МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
ХАРКІВСЬКИЙ НАЦІОНАЛЬНИЙ ЕКОНОМІЧНИЙ УНІВЕРСИТЕТ
ІМЕНІ СЕМЕНА КУЗНЕЦЯ

ЗАТВЕРДЖЕНО
на засіданні кафедри економічної кібернетики
і системного аналізу

Протокол №1 від 22.08.2023 р.

ПОГОДЖЕНО
Проректор з навчально-методичної роботи

_____ Каріна НЕМАШКАЛО

МАТЕМАТИЧНІ МЕТОДИ ТА МОДЕЛІ У НАУКОВИХ ДОСЛІДЖЕННЯХ

робоча програма навчальної дисципліни (РПНД)

Галузь знань	**05 Соціальні та поведінкові науки**
Спеціальність	**051 Економіка**
Освітній рівень	**третій (освітньо-науковий)**
Освітня програма	**Економіка**

Статус дисципліни	**обов'язкова**
Мова викладання, навчання та оцінювання	**англійська**

Розробники:
Д.е.н., професор Лідія ГУР'ЯНОВА
К.е.н., доцент Віталій ГВОЗДИЦЬКИЙ

Завідувач кафедри
економічної кібернетики
і системного аналізу Лідія ГУР'ЯНОВА

Гарант програми Галина НАЗАРОВА

Харків
2024

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
SIMON KUZNETS KHARKIV NATIONAL UNIVERSITY OF ECONOMICS

APPROVED
at the meeting of the department of tconomic cybernetics and system analysis

Protocol №1 of 22.08.2023

AGREED
Vice-rector for educational and methodical work

_____ Karina NEMASHKALO

MATHEMATICAL METHODS AND MODELS IN SCIENTIFIC RESEARCH

Program of the course

Field of knowledge	**05 Social and behavioral sciences**
Specialty	**051 Economics**
Study cycle	**the third (educational and scientific)**
Study programme	**Economics**

Course status	**mandatory**
Language	**English**

Developers:
Doctor of Economics, professor — Lidiya GURYANOVA
academic title
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Head of Department of Economic Cybernetics and System Analysis — Lidiya GURYANOVA

Guarantor of the program — Galina NAZAROVA

Kharkiv
2024

INTRODUCTION

A necessary condition for the effective and successful scientific activity of post-graduate students is knowledge of the essence of the methodology and organization of scientific research. An important place in this knowledge is occupied by mathematical methods and models. Therefore, the course "Mathematical methods and models in scientific research" is very important in the training of scientific researchers. The course consists of two content modules: methods and models of multidimensional data analysis, applied econometrics.

Mathematical methods and models reproduce socio-economic processes and phenomena that depend on a large number of parameters characterizing them. This determines the difficulties associated with identifying the structure of relationships of these parameters. In conditions where decisions are made on the basis of stochastic, incomplete information, the use of methods of mathematical modelling of objects is necessary.

The purpose of the educational course: study of the theoretical foundations and possibilities of practical application of methods of modeling systems operating under conditions of uncertainty during scientific research.

The tasks of studying the course are to form in the recipient of the educational and scientific degree of Doctor of Philosophy a conceptual knowledge of methods and models, mathematical apparatus, modern concepts that determine different approaches to modelling complex systems, knowledge of the basic tools for solving the tasks of scientific research, processing, information presentation and communication with colleagues during research.

The object of the academic course is complex socio-economic systems functioning in conditions of uncertainty.

The subject of the academic course is methods of modelling socio-economic systems.

The learning outcomes and competencies formed by the course are defined in table 1.

Table 1

Learning outcomes and competencies formed by the course

Learning outcomes	Competencies
LO01	SK 6
LO03	SK 6
LO04	GK 2, SK 6
LO08	SK 3
LO09	GK2, SK3, SK 6, SK 8
LO10	SK6
LO11	SK6

