AGRICULTURAL UNIVERSITY – PLOVDIV
FACULTY OF ECONOMICS
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EVALUATION OF INVESTMENTS IN AGRICULTURE: SYSTEMIC RELATIONS AND CONTEXTUAL INFLUENCES ON COST EFFICIENCY

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AUTHOR'S SUMMARY

For the Award of the Educational and Scientific Degree of DOCTOR

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The dissertation was discussed and allowed to be defended at a meeting on …………., held on ……………….

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1) ………………………………………

2) ………………………………………

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4) ………………………………………

5) ………………………………………

The dissertation is structured as follows: a list of abbreviations, acknowledgments, introduction, exposition in three (3) chapters, conclusion, and bibliography.

The dissertation has a total length of 216 pages and includes 19 tables, 19 figures, 13 panels with charts, and 25 equations.

The cited and analyzed literature comprises 194 sources in Latin script.

Contents of the Author's Summary

I. General Characteristics of the Dissertation

1. Relevance of the Topic

The topic of the impact of investments in fixed assets on the productivity and efficiency of agricultural production has been central to agricultural economists over the past decades. In the context of modern agriculture, focused on improving efficiency, competitiveness, and sustainability, investments in durable assets such as machinery, equipment, and infrastructure play a decisive role.

However, the effect of these investments on efficiency and productivity often remains uncertain due to the influence of numerous factors—socio-economic, geopolitical, demographic, climatic, and environmental. These factors not only vary across regions and sectors but also interact with one another, creating complex and dynamic interdependencies.

The disparities in agricultural production efficiency arising from these interactions necessitate the application of complex systemic approaches to assess investment impacts. This complexity and contextuality emphasize the need for in-depth scientific research to support the development of more precise evaluation methodologies and strategies for managing investments in agriculture.

2. Purpose of the Study

The aim of this study is to examine the impact of investments in long-term tangible assets on the comparative cost efficiency in agriculture. The research seeks to emphasize the necessity of advancing practices for evaluating investment effects by considering a systemic approach and analyzing regional differences and sectoral characteristics.

The study aims to provide a holistic understanding of the systemic relationships and contextual influences of investments on comparative cost efficiency, which could be valuable for the development of policies and strategies for agricultural investment.

3. Object, Problem, and Subject of the Study

The object of this study is investments in long-term tangible assets for groups of European agricultural holdings during the period 2014–2020.

The problem under investigation is the role of different approaches in evaluating the effects of LTA investments on comparative cost efficiency.

The subject of the study is the comparative performance of logistic models in assessing the effects of investments in long-term tangible assets on comparative cost efficiency.

4. Scope of the Study

This study focuses on the analysis and establishment of the importance of systemic dependencies and contextual factors, such as regional differences and sectoral characteristics, in the evaluation of agricultural investments. The theoretical part covers an exploration of the main concepts and approaches related to these dependencies, while the quantitative analysis concentrates on developing and testing models that account for these factors.

It is important to note that this work does not address the analysis and interpretation of specific investment effects identified in the modeling process. These aspects are beyond the scope of the study, as the focus is placed on the development of methodology and expanding the understanding of the impact of contextual factors.

5. Research Thesis

The research thesis of this paper asserts that the relationship between investments in long-term tangible assets and cost efficiency in agriculture is complex and highly contextual. It varies depending on regional differences and sectoral characteristics. Evaluation approaches that integrate systemic relationships and contextual influences provide a more reliable and applicable understanding of investment effects, significantly enhancing the accuracy of predictions.

6. Research question

The main research question in this dissertation is: Does the inclusion of regional differences and sectoral characteristics improve the model's ability to identify and analyze complex relationships? Specifically, the question focuses on examining the influence of these contextual factors on the relationship between annually distributed investment costs in long-term tangible assets (depreciation) and relative cost efficiency.

7. Objectives of the Study

Based on the stated objectives, thesis, and questions, the following **research objectives** have been formulated:

1. Review of existing literature and theories regarding investment evaluation in agriculture.
2. Development of a conceptual framework for a holistic evaluation of investments in agriculture.
3. Conducting mathematical and statistical analysis of data from the Farm Accountancy Data Network (FADN) regarding investments in long-term tangible assets and the costs of agricultural holdings in the European Union for the period 2014-2020, including:

    3.1 Deriving indices for the comparative cost efficiency of agricultural holdings in the European Union.

    3.2 Developing and testing models for evaluating investment effects on cost efficiency.

    3.3 Analyzing the credibility and accuracy of the models in making predictions, considering regional differences and sectoral characteristics of agricultural production.

8. Structure of the Study

II. Main Outline of the Dissertation

CHAPTER ONE. Theoretical Foundations of Investments and Investment Evaluation

Chapter One presents the theoretical framework, including:

- Investment concepts and classifications;
- Key objectives, benefits, and challenges of investments in long-term tangible assets in agriculture;
- Conceptual framework and approaches in holistic investment evaluation;
- Theoretical introduction to the systemic approach in investment assessment.

Investments are a key concept in economics, finance, and other disciplines. They represent the allocation of resources with the aim of achieving future benefits. The term originates from the Latin word "investire" and, in general, denotes a current expenditure made in anticipation of future returns. Definitions of investments vary across economic and financial disciplines, with each field emphasizing different aspects of the assets invested and their outcomes.

