression methods for data processing and analysis were applied. Based on the performance indicators of existing cluster associations, these methods allow for a quantitative assessment of the influence of key factors (X_1, X_2, X_3) on the dependent variable Y (total innovation investments — expenditures on R&D, equipment modernization, digitalization) and enable the identification of insignificant development drivers for each cluster individually. It should be noted that correlation-regression analysis allows for the consideration of a broader set of potential independent variables or factors (X), covering the economic, technological, human resources, institutional, and market characteristics of the clusters (see Table 2). In this context, correlation-regression models undergo analytical adaptation to local conditions during their formation, without losing overall scientific rigor.

It should be noted that the variables X, which may potentially be selected for inclusion in a multiple regression model, must satisfy a number of methodological requirements. First and foremost, they should be represented as numerical values, ensuring their suitability for subsequent statistical processing. If qualitative indicators that do not possess a natural numerical representation need to be included in the analysis, they should be assigned a quantitative interpretation. This can be achieved through the use of binary (dummy) variables, ordinal scales, or composite indices that aggregate expert or survey assessments.

Simultaneously, in order to construct a multiple correlation-regression equation reflecting the innovative development of Ukraine's agricultural sector based on a cluster approach, it is appropriate to follow the classical logic of building a multiple regression model, which includes: Stage 1 — selection and coding of variables; Stage 2 — preliminary data analysis and factor selection based on correlations; Stage 3 — assessment of multicollinearity and intercorrelations; Stage 4 — specification of the model in both structural and matrix form [5].

Stage 1 focuses on the identification and initial coding of variables. Specifically, it is necessary to define the dependent variable Y (e.g., expenditures on R&D, equipment modernization, digitalization [3—4]) and to select an initial set of factors X_1, X_2, ..., X_p from Table 1. It is also recommended to perform normalization or standardization to ensure comparability of variables (for example, standardizing via z-scores or applying a logarithmic transformation for highly skewed values, such as R&D activity within the cluster).

Stage 2, the preliminary data analysis, entails that the variables X, which can realistically be included in the model, must exhibit a statistically significant relationship with the dependent variable Y. This implies that the pairwise correlation coefficient |r| (correlation matrix) between the factor and the outcome should not only be statistically significant (in practice, |r| thresholds of 0.2—0.3 are generally considered) but also sufficiently high to justify its inclusion in the regression equation. In the absence of a discernible relationship, the variable will not contribute to improving the model's accuracy and may merely introduce additional statistical noise [5; 8].

Stage 3, the assessment of intercorrelations and multicollinearity, primarily involves analyzing the correlation matrix among the X variables. Factor variables should not exhibit strong linear relationships with one another, as this leads to intercorrelations that distort parameter estimates, complicate the interpretation of results, and reduce the reliability of regression conclusions. If, for a pair of variables X_i and X_j, the correlation coefficient satisfies $|r| > 0.7$—0.8, it is advisable to consider aggregation, removal, or the application of regularization methods (Ridge, Lasso) [4].

Regarding the formal assessment of multicollinearity, it can be conducted using the Fisher F-test according to the Farrar-Glauber methodology. The calculated F-values are compared with the critical (tabular) values at degrees of freedom $v_1 = n - m$ and $v_2 = m - 1$ and a significance level α. If, for the k-th variable, the condition $F_k > F_{ta}b$ is satisfied, the variable is considered to be multicollinear with the other factors [5-6].

Stage 4. Model specification involves presenting the regression equation in its optimal basic form (1) and transitioning to the matrix formulation of the model.

The basic form of a multiple linear regression is given by the equation [4]:

$$Yi=\beta0+\beta1X1i+\beta2X2i+\cdots+\beta pXpi+\varepsilon i \quad (1);$$

where: Y — dependent variable (i-th observation), X — value of the j-th predictor for the i-th observation" β_0 — intercept, $\beta_1,\ldots,\beta_p$ — regression coefficients, ε — error term.

In this case, the matrix form of the model will be as follows:

$$Y=X\beta+\varepsilon,\ \beta n=(XTX)\ -1X\ T\ Y,$$

where β is chosen to minimize $\|Y-X\beta\|^2$, (2);

where: Y — n×1 vector of dependent variables; X — n×(p+1) matrix of predictors (the first column consists of ones), β — (p+1)×1 vector of parameters, ε — n×1 error vector.