where, LO01. To have advanced conceptual and methodological knowledge of economics, management of socio-economic systems and at the border of subject areas, as well as research skills sufficient for conducting fundamental and applied research at the level of world achievements in the relevant field.
LO03. To develop and to research fundamental and applied models of socio-economic processes and systems, effectively use them to obtain new knowledge and/or create innovative products in economics and related interdisciplinary areas.
LO04. To apply modern tools and technologies of information search, processing and analysis, in particular, statistical methods of analysis of big data sets and/or complex structure, specialized software and information systems.
LO08. To plan and to carry out empirical and/or theoretical research in the field of economics and related interdisciplinary areas, critically analyze the results of own research and the results of other researchers in the context of the entire complex of modern knowledge regarding the researched problem.
LO09. To formulate and to test hypotheses; to use appropriate evidence to substantiate conclusions, in particular, the results of theoretical analysis, empirical research and mathematical and/or computer modelling, available literature data.
LO10. To apply creative technologies and mathematical methods and models when conducting scientific research and identifying cause-and-effect relationships and trends in the development of economic phenomena and processes.
LO11. To propose new solutions in the socio-economic sphere to ensure balanced socio-economic development in the new global socio-economic reality.
GK02. Ability to search, process and analyze information from various sources.
SK03. The ability to use modern methodologies, methods and tools of empirical and theoretical research in the field of economics, computer modelling methods, modern digital technologies, databases and other electronic resources, specialized software in scientific and scientific-pedagogical activities.
SK06. The ability to substantiate and prepare economic decisions based on an understanding of the patterns of development of socio-economic systems and processes using mathematical methods and models.
SK08. The ability to identify new trends and tendencies in the development of socio-economic phenomena and processes, to identify cause-and-effect relationships with the use of creative technologies in the implementation of scientific research.

COURSE CONTENT

Content module 1.
Methods and models of multidimensional data analysis

Topic 1. Modelling as a method of scientific knowledge of complex systems. Peculiarities of the application of cluster analysis methods.

1.1. Peculiarities of multidimensional statistical data processing.

Methods of multidimensional statistical analysis. Types of feature space. Stages of research using multidimensional statistical analysis.

1.2. Methods of multidimensional processing, comparison and modeling of populations.

Connection of the course with other courses of the specialty. Typology of methods of multidimensional data analysis.

1.3. Peculiarities of the application of cluster analysis methods.

The concept of cluster analysis, its tasks. Basic approaches to the classification of objects.

1.4. Terminology of cluster analysis

Concept of "cluster", properties of "cluster". Types of cluster structures. General characteristics of cluster analysis methods. Stages of cluster analysis. Requirements for input data.

1.5. Similarity measures.

Peculiarities of the measure of similarity. Measures of similarity: correlation coefficient. Distance measures, associativity coefficients.

1.6. Classification of cluster procedures.

Groups of cluster analysis methods. Distance between clusters.

1.7. Hierarchical agglomerative and iterative cluster procedures.

Hierarchical grouping methods. Algorithm of Ward's method. Iterative classification methods of cluster analysis. K-means method

1.8. Alternative methods of classification of multidimensional objects

Fuzzy clustering. Basic fuzzy k-means algorithm. Fuzzy c-means method. Geometric methods. The "trout" method of searching for thickening. Dendrite method. Ball method.

1.9. Cluster analysis classification quality criteria.

Clustering quality criteria, in which evaluation methods and cluster analysis quality criteria are implemented.

Topic 2. Classification with training. Methods of discriminant analysis

2.1. Basic provisions of discriminant analysis.

The essence of discriminant analysis. Basic concepts of discriminant analysis. The task of discriminant analysis. History of discriminant analysis.

2.2 Methods of discriminant analysis

Classification in the presence of two training samples. Classification in the presence of k training samples. Limitations when using discriminant variables

2.3. Fisher's linear discriminant analysis algorithm for two classes.

Discriminant functions and their geometric interpretation. Calculation of the coefficients of the discriminant function. Checking the quality of discrimination. An example of using discriminant analysis. Packages of application programs in which the methods of discriminant analysis are implemented.

Topic 3. Methods of reducing the feature space

3.1. The concept of reduction and the history of reducing the dimensionality of the feature space.

The task of reducing the dimensionality of the feature space. Concept and history of feature space reduction methods.

3.2. Methods of feature space reduction.

Methods of solving the problem of dimensionality reduction and its formulation. Methods of incomplete reduction. Center of gravity method. Methods of complete reduction. Taxonomic indicator of the level of development

3.3. Algorithm of the center of gravity method.

Algorithm of the center of gravity method. Rules for choosing a representative indicator. Grouping and selection of representatives. An example of the implementation of the center of gravity method.

3.4. Taxonomic indicator of the level of development.

Algorithm for building a taxonomic indicator. An example of calculating a taxonomic index. Packages of application programs in which reduction methods are implemented.