A review is presented of various definitions and concepts of investments from different perspectives—economics, finance, and agriculture. The definitions examined emphasize that investments can include both the acquisition of physical assets such as real estate, machinery, and buildings, as well as financial transactions such as the purchase of stocks and bonds, although the latter are not the subject of the specific study

A significant challenge is distinguishing between investments and short-term expenditures in the process of capital formation within the agricultural context. The separation of current expenses from investments in the agricultural sector often depends on the timeframe in which returns are realized. For example, planting trees, which requires a longer period for return on investment, is considered an investment, while the application of fertilizers is deemed a current expense. However, fertilizers can also impact the long-term fertility of the soil and may thus be regarded as an investment in future productivity.

Over the years, the definition of "investment" has undergone various stages of development, reflecting both historical and contemporary perspectives on the topic.

Alongside investment concepts, different classifications of investment assets have also been proposed. Among these, physical assets—such as machinery and buildings, which are the focus of this study—are tangible assets that can be reproduced by humans, unlike natural capital, such as land, which cannot be regenerated.

Long-term tangible assets occupy a central place in the capital structure of enterprises, and their strategic classification contributes to resource optimization. Misallocation of long-term tangible assets can lead to either overcapitalization or undercapitalization. Overcapitalization occurs when investments exceed the actual production capacity or market demand, while undercapitalization restricts production capabilities and competitiveness. Proper classification of long-term tangible assets helps avoid these extremes, ensuring an optimal capital structure and efficient use of resources.

Investments are viewed across four key dimensions: asset, project, program, and strategy. An investment project, as a unified set of assets and activities, is assessed as a whole and represents a combination of various resources (financial, natural, social, human) that interact and collectively contribute to achieving a common investment objective. The management of investment projects is critical, as projects are constrained by costs and time while aiming to achieve quantitative and qualitative goals that result in favorable transformations within the enterprise.

The main objectives and benefits of investing in physical assets (as well as their conceptual distinction) are presented at both business and sectoral levels—overcoming constraints, mitigating risks, acquiring opportunities to improve productivity and efficiency, and enhancing competitiveness; at the global level—agricultural growth, poverty and hunger reduction, and sustainable development.

The benefits of investments in long-term tangible assets at the lower levels (farms and sectors) unfold across three main targets: (1) economic profit, (2) non-monetary private benefits, and (3) public benefits. At the farm level, investments enhance competitiveness by improving productivity and efficiency. The concepts of competitiveness, productivity, and efficiency discussed emphasize the lack of consensus on a method for measuring competitiveness. However, the European Commission identifies productivity and efficiency as reliable indicators of competitiveness, although these metrics are often evaluated separately.

The examination of risk management in its close relationship with investment evaluation plays a key role in understanding competitiveness and the future potential for improving the efficiency of farms and sectors. The challenges and benefits of risk management practices in agriculture highlight the importance of coordinating different tools and strategies for risk management—differentiating between strategies for risk mitigation, transfer, and sharing, as well as distinguishing between competing and complementary tools in risk management and investment management. It is emphasized that risk assessment is contextual and case-specific.

The relationship between uncertainty, risk, and opportunities in managing uncertainties in investment is examined to highlight the limitations of conventional risk management practices. An alternative perspective from some authors is presented, viewing uncertainty management as a combination of risk and opportunities, offering a broader approach than focusing solely on risk management.

The superiority of investments as a tool for addressing the root causes of certain risks compared to other risk management instruments is demonstrated through *fostering innovation, capitalizing on opportunities to improve productivity, and preventing the spread of risks to other systems.* This contributes to the long-term sustainability not only of the food system but also of broader systems.

The briefly presented main objectives, challenges, and benefits of investing in physical assets at business, sectoral, and global levels provide a theoretical foundation for further understanding the complex and multifaceted nature of the concept of investment evaluation.

In the dissertation, the conceptual evaluation of investments in the agricultural sector is explored, moving beyond the standard financial focus. A holistic definition of evaluation is proposed, encompassing the dynamic interaction of various elements of evaluation—criteria, aspects, methods, and logical models—that continuously adapt and evolve in response to the need for a more comprehensive understanding of investments.

Based on a *synthetic-analytic approach*, the author’s definition is presented, where evaluation is regarded as a **systematic analysis of information according to clearly defined criteria, aspects, methods, and logical models, with the aim of generating necessary knowledge about a specific investment activity and/or provoking a change in the approach to analysis.**

This understanding highlights the dual nature of evaluation—it is both static (at a specific moment with fixed elements) and dynamic (due to changes in the elements in response to the need for better informativeness).

Supporting this understanding, a conceptual framework is introduced, illustrated in **Figure** 1, which shows how the static and dynamic aspects of evaluation are interdependent. Evaluation is viewed as a cyclical process in which the accumulated knowledge about the evaluated object leads to the adaptation of elements, and the choice of the evaluation approach changes in response to new information, making the evaluation process iterative.