Parameter estimation is performed using the least squares method, which involves minimizing the residual sum of squares with respect to β. A closed-form analytical solution exists only if the matrix XTX is non-singular (i.e., invertible) [4].

In particular, following the outlined stages, the authors conducted economic-mathematical modeling of the innovative development of the Agrocluster "AgroVin" (Vinnytsia region, a member of the Ukrainian Cluster Alliance, specializing in grape cultivation and wine production) and the Cluster "Sil'tse" (Zakarpattia region, specializing in the cultivation of typical vegetables). It should be noted, however, that due to their relatively short period of operation, only four years of data were available for analytical processing. The modeling employed indicators of total domestic investments in innovations as the dependent variable Y, and a set of independent variables X, as presented in Table 1.

Based on the preliminary correlation analysis, it was established that:

For the "AgroVin" cluster (64 active participants), the most significant factors are:

— X_1 — average volume of credit resources available to the cluster's agricultural producers (reflecting the financial capacity for modernization and the implementation of innovations);

— X_2 — cost of implementing digital solutions (determining the investment barrier for technological innovations in production, logistics, or processing);

— X_3 — investments in educational and research institutions within the cluster (shaping innovation potential and the capacity for "education-science-business" cooperation).

For the "Sil'tse" cluster (55 active participants), the most significant factors are:

— X_1 — efficiency of farm management (affecting the ability to optimize processes, implement technological solutions, and manage resources);

— X_2 — cost of implementing digital solutions (similarly to the AgroVin cluster, determining the entry barrier for innovative technologies);

— X_3 — volume of investments in the technological level of enterprises (reflecting the renewal of technical and technological infrastructure and the pace of production modernization).

These variables were precisely those included in the multiple regression model of innovative development for the respective clusters.

The input data used to construct the economic-mathematical models of innovative development

Table 3. Input and output data used to construct economic-mathematical models of innovative development for the Agroclusters "AgroVin" and "Sil'tse" 2021—2025, million UAH

XY	"AgroVin"								"Sil'tse"							
	2021	2022	2023	2024	2025	2026	Innovative development model	Model significance	2021	2022	2023	2024	2025	2026	Innovative development model	Model significance
	Actual				Forecast according to the model*				Actual				Forecast according to the model**			
У	11,8	13,5	10,4	15,9	17,6	19	Y=4.66+ 1.12X1+ 2.41X2-2.11X3	100% of the change in Y is explained by the change in X_j	9	17	13	20	21	24,7	Y= 5.67-0.54X1 + 5.09X2 + 0.5475X3	100% of the change in Y is explained by the change in X_j
X1	3	3,9	4	6,7	7,37	8,48			2,2	3	4	5,3	5,3	5,3		
X2	3,7	3	2,28	3,4	3,79	3,88			1,1	2	1,5	3	3,35	3,78		
X3	1,9	1,3	2	2,1	2,1	2,1			2,4	3	3,6	4,9	4,9	4,9		

Note:

* It is assumed that cluster participants will increase the average volume of credit resources available for attraction (X_1) by engaging the cluster's partner banks (by 10% by the end of 2025 and by 15% by the end of 2026); and will increase investments in the implementation of digital solutions (X_2) through the use of digital platforms for production, logistics, and sales management (by 11.5% by the end of 2025 and by 12.6% by the end of 2026).

* It is assumed that cluster participants will increase the cost of implementing digital solutions (X_2) through the use of digital platforms for production, logistics, and sales management (by 11.5% by the end of 2025 and by 12.6% by the end of 2026).

Source: authors' own elaboration/

for the Agroclusters "AgroVin" and "Sil'tse" are presented in Table 3.

Thus, as a result of constructing the multifactor linear regression model for the innovative development of "AgroVin" and obtaining a closed-form analytical solution, the model takes the form $Y = 4.6642 + 1.12X_1 + 2.41X_2 - 2.11X_3$.

Furthermore, according to the matrix of pairwise correlation coefficients, all $|r| < 0.7$, indicating the absence of multicollinearity among the factors (see Table 4).

Accordingly, the innovative development model should be structured so that changes in the internal innovation investments of "AgroVin" participants follow a clear and interpretable pattern, in which:

1. An increase in the average volume of credit resources available for attraction, X_1, by 1 million UAH leads to an average increase in Y of 1.116 million UAH. This indicates that access to credit facilitates production modernization and enhances the willingness of cluster participants to invest in technological innovations.