Topic 4. Models and methods of factor analysis

4.1. The essence of the factor analysis model, its main tasks.

Concept of factor analysis. The history of the development of factor analysis. Classification of methods of factor analysis. The task of factor analysis. Formulation of the problem of factor analysis

4.2. Determination of the structure and statistical study of the factor analysis model.

The basic model of factor analysis. The basic scheme of implementing factor analysis. Matrix form of factor analysis model. Factor analysis variance components. Fundamental theorem of factor analysis. Variants of implementation of computational procedures of factor analysis.

4.3. Method of principal components. Assessment of factors and classification problems.

Methods of calculating commonalities. Algorithm of the principal components method. Assessment of the significance of the factor analysis model. Interpretation of the obtained factors. Rotation problem. An example of the implementation of the method of principal components.

Content module 2.
Methods of advanced econometrics

Topic 5. Problems of developing econometric models

5.1. Peculiarities of building an econometric model.

Econometric model, its types. Stages of construction of econometric models. Peculiarities of justification of the form of the econometric model. Factor selection methods. Quality criteria of econometric models.

5.2. Methods of developing an econometric model under conditions of multicollinearity.

Construction of econometric models in conditions of multicollinearity of independent variables. Signs of multicollinearity. Methods of freeing from multicollinearity.

5.3. Construction of econometric models with non-standard errors.

Checking for autocorrelation. Estimation of parameters of models with autocorrelated residuals. Methods of determining heteroskedasticity. Estimation of model parameters with heteroscedastic errors.

Topic 6. Models with discrete variables

6.1 Concept of dummy variables. Types of models with dummy variables.

The essence of dummy variables. Regression of quantitative and qualitative variables. Measures of communication. Models with multiple dummy variables. Interaction of dummy variables.

6.2. Peculiarities of constructing models with dummy variables.

Features of the model specification with dummy variables. Displacement dummy variable. Slope dummy variable. Chow's test. Spline functions.

6.3. Concept and classification of models with discrete dependent variables.

Binary choice models. Multiple choice models. Models with ordered alternatives.

6.4. Methods of probit and logit analysis.

Features of the probit and logit models. Estimation of model parameters. Quality criteria of models. Multiple choice models. Peculiarities of building models with unordered alternatives. Latent variables. Peculiarities of developing models with ordered alternatives.

6.5. Models with limited dependent variables

The concept of censored and truncated samples. Examples and characteristics of truncated samples. Examples and characteristics of censored samples. Models of censored samples. Tobit model. Heckman's model. Evaluation of model parameters. Quality criteria.

Topic 7. Panel data models

7.1. The concept of panel data. Types of panel data.

Spatio-temporal samples. Balanced panel. Unbalanced panel. Rotary panel.

7.2. Classification of panel data models. Methods of estimating parameters.

The usual panel data model. Fixed effect model. A random effect model. Intragroup transformation. Executive Generalized Least Squares Method.

7.3. Model specification tests.

Hierarchy of panel data models. Content of hypotheses. Fisher's test. Breusch-Pagan test. Hausman test.

Topic 8. VAR and ECM models

8.1. Peculiarities of developing a VAR model

Theoretical foundations of modeling economic systems using VAR technologies. ADF test, Granger test. Evaluation of the VAR model. Choosing the order of the VAR model. Analysis of the impulse response function. Assessment of system stability. Decomposition of forecast error variance in VAR modeling.

8.2. Concept of error correction and cointegration model.

Mechanism of error correction and cointegration. Testing time series for cointegration. Peculiarities of developing ECM models.

The list of laboratory studies in the course is given in the table 2.