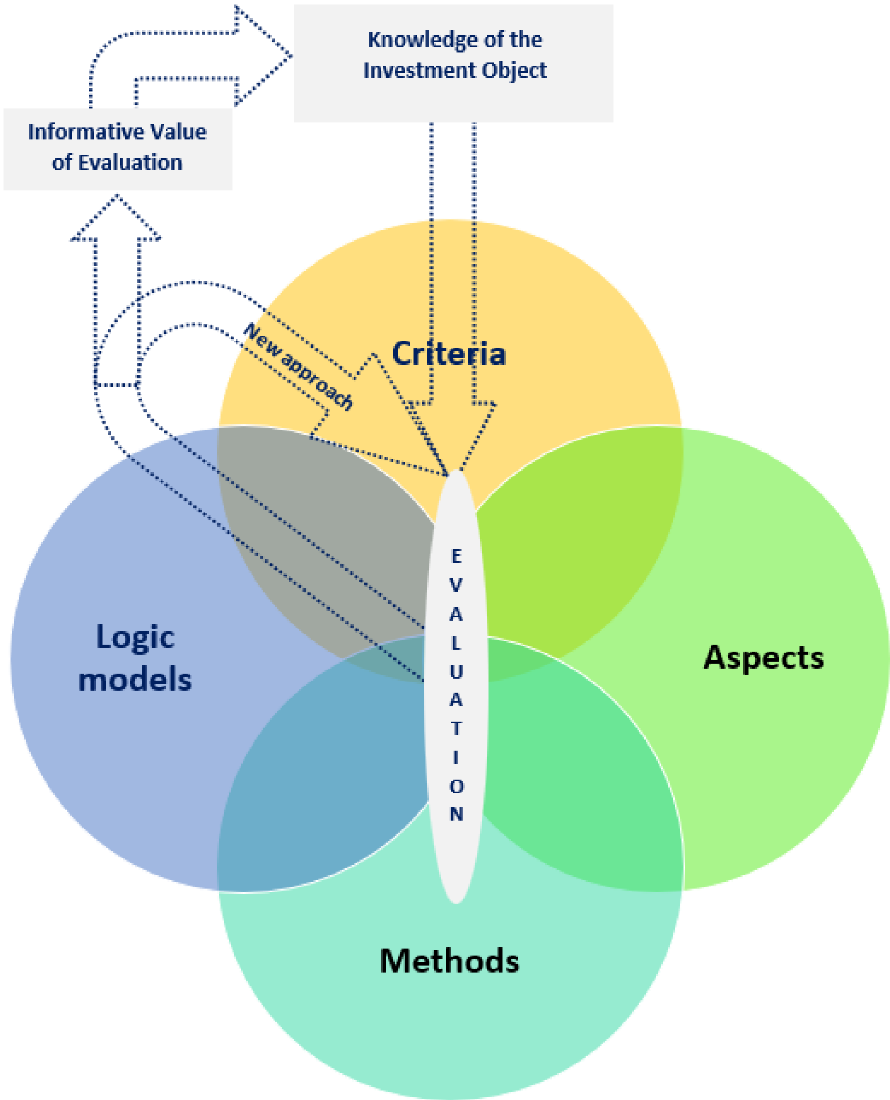

Figure 1. Conceptual Framework for the Selection of an Evaluation Approach in Investment Assessment

Source: Author's own

The elements of investment evaluation—criteria, aspects, methods, and logical models—are analyzed in detail, with a focus on the role of the Organisation for Economic Co-operation and Development (OECD) in developing guidelines and criteria for evaluating development aid.

The OECD has established six criteria (relevance, coherence, efficiency, effectiveness, impact, and sustainability) for evaluation and has published several documents over the years, providing definitions, standards, and principles for evaluation. These criteria have had a significant influence on evaluation practices and have improved the quality of assessments of development aid and its outcomes.

In addition to clarifying the six criteria, a seventh criterion (feasibility) is introduced, and the author's analogy of applying these criteria to the evaluation of investments at the farm level is presented. This aims to expand the concept of the criteria and establish them as an objective logical foundation for investment evaluation.

The evaluation of relevance, coherence, efficiency, feasibility, effectiveness, impact, and sustainability is considered as independent but interrelated criteria. Despite the independence of the various criteria, the idea of classifying the relationships between the criteria—complementing, contributing, and conditioning—is developed in building the overall investment evaluation.

The aspects to be considered when applying the evaluation criteria are briefly presented, namely: stakeholders, context, the object of evaluation, and the purpose of the evaluation.

Evaluating the investment from different perspectives highlights the importance of distinguishing between the perspective of farmers (needs, concerns, and perceptions) and the public perspective (public acceptability and environmental protection). Outlining the similarities between the "Principles for Responsible Investment in Agriculture and Food Systems" and the "Sustainable Development Goals" in the guidelines for responsible practices in investment activities reinforces the need for investment evaluation towards sustainable development.

The discussed characteristics of **the object of evaluation**—dimensions, levels, time aspects, and progression—introduce the concept of the investment cycle and the types of investment evaluations according to the phases of the investment cycle: ex-ante, formative, summative, ex-post, and meta-evaluation.

The examination of **methods for data collection and analysis** in the context of investment evaluation highlights the importance of selecting appropriate methods based on the level of knowledge and understanding of the evaluated object.

The concept of **logical models** in investment evaluation emphasizes the universality of logical thinking as foundational, focusing on the fundamental role of assumptions in building and testing (verification) Theories of Change: (i) assumptions about the necessary and sufficient conditions that contribute to causal relationships in the path of change; (ii) assumptions derived from scientific research and "best practices"; and (iii) assumptions about contextual factors and the environment within the context of the Theory of Change.

The concept of necessary and sufficient assumptions within the Theory of Change reveals the probabilistic nature of causal relationships, demonstrating that causality is not always deterministic, and that factors can contribute to outcomes with varying probabilities. This concept of the probabilistic nature of the association between factors and outcomes is partly the reason for choosing binary logistic regression as the statistical method for exploring these relationships in this study.