2. An increase in X_2 by 1 million UAH leads to an average increase in Y of 2.409 million UAH. This demonstrates that investments in digitalization

Table 4. Matrix of pairwise correlation coefficients of all variables in the "AgroVin" innovative development model

-	y	x1	x2	x3	Conclusions from the correlation analysis
y	1	0.7457	0.511	-0.00392	The strongest driver of innovation is X_1 (credits), followed in significance by X_2 (digitalization). Weak or nearly zero relationships between X_2 and X_3, as well as between X_3 and Y, indicate the absence of multicollinearity for these factors.
x1	0.7457	1	-0.1058	0.3095	
x2	0.511	-0.1058	1	0.0551	
x3	-0.00392	0.3095	0.0551	1	

Source: authors' own elaboration based on SPSS modules.

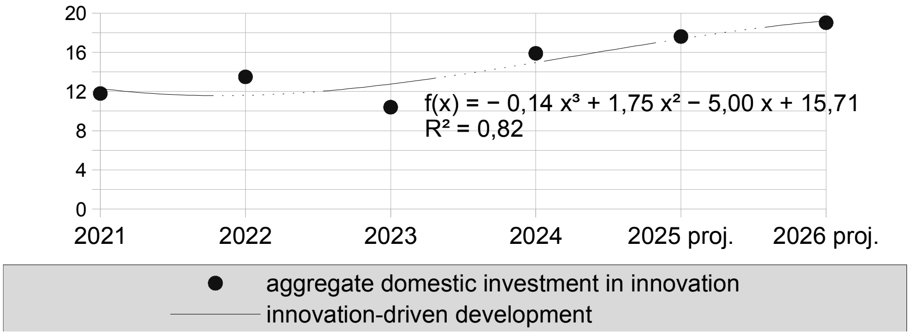

Figure 1. Actual and forecasted changes in internal innovation investments of "AgroVin" participants from 2021 to 2026, million UAH

Source: authors' own elaboration based on SPSS modules.

exert the strongest positive effect, highlighting that digital solutions are a key driver of development in production, logistics, and processing.

3. An increase in X_3 by 1 million UAH leads to an average decrease in Y of 2.11 million UAH. This suggests that the effect of investments in "education-science-business" cooperation is delayed-resources are expended in the short term, while benefits materialize later.

Based on the planned changes in X_1 and X_2, it is possible to visualize the projected trend of innovative development in the "AgroVin" cluster from 2021 to 2026 (see Figure 1).

The impact of the changes illustrated in the figure on the average volume of credit resources available to the cluster's agricultural producers and the cost of implementing digital solutions is evident, as, under unchanged conditions, it will enable a transition to a sustainable increase in internal innovation investments by "AgroVin" participants starting from 2025.

Meanwhile, as a result of constructing the multifactor linear regression model for the innovative development of "Sil'tse" and obtaining a closed-form analytical solution, it takes the form $Y = 5.6711 - 0.5421X_1 + 5.0923X_2 + 0.5475X_3$. According to the matrix of pairwise correlation coefficients, all $|r| < 0.7$, indicating the absence of multicollinearity among the factors; that is, the independent variables are not strongly correlated and can be reliably used in the model (see Table 5).

The innovative development model should be structured so that changes in internal innovation investments of "Sil'tse" participants follow a clear and interpretable pattern, in which:

1. An increase in farm management efficiency, X_1, by 1 million UAH leads to an average decrease in Y of 0.542 million UAH. Improving management efficiency may temporarily reduce internal innovation investments, as resources are directed toward optimizing current processes and monitoring operational activities.

2. An increase in the cost of implementing digital solutions, X_2, by 1 million UAH leads to an average increase in Y of 5.092 million UAH. Investments in digitalization stimulate production modernization and productivity growth.

3. An increase in investments in the technological level of enterprises, X_3, by 1 million UAH leads to an average increase in Y of 0.548 million UAH. Modernization of the technical and techno-

Table 5. Matrix of pairwise correlation coefficients of all variables in the "Sil'tse" innovative development model, 2021—2025, million UAH

-	y	x1	x2	x3	Conclusions from the correlation analysis
y	1	0.5584	0.9912	0.3445	The strongest driver of innovation is X_2 (cost of implementing digital solutions), as evidenced by its very high correlation with Y (0.9912). All $\lvert r\rvert < 0.7$ (except for the Y–X_2 relationship) → multicollinearity among X_1, X_2, and X_3 is generally low, making the model statistically reliable.
x1	0.5584	1	0.639	0.00956	
x2	0.9912	0.639	1	0.2434	
x3	0.3445	0.00956	0.2434	1	

Source: authors' own elaboration based on SPSS modules.