Table 2

The list of laboratory studies

Title of the task	Content
Topic 1.	With the help of methods of cluster analysis, according to the above options, classify economic objects according to the following algorithms: hierarchical agglomerative method; k-means method; ball method; method of dendrites. Normalize the output data. Give a graphic and economic interpretation, build a dendrogram. Compare the breakdown into clusters, calculating the classification quality functions, draw conclusions)
Topic 2.	With the help of methods of discriminant analysis according to the above options, using classes as training samples, discriminate the specified economic objects, each of which is characterized by a system of indicators, and assign them to the appropriate class. Give an economic interpretation and draw conclusions.
Topic 3.	To carry out the reduction of features on the basis of the "center of gravity" methods, the level of development (taxonomic indicator of the level of development). Give an economic interpretation and draw conclusions.
Topic 4.	The tables show indicators of financial and economic activity of enterprises. It is necessary to calculate the factor loadings using the method of principal components, determine the values of the factors and highlight the most significant indicators, calculate the informativeness coefficients of the factor space.
Topic 5.	Build a linear multifactor econometric model (include all relevant factors and determine all its characteristics). Check the statistical significance of model parameters, multiple correlation coefficient). Check the adequacy of the model using Fisher's test. Check the model for multicollinearity. Provide a matrix of pairwise correlations for factor characteristics. To assess the significance of multicollinearity using the Farrar-Glober method. Give the results of the study of the model according to the Durbin-Watson criterion and the non-cyclic autocorrelation coefficient. Draw conclusions about the presence of autocorrelation. Build a histogram and a graph of the distribution of errors. Group data by error values, give an economic interpretation. Check the model for the presence of heteroskedasticity according to the Golfred-Quandt test, the Glaser test, and the Spearman test. Draw conclusions about the presence of pure, mixed and complete heteroscedasticity, conduct a graphical analysis, draw conclusions about the adequacy of the built multifactor model, give an economic interpretation of the model as a whole. Build and interpret models built on the basis of stepwise inclusion and stepwise exclusion of variables. If there is multicollinearity in the model, use the ridge regression method to estimate the parameters. Determine all the characteristics of the model. Draw graphs of changes in the values of ridge model parameter estimates depending on the value of the parameter. Estimate the degree of shift in grades. If there is autocorrelation or heteroskedasticity in the model, then to estimate the parameters, use appropriate methods of its correction and elimination. Make a comparative analysis of the built models. Determine the most adequate and economically interpreted model.
Topic 6.	Build a logistic regression, determine all its characteristics, evaluate its adequacy, provide a type of model. Build a probit regression, determine all its characteristics, assess its adequacy, and provide a type of model.

	Conduct a comparative analysis of models, provide a matrix of classifications, determine predictive values of probabilities, marginal effects. Present the economic interpretation of the modelling results. Build a model with dummy variables. Test the hypothesis that there is no structural shift in the data using the Chow test.
Topic 7.	Build a normal panel data model, a fixed-effect model, a random-effect model. Determine all their characteristics, evaluate the adequacy of the models. Conduct a comparative analysis of models based on Fisher, Breusch-Pagan, Hausman tests. Draw conclusions. Provide an economic interpretation of the modelling results
Topic 8.	Check time series for stationarity, make a transformation of time series. Determine the nature of cause-and-effect relationships based on the Granger test. Evaluate the VAR model, conduct impulse analysis and variance decomposition. Check time series for cointegration based on Ingle-Granger, Johansen tests, evaluate ECM model, system stability. Find a forecast. Provide an economic interpretation of the modelling results.

The list of self-studies in the course is given in the table 3.

Table 3

List of self-studies

Title of the task	Content
Topic 1.	Based on the data of socio-economic systems, develop cluster analysis models
Topic 2.	Based on the data of socio-economic systems, develop models of discriminant analysis
Topic 3.	On the basis of these socio-economic systems, carry out reduction of features
Topic 4.	Based on these socio-economic objects, form a system of principal components
Topic 5.	Develop econometric models based on the data of socio-economic systems
Topic 6.	Based on the data of socio-economic systems, develop probit, logit models, models with dummy variables
Topic 7.	Develop panel data models of socio-economic systems
Topic 8.	Based on the data of socio-economic systems, develop VAR and ECM models

The number of hours of lectures, laboratory studies, and hours of self-studies work is given in the technological card of the course.

TEACHING METHODS

In the process of teaching an academic course, in order to activate the educational and cognitive activity of students, the use of both active and interactive educational technologies is provided, including: lectures of a problem nature, mini-lectures, work in small groups, presentations, banks of visual support (Tables 4 and 5). The division of forms and methods of activation of the learning process by the topics of the educational course is given in the Table 4.

Table 4

Distribution of forms and methods of activation of the learning process according to the topics of the course

Topic	Practical application of educational technologies
Topic 1.	Lecture of a problematic nature on the issue of "Classification of methods of multivariate analysis and their features", Mini-lecture on the issue of "Hierarchical cluster procedures", banks of visual support of work in small groups, presentation of results
Topic 2.	Problem-based lecture on "Development of discriminant models", work in small groups, presentation of results, banks of visual support
Topic 3.	A lecture of a problematic nature on the issue "The task of reducing the dimensionality of the feature space", work in small groups, presentation of the results
Topic 4.	Lecture of a problematic nature on the issue of "Statement of the problem of factor analysis", banks of visual support
Topic 5.	Lecture of a problematic nature on the issue "Problems of developing an econometric model in the conditions of multicollinearity, autocorrelation, heteroskedasticity", banks of visual support for work in small groups, presentation of results
Topic 6.	Problem-based lecture on the issue of "Development of multiple choice models", banks of visual support of the robot in small groups, presentation of results
Topic 7.	Mini-lecture on the issue of "Choosing the panel data model specification", banks of visual support of the robot in small groups, presentation of the results
Topic 8.	Mini-lecture on the issue "Algorithm of cointegration analysis", banks of visual support of the robot in small groups, presentation of results