Avoiding trivialization and linearization of logical thinking in testing, refining, and adapting theories over time contributes to more reliable and valid conclusions, thereby enhancing the applicability of evaluation frameworks.

Logical models in evaluation represent a statistical expression of the relationships between the studied variables and play a crucial role in differentiating between the systems approach and the reductionist approach.

The reductionist approach is characterized by a focus on isolated factors and measuring their individual contributions to outcomes, aiming to simplify the evaluation process by considering separate elements and their independent assessment. This approach allows for determining the influence of each factor on the result, but it excludes interactions and interdependencies between them.

In contrast, the systems approach adopts a holistic perspective, recognizing that the outcome of an investment is the result of a complex network of factors and dynamic system relationships. *It includes a broader context, such as social, economic, environmental, political, geographical, and climatic factors, which exert complex and interrelated influences on different regions and sectors.* This implies that investment evaluation should encompass not only their direct impact but also an understanding of these multidisciplinary, multi-regional, and multi-sectoral relationships.

Main Findings from Chapter I

The evaluation of investments should be viewed as a systematic analysis of information based on clearly defined criteria, aspects, methods, and logical models. The goal is to provide the necessary knowledge about a specific investment activity and/or to provoke a change in the approach to analysis.

The primary task of evaluation is to enhance understanding of the object being assessed, while this understanding simultaneously influences the choice of approaches in the evaluation process. Thus, in a cyclical process, evaluation evolves and establishes itself as an adaptive system that changes in response to the need for better informativeness.

Despite their significance, investments are not the sole factor for sustainable economic development. This necessitates a rethinking of the approaches to their evaluation and regulation.

The characteristic combinations and complex interrelations among key factors are manifested through regional and sectoral specifics. Therefore, a systemic approach that considers these contextual factors is needed to assess the impact of investments in long-term tangible assets on the dynamics of cost efficiency in European agricultural holdings.

CHAPTER TWO. Methodology of the Study

Chapter Two presents the methods used for assessing cost-efficiency and their applicability, including:

- Sources of data for the study;
- Description of methods for calculating the annually allocated costs for investments in fixed assets (independent variable) and the comparative cost-efficiency (dependent variable);
- Justification for the choice of logistic regression models to evaluate the relationship between the independent and dependent variables;
- Criteria for evaluating the performance of the models;
- Conclusions on the applicability of the models for assessing investments in agriculture.

The primary data source for the study is the Farm Accountancy Data Network (FADN), maintained by the Directorate-General for Agriculture and Rural Development of the European Commission. The FADN provides a reliable and representative sample of agricultural holdings in EU Member States, containing financial and economic information. The database is updated annually, enabling the analysis of trends and patterns in the comparative cost-efficiency of groups of farms.

The comparative efficiency analysis represents a systematic comparison of the performance of certain DMUs (groups of farms) with others within a common technological frontier.

The use of a pan-European technological frontier in studying the cost efficiency of the agricultural sector in the EU is motivated by the need to account for contextual factors such as regional and sectoral differentiation and to ensure the comparability of results across Member States operating under a common market and shared EU regulations. This approach facilitates the identification of systematic pan-European challenges, the development of targeted regional policies and measures for rural development, and the optimization of investments and support.

The analysis in the study focuses on the period 2014–2020 and includes seven technological frontiers calculated using a mathematical model based on **Data Envelopment Analysis (DEA)** (Equation 1). The model is grounded in Variable Returns to Scale (VRS) and is input-oriented, as this orientation addresses the imperative of sustainability by aiming to reduce excessive resource use.

Equation 1. Mathematical Model DEA

$$
\begin{aligned}
& min\ \theta \\
& \text{st.} \\
& \sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{ij_0} \quad i = 1,2,\ldots\ldots,m \\
& \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rj_0} \quad r = 1,2,\ldots\ldots,s \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \lambda_j \geq 0 \qquad\qquad j = 1,2,\ldots\ldots,n
\end{aligned}
$$

Data Envelopment Analysis (DEA) is preferred due to its ability to evaluate the efficiency of production units without imposing assumptions about the production function. It is widely used in analyses of the agricultural sector because it can simultaneously incorporate multiple inputs and outputs.

The model uses three variables as inputs (m = 3), reflecting the structure of farms' monetary expenditures:

1. SE281 Total specific costs
2. SE336 Total farming overheads
3. SE365 Total external services

As an output (s = 1), the model uses a production measure:

4. SE131 Total output

The number of DMUs (n) varies by year:

2014(n=1296), 2015(n=1271), 2016(n=1313), 2017(n=1336), 2018(n=1325), 2019(n=1315), and 2020(n=1327).

Including depreciation costs as part of the efficiency model ignores the impact of investments in long-term tangible assets and, consequently, does not allow for the calculation of these effects. Therefore, the present study considers *depreciation costs as a proxy variable for capital investments* to analyze their impact on cost efficiency in the agricultural sector.

Depreciation (SE360) is the systematic allocation of an asset's value over its useful life, reflecting the gradual reduction in the value of fixed capital. This variable, calculated using the straight-line method based on the market value of long-term tangible assets, ensures comparability between different farms and periods. For this reason, it is assigned the role of a *factor variable in the analytical model of the study*.

Analytical models are simplified representations of reality. They are abstractions used as "models for" uncovering insights rather than exact replicas of actual conditions. While models do not capture the full complexity of reality, they are valuable for investigating effects supported by the available data. Recognizing these limitations prevents unwarranted assumptions and promotes the use of models as analytical tools rather than absolute truths.