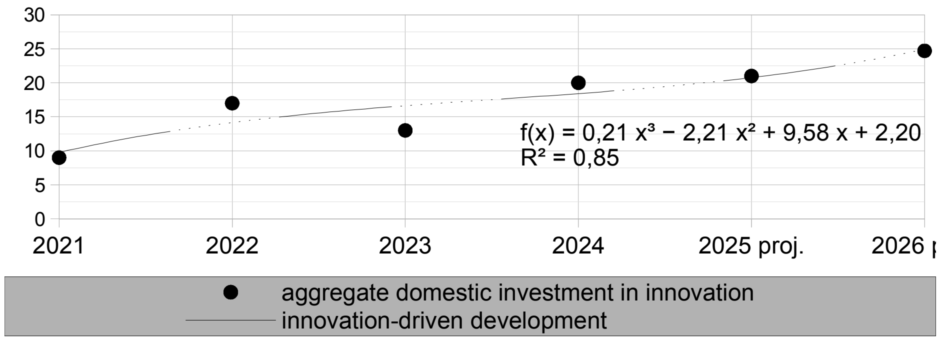

Figure 2. Actual and forecasted changes in internal innovation investments of "Sil'tse" participants from 2021 to 2026, million UAH

Source: compiled by the authors based on SPSS modules.

logical base of enterprises encourages innovation investments, although the effect is less pronounced than that of digitalization.

Based on the planned changes in X_2, it is possible to visualize the trend of innovative development of the "Sil'tse" cluster from 2021 to 2026 (see Figure 2).

Thus, the effect of the changes in the cost of implementing digital solutions, as outlined in the figure, is evident, since, under unchanged conditions, it will allow a transition from 2025 to a sustainable increase in internal investments in innovation by the participants of "Sil'tse."

It should be noted that the approach we propose for constructing models of innovative development in the agricultural sector, based on a cluster approach, allows for a systematic assessment of the impact of key factors on total investments in innovation, taking into account the specific conditions in which each individual cluster operates.

CONCLUSIONS

Within the scope of this study, it was noted that economic-mathematical modeling of innovative development based on a cluster approach is an extremely complex scientific task, as it requires the construction of models capable not only of systematically assessing the impact of key factors on total investments in innovation, but also of reflecting the specific conditions under which each cluster operates.

The results of the study demonstrate that the most suitable approach for addressing this task is a correlation-regression model, which evaluates the impact of key factors on the dependent variable while undergoing analytical adaptation to local conditions during its formation, without compromising overall scientific rigor. Thus, the model identifies critically important influencing factors and enables the simulation of various development scenarios, while supporting the substantiation of political and economic decisions in the agricultural sector.

The innovation development model constructed within the framework of this study, exemplified by the clusters "AgroVin" (Vinnytsia region, a participant of the Ukrainian Cluster Alliance, specializing in grape cultivation and wine production) and "Sil'tse" (Zakarpattia region, specializing in the cultivation of typical vegetables), demonstrated its inherent ability to systematically assess the impact of key factors on total investments in innovation. The study showed that for the "AgroVin" cluster, the main drivers are financial support (loans) and digitalization. For the "Sil'tse" cluster, the primary factors are digitalization, technical modernization of enterprises, and the efficiency of farm management.

It should be noted that the practical value of this model lies in its ability to quantitatively forecast innovative development while accounting for the specific conditions under which each cluster operates and evolves. This allows cluster managers and government support bodies to anticipate the effects of changes in financial, technological, and managerial resources. Furthermore, given that digitalization is a key driver of innovation in both clusters, this highlights the need for state support in implementing digital solutions and developing IT infrastructure within the agricultural sector.

Prospects for further research include the refinement and adaptation of economic-mathematical models of innovative development in the agricultural sector, taking into account the regional characteristics of clusters, as well as the integration of advanced data analysis and forecasting methods to enhance the effectiveness of managerial decisions and support the sustainable competitiveness of national agriculture.

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