Table 5

Use of methods of activation of the learning process

Topic of the academic course	Practical application of methods	Methods of activation of the learning process
Topic 1.	Task 1. "Methods and models of cluster analysis. Classification without learning".	Work in small groups, computer simulation
Topic 2.	Task 2. "Development of discriminant models"	Work in small groups, computer simulation
Topic 3.	Task 3. "Methods for reducing the feature space"	Work in small groups, computer simulation
Topic 4.	Task 4. "Methods and models of factor analysis."	Work in small groups, computer simulation
Topic 5.	Task 5. Construction of an econometric model under conditions of multicollinearity, autocorrelation, and heteroskedasticity	Work in small groups, computer simulation
Topic 6.	Task 6. Construction and analysis of a model with dummy variables	Work in small groups, computer simulation

Topic 7.	Task 7. Construction of logit and probit models	Work in small groups, computer simulation
Topic 8.	Task 8. Construction and analysis of panel data models	Work in small groups, computer simulation

Lectures of a problematic nature are one of the most important elements of problem-based learning of applicants. Along with the consideration of the main lecture material, they provide for the establishment and consideration of a range of problematic issues of a debatable nature, which are not sufficiently developed in science and are of actual importance for theory and practice. Lectures of a problematic nature are distinguished by an in-depth argumentation of the taught material. They contribute to the formation of independent creative thinking in graduate students, instill cognitive skills in them. Applicants become participants in scientific research and solving problem situations.

Mini-lectures involve the presentation of educational material in a short period of time and are characterized by a significant capacity, complexity of logical constructions, images, proofs and generalizations. They are conducted, as a rule, as part of a study-research. Mini-lectures differ from full-length lectures by a much shorter duration. Usually, mini-lectures last no more than 10-15 minutes and are used to concisely convey new information. Mini-lectures are often used as parts of a coherent topic, which is preferably taught as a full-length lecture in order not to tire the audience. Then the information is provided alternately in several separate segments, between which other forms and methods of training are applied.

Seminars-discussions provide for the exchange of thoughts and views of participants on a given topic, as well as develop thinking, help to form views and beliefs, develop the ability to formulate thoughts and express them.

Working in small groups makes it possible to structure practical-seminar and laboratory studies in terms of form and content, creates opportunities for the participation of each student in the work on the topic of the class, ensures the formation of personal qualities and experience of social communication.

Presentations are speeches in front of an audience, used to present certain achievements, results of group work, a report on the completion of individual tasks, project works. Presentations can be both individual, for example, the speech of one applicant, and collective, that is, speeches of two or more applicants.

Computer simulation (game) is a method of learning based on the use of special computer programs, with the help of which virtual simulation is possible. Applicants can change parameters and data, make decisions, and analyze the consequences of those decisions. The purpose of using this method is to develop the system thinking of applicants, their planning abilities, the formation of skills to recognize and analyze problems, compare and evaluate alternatives, make optimal decisions and act in conditions of limited time.

Banks of visual support contribute to the activation of the learning process on the topics of the academic course with the help of visualization.

FORMS AND METHODS OF ASSESSMENT

The University uses a 100-point cumulative system for assessing the learning

outcomes of students.

Current control is carried out during lectures and laboratory studies and is aimed at checking the level of preparedness of the student of higher education to perform a specific job and is evaluated by the sum of points scored. For courses with a form of semester control credit: the maximum amount is 100 points; the minimum amount is 60 points.

The final control includes current control and assessment of the student.

Semester control is carried out in the form of grading.

The final grade in the course is determined the amount of all points received during the current control.

During the teaching of the course, the following control measures are used:

defense of laboratory assignments (60 points);

carrying out control works (20 points);

performance of an individual scientific and research task (20 points).

Modular control is carried out in the form of complex control work. The modular control is carried out at the PNS after all the theoretical material has been reviewed and individual tasks have been completed within each of the two modules.

More detailed information on the assessment system is provided in technological card of the course.

RECOMMENDED LITERATURE

Main

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