In the present study, logistic regression is employed as an analytical tool to model the relationship between investments in long-term tangible assets and comparative cost efficiency.

Six statistical models, **M1-M6** (Equation 2 - Equation 7), were formulated, incorporating different sets of factor variables categorized by approach (type of effects evaluated) and level of complexity (Table 1).

Equation 2. Model 1

$$Logit(p) = \beta 0 + \beta 1 \cdot Logarithm\ of\ depreciation$$

Equation 3. Model 2

$$\begin{aligned} Logit(p) = \beta 0 + \beta 1 \cdot & Logarithm\ of\ depreciation \\ & + \beta 2 \cdot Sector \end{aligned}$$

Equation 4. Model 3

$$\begin{aligned} Logit(p) = \beta 0 + \beta 1 \cdot & Logarithm\ of\ depreciation \\ & + \beta 2 \cdot Sector \\ & + \beta 3 \cdot EU\ Member\ State \end{aligned}$$

Equation 5. Model 4

$$\begin{aligned} Logit(p) = \beta 0 + \beta 1 \cdot & Logarithm\ of\ depreciation \\ & + \beta 2 \cdot Sector \\ & + \beta 3 \cdot EU\ Member\ State \\ & + \beta 4 \cdot Logarithm\ of\ depreciation * Sector \end{aligned}$$

Equation 6. Model 5

$$\begin{aligned} Logit(p) = \beta 0 + \beta 1 \cdot & Logarithm\ of\ depreciation \\ & + \beta 2 \cdot Sector \\ & + \beta 3 \cdot EU\ Member\ State \\ & + \beta 4 \cdot Logarithm\ of\ depreciation * Sector \\ & + \beta 5 \cdot Logarithm\ of\ depreciation * EU\ Member\ State \end{aligned}$$

Equation 7. Model 6

$$\begin{aligned} Logit(p) = \beta 0 + \beta 1 \cdot & Logarithm\ of\ depreciation \\ & + \beta 2 \cdot Sector \\ & + \beta 3 \cdot EU\ Member\ State \\ & + \beta 4 \cdot Logarithm\ of\ depreciation * Sector \\ & + \beta 5 \cdot Logarithm\ of\ depreciation * EU\ Member\ State \\ & + \beta 6 \cdot Logarithm\ of\ depreciation\hat{}\mathbf{2} \end{aligned}$$

- $\beta 0, \beta 1, \beta 2, \beta 3, \beta 4, \beta 5, \beta 6$ are the model parameters estimated during the analysis.
- *Logarithm of depreciation* is the factor variable.
- $Sector$ is a categorical variable with 7 subcategories, representing the different agricultural sectors.
- $EU\ Member\ State$ is a categorical variable with 27 subcategories, representing the different EU member states.
- *Logarithm of depreciation* $\ast$ $Sector$ is a variable that accounts for the interactions between the logarithm of depreciation and the sector.
- *Logarithm of depreciation* $\ast$ $EU\ Member\ State$ is a variable that accounts for the interactions between the logarithm of depreciation and the EU member state.
- *Logarithm of depreciation* ^2 is a variable that accounts for U-shaped relationships between the logarithm of depreciation and the outcome variable.

Table 1. Classification of Models in the Study

		MODELS					
EFFECTS	**FACTOR VARIABLES**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**
MAIN	**Logarithm of depreciation**	1	1	1	1	1	1
	Sector		7	7	7	7	7
	EU Member State			27	27	27	27
MODERAITING	**Logarithm of depreciation ∗ Sector**				7	7	7
	Logarithm of depreciation ∗ EU Member State					27	27
	Logarithm of depreciation ^2						1
Sum of freely estimated parameters		1	8	35	42	69	70

Using the six models, the study aims to provide a comprehensive understanding of how different methodological approaches can reveal insights into the systemic aspects of agricultural investments.

For this purpose, the analysis uses established criteria for evaluating model performance:

1. Likelihood Ratio Tests (LRT);
2. Pseudo R-squared measures of fit;
3. Information-theoretic criteria, measured in both their absolute and relative scales;
4. Classification/Prediction metrics.

Main Findings from Chapter II

A sufficiently large sample and data from the Farm Accountancy Data Network (FADN) provide a robust empirical foundation, enabling well-founded conclusions and informed recommendations.

The use of the DEA (Data Envelopment Analysis) method for calculating comparative efficiency is a key advantage of this study. This method allows for a comprehensive evaluation of the simultaneous impact of the three cost categories within the cost structure of farms on the production process, without prior assumptions about their interrelationships.

This makes DEA a preferred method for measuring efficiency, particularly in the context of European agriculture, where the goal is to identify common systemic issues across Europe and formulate effective policies for rural development.

Logistic models offer good interpretability. At the same time, they account for the probabilistic nature of the relationships between factor and outcome variables, allowing nonlinear dependencies to be captured through the incorporation of moderating variables.

The use of second-degree variables enables the identification of U-shaped or inverted U-shaped relationships, while the integration of contextual moderators such as regional differences and sectoral characteristics allows for the exploration of interactions between factor and outcome variables in different contexts.

The methodological approach, based on the integration of moderating variables, demonstrates the significance of contextual factors on the relationship between investments and comparative cost efficiency.

Widely used tests for overall evaluation and model comparison are based on the likelihood ratio coefficient. Pseudo R-squared measures, such as those from McFadden, Cox & Snell, and

Nagelkerke, provide different perspectives on the explanatory power of the models, enabling a more comprehensive assessment of their performance. Information-theoretic criteria like the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) play a key role in model optimization, balancing model complexity and helping to avoid overfitting with unnecessary parameters. Additionally, in terms of predictive capabilities, the analysis using the ROC curve and calculating the area under the curve (AUC) provides a clear evaluation of the models' ability to correctly classify outcomes.

CHAPTER THREE. Results and Analysis

Chapter Three presents:

- The results (Table 2 - Table 5), their interpretation, and significance for investment evaluation;
- The potential of systems thinking in investment evaluation approaches;
- Trends in systems thinking in contemporary research;
- Theoretical premises in the field of agricultural systems relationships, explaining the results from empirical data;
- Challenges in the evaluation and regulation of agricultural investments under complex systemic uncertainties.

Table 2. Likelihood Ratio Tests (LRT) for Model Evaluation

χ²	MF	MR	2014	2015	2016	2017	2018	2019	2020
			Year						
LRT - Overall Model Test	M1	M0	0,1	9,96	0,12	2,07	1,5	21,6	7,96
	M2	M0	222,42	349,13	323,37	449,47	274,71	332,2	263
	M3	M0	495,17	602,44	612,69	721,02	478,61	598,1	483,97
	M4	M0	558,43	642,75	691,01	768,34	523,97	640,7	545,68
	M5	M0	805,27	840,85	868,88	896,48	674,39	812,7	721,4
	M6	M0	913,13	925,98	936,37	943,88	710,97	877,6	790,75
LRT - Model Comparison Test	M1	M0	0,1	9,96	0,12	2,07	1,5	21,6	7,96
	M2	M1	222,3	339,2	323,2	447,4	273,2	310,6	255
	M3	M2	272,7	253,3	289,3	271,6	203,9	265,9	221
	M4	M3	63,3	40,3	78,3	47,3	45,4	42,6	61,7
	M5	M4	246,8	198,1	177,9	128,1	150,4	172	175,7
	M6	M5	107,9	85,1	67,5	47,4	36,6	64,9	69,3

Source: Own calculations based on FADN data

The analysis of the χ^2-statistic in the **Overall Model Test** shows that Model M1, which includes only the logarithm of depreciation costs as a factor variable, has low effectiveness in explaining the data, with minimal values in 2014 ($\chi^2 \sim 0.10$, $p = 0.755$) and limited improvement in 2019 ($\chi^2 \sim 21.60$, $p<0.001$). In contrast, more complex models M2 to M6 demonstrate significant improvements, with χ^2-statistics steadily increasing with statistical significance ($p<0.001$). The highest values are observed for M6, with χ^2-statistics ranging from 710.97 (2018) to 943.88 (2017), highlighting that more complex models provide significantly better data fit and greater explanatory power.

During the period 2014–2020, in the **Model Comparison Test**, Model M1, which includes only the logarithm of depreciation costs as a factor variable, does not demonstrate significant improvement over the null model M0 in terms of data fit. As complexity increases from M1 to M6, the χ^2-statistic rises unevenly but consistently, with the most notable increments observed during the transition from M1 to M2 (average $\chi^2 \sim 310.13$) and from M2 to M3 (average $\chi^2 \sim 212.63$). These results indicate that increasing model complexity leads to significant improvement in its fit, albeit with varying intensity.

Table 3. Pseudo R-squared

		Year						
Pseudo R-squared	**Mj**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
R^2McF	M1	0,0000546	0,00566	0,0000681	0,00112	0,00096	0,012	0,00433
	M2	0,124	0,19842	0,178	0,24271	0,176	0,1839	0,14318
	M3	0,277	0,34237	0,337	0,38935	0,307	0,3311	0,26348
	M4	0,312	0,36528	0,38	0,41491	0,336	0,3547	0,29708
	M5	0,45	0,47787	0,478	0,4841	0,432	0,4498	0,39275
	M6	0,51	0,52624	0,515	0,50969	0,456	0,4858	0,4305
R^2CS	M1	0,0000754	0,0078	0,0000943	0,00155	0,00113	0,0163	0,00598
	M2	0,158	0,24019	0,218	0,28568	0,18725	0,2232	0,17979
	M3	0,318	0,37749	0,373	0,41707	0,30317	0,3654	0,3056
	M4	0,35	0,39692	0,409	0,43735	0,32662	0,3857	0,33716
	M5	0,463	0,48396	0,484	0,48881	0,39889	0,461	0,41937
	M6	0,506	0,51739	0,51	0,50663	0,41525	0,4869	0,44893
R^2N	M1	0,000101	0,0104	0,000126	0,00207	0,00163	0,0218	0,00798
	M2	0,211	0,3205	0,291	0,38093	0,27063	0,2989	0,23989
	M3	0,424	0,5036	0,497	0,55613	0,43819	0,4893	0,40776
	M4	0,468	0,5296	0,546	0,58317	0,47208	0,5164	0,44986
	M5	0,618	0,6457	0,646	0,65179	0,57653	0,6172	0,55955
	M6	0,675	0,6903	0,68	0,67555	0,60019	0,652	0,599

Source: Own calculations based on FADN data

The analysis of **Pseudo R-squared** values for the period 2014–2020 reveals four key trends.

First, Model M1 demonstrates exceptionally low pseudo R-squared values, highlighting its inability to differ significantly from the null model in predicting probabilities. *Second*, increasing model complexity by adding factor variables (from M1 to M6) improves the model's fit to the data, with pseudo R-squared values increasing progressively. *Third*, the most complex model, M6, consistently achieves the highest pseudo R-squared values, with average values of $R^2McF = 0.490$, $R^2CS = 0.484$, and $R^2N = 0.653$. *Fourth,* the metrics R^2McF, R^2CS, and R^2N consistently rank the performance of the models in the same order, emphasizing their reliability in evaluating performance.

Table 4. Information-Theoretic Criteria: Evidence Ratios

		Year						
Log10 (Evidence Ratios)	**Mj**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
ER_Deviance	M1	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	M2	48,21	73,83	70,14	97,28	59,28	67,53	55,37
	M3	107,49	128,77	133,11	156,13	103,58	125,29	103,36
	M4	121,17	137,45	150,05	166,33	113,35	134,41	116,83
	M5	174,80	180,45	188,70	194,35	146,14	171,76	155,04
	M6	198,26	198,91	203,25	204,55	153,96	185,88	170,03
ER_AIC	M1	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	M2	45,17	70,79	67,10	94,24	56,24	64,49	52,33
	M3	92,72	114,00	118,34	141,36	88,81	110,53	88,60
	M4	103,36	119,65	132,24	148,53	95,54	116,61	99,02
	M5	145,27	150,92	159,17	164,81	116,61	142,23	125,51
	M6	168,29	168,94	173,28	174,59	123,99	155,91	140,06

Source: Own calculations based on FADN data

The results of the **Evidence Ratio** analysis in favor of a given model reveal very strong evidence supporting the other models in the set over M1. This underscores that M1 is unquestionably the least supported model in the set, while M6, which incorporates a full set of moderator variables accounting for regional differences and sectoral characteristics in the investment impact on comparative cost efficiency, demonstrates convincingly the greatest relative strength of evidence compared to M1.

Table 5. Classification/Prediction Metrics: Area Under the Curve (AUC) Values

		Year						
	Mj	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
AUC	**M1**	**0,498**	**0,569**	**0,519**	**0,533**	**0,495**	**0,597**	**0,566**
	M2	**0,718**	**0,769**	**0,758**	**0,813**	**0,758**	**0,784**	**0,753**
	M3	**0,837**	**0,868**	**0,865**	**0,888**	**0,855**	**0,865**	**0,832**
	M4	**0,855**	**0,878**	**0,885**	**0,898**	**0,869**	**0,875**	**0,848**
	M5	**0,910**	**0,920**	**0,920**	**0,921**	**0,909**	**0,911**	**0,890**
	M6	**0,929**	**0,935**	**0,930**	**0,929**	**0,918**	**0,922**	**0,906**

Source: Own calculations based on FADN data

The analysis of **AUC values** for models M1 through M6 reveals significant differences in their classification capability. Model M1 exhibits the lowest AUC values (ranging from 0.495 to 0.597), making it the weakest classification model, with its values falling below those of random guessing in 2014 and 2018. As the complexity of the models increases from M2 to M6, the AUC values rise, and the range of these values narrows, indicating improved classification power and model stability. The most complex model, M6, demonstrates the highest AUC values (ranging from 0.906 to 0.935) with minimal variability, confirming its superior and consistent predictive ability. This trend clearly indicates that incorporating regional differences and sectoral characteristics in investment evaluation significantly and sustainably enhances the classification strength of the models.

Main Findings from Chapter III

The hypothesized patterns regarding the contextual influence of investments across different regions and sectors during the 2014–2020 period are confirmed by all analyzed metrics and performance indicators for model evaluation, from which the following conclusions can be summarized:

- The simplest model, M1, with only one factor variable—logarithm of depreciation expenses—performs the worst among the set of models. Model M1 does not significantly improve upon the null model in terms of data fit, meaning it lacks a meaningful difference in its suitability for predicting probabilities compared to the null model. It is also the poorest-performing model in the set relative to the saturated model.
- As model complexity increases through the inclusion of regional differences and sectoral characteristics, the ability to explain the impact of depreciation expenses on comparative cost efficiency improves significantly.
- Model M6, which accounts for regional differences, sectoral characteristics, and nonlinear U-shaped relationships, is the best-performing model.
- The performance indicators consistently and persistently rank the models in the same sequence relative to one another.
- Progressing from M1 to M6 within each year reveals a compelling trend of continuous, albeit uneven, improvement in model performance.

The identified trends in model performance observed during the analyzed period confirm the presence of systemic relationships characterized by persistent complex nonlinear patterns over time.

This complexity often renders the processes and outcomes of interventions within systems difficult to predict, with prior experience and reductionist approaches offering limited guidance. In such situations, systems thinking enables a deeper understanding of the interconnections between various factors, which simpler approaches tend to overlook.

The analysis of models (M1-M6) offers an exploration of the relationships between investments in long-term tangible assets and the comparative cost efficiency, emphasizing the need to integrate a systemic approach through contextual factors. The interpretation of the results highlights the importance of regional differences and sectoral specifics in understanding this relationship.

- **Regional Differences**

  Models M5-M6, incorporating regional moderators, demonstrate how the cumulative effects of climatic, environmental, technological, political, socio-economic, and other conditions in a given region influence the effects of investments on cost efficiency.

- **Sectoral Specifics**

  Models including sectoral moderators allow for the examination of differences between agricultural sectors. In these sectors, specific dependencies between investments and efficiency can be observed, which models like M5-M6 are able to capture.

- **Nonlinear Relationships**

  The analysis of nonlinear relationships, such as U-shaped and inverted U-shaped links through model M6, adds important depth to the understanding of complex effects. These relationships indicate that the effect of investments may be positive only up to a certain level, beyond which a decline in efficiency is observed.

Model M6 demonstrates the ability to more accurately predict the effects of investments by combining diverse methodologies. The use of logistic regression enables the models to determine the probability of success or failure of investment decisions, while the integration of moderator interactions allows for the analysis of changes in this probability under varying conditions, enhancing their predictive value and making the models applicable across different contexts.

The inclusion of nonlinear relationships, accounting for U-shaped and inverted U-shaped links (the square of the logarithm of depreciation), allows for accounting for the influence of critical points at which investments lead to minimal or maximal comparative cost efficiency. This is crucial for planning investment strategies and supports the formulation of more targeted and effective investment policies, particularly in resource-constrained sectors.

Conclusion

The evaluation of investments in the agricultural sector should be viewed as a comprehensive and structured process that analyzes information based on clearly defined criteria, aspects, methods, and models. The primary goal is to gain a better understanding of specific investments and/or to propose a new approach to analysis and evaluation. In this sense, evaluation is perceived as an *adaptive system* that can be modified and improved to provide more accurate and useful results.

Investments in long-term tangible assets play an important role in enhancing comparative cost efficiency but are not sufficient on their own. Changes in investments in long-term tangible assets are a necessary but not sufficient factor for the dynamics of comparative cost efficiency. This supports the argument that models evaluating the impact of investments on comparative cost efficiency should consider long-term tangible assets, regional differences, and sectoral characteristics as collectively contributing factors.

The relationship between investments and comparative cost efficiency is complex and context-dependent. Accurate evaluation requires analytical tools that account for the interactions between various factors.

The models developed in the dissertation provide an opportunity for comparative analysis of different concepts for evaluating investment effects. The significance of comparative analysis lies in highlighting key aspects related to the incorporation of systemic approaches in investment evaluation.

The systemic approaches embedded in the developed models emphasize the need to integrate regional and sectoral specifics into the analysis. Such approaches broaden the understanding of investment impacts and enhance the predictive capabilities of the evaluation models.

III. Guidelines for Future Research Related to the Dissertation Topic

In this regard, future research related to investment impact would provide more comprehensive recommendations regarding investments and their regulation in the agricultural sector, such as:

1. Analysis of the assessed parameters of the examined models.
2. Analysis of the forecasted impact of investments in fixed assets on the comparative cost efficiency, calculated on different technological set, with the aim of confirming the dependencies.
3. Future research on various factors contributing to the cumulative effect of regional and sectoral contexts, in order to identify intervention tools to influence investment outcomes.
4. Study of possible dichotomous variables related to critical points, which turn the investment impact from positive to negative or vice versa. The established U-relationship between the dynamics of investments in long-term tangible assets and comparative cost efficiency in some regions, including Bulgaria, suggests the influence of such a dichotomous variable, which, however, is unknown in the current study.
5. Analysis of the impact of investments not only on comparative cost efficiency but also on other efficiency indices calculated using DEA methods, which would incorporate the simultaneous influence of various variables, including non-financial ones such as social indicators or ecosystem services. Such research would be useful for improving the understanding of the impact of investments on the sustainable development of European agriculture.

IV. Scientific-Theoretical Contributions of the Dissertation

1. **An original concept for holistic investment evaluation has been proposed**, integrating both static and dynamic aspects of the evaluation process. The concept builds upon existing approaches, emphasizing the dynamic adaptation of evaluation frameworks to the specific conditions of the studied object.

2. **An analogy of investment evaluation criteria at the farm level has been presented,** aiming to expand the concept and application of these criteria.

3. **A classification of the relationships between evaluation criteria has been introduced,** aiming to improve the planning and coordination of various intervention tools in the regulation of the agricultural sector.

4. **Systemic dependencies and contextual influences of investments** on comparative cost efficiency in European agriculture have been identified through a comparative analysis of logistic regression models representing different concepts for evaluating investment effects.

V. Scientific-Applied Contributions of the Dissertation

1. **The importance of the systemic approach in evaluating the investment impact** on the probability of achieving a certain comparative cost efficiency has been substantiated. The analyzed systemic approach includes:

    • ***Regional and sectoral specifics*** reflecting the cumulative influence of climatic, environmental, technological, political, socio-economic, and other conditions in a given region and sector.

    • ***U-shaped and inverse U-shaped relationships*** reflecting the negative impact of excessive or insufficient investments.

2. **The limitations of the standardized approach in regulation have been argued, along with the need for regional and sectoral adaptation of agricultural policies.**

VI. Publications Related to the Dissertation

Mitseva, Y. Y. (2022). Efficiency of using environmentally harmful inputs in field crop production in Bulgaria. *Agricultural Sciences/Agrarni Nauki*, *14*(35). http://dx.doi.org/10.22620/agrisci.2022.35.007

Mitseva, Y. Y. (2024). Systemic Aspects of Agricultural Investments: Regional Variability and Sector-Specific Characteristics in Cost Efficiency. *Agricultural Sciences/Agrarni Nauki*, *16(43)*, *под печат*