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INTERNATIONAL CONFERENCE ON APPLIED ECONOMICS AND FINANCE

WELCOME MESSAGE

International Conference on Applied Economics and Finance (ICOAEF XV) held on 11th-12th May, 2026 in Kyrgyzstan-Türkiye Manas University, Bishkek/ Kyrgyz Republic. We are glad ICOAEF-XV gathered many successful academics and professionals around the World. 63 papers were submitted, and 57 papers presented during ICOAEF-XV from 16 different countries.

This conference provided as a suitable platform for discussions about the researches. This conference abstract proceeding contains 63 papers presented both online and in person. ICOAEF-XV participants consisted of from 17 different countries, 16 Turkish universities. Scientific board rejected 11 papers directly due to the inconvenience of conference topics, theme and structure of ICOAEF-XV. Scientific committee also requested some corrections to 11 different papers then these papers accepted and presented during the conference. All submissions for ICOAEF-XV scientifically reviewed and evaluated by scientific committee members.

We believe that ICOAEF-XV provided an opportunity for national and international participants to present, discuss and share practical and theoretical issues in the fields of Economics, Finance and related social sciences. The papers submitted from 16 different countries beyond Türkiye. We accepted papers of the participants from Algeria (1), Belgium (1), Turkish Republic of Northern Cyprus (1), Ethiopia (1), France (1), Gambia (1), Greece (1), Italy (2), Iran (1), Kyrgyzstan (13), Latvia (1), Morocco (1), Romania (1), Russian Federation (1), Türkiye (30), United Kingdom (2), and United States (2). Finally, we would like to thank Kyrgyzstan-Türkiye Manas University and our esteemed ICOAEF-XV participants who shared their deep knowledge and experience at ICOAEF-XV. We would like to be together in our following organizations.

On behalf of Conference Organization Committee

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TIME-SERIES DEMAND FORECASTING FOR THE TURKISH ELECTRICITY MARKET: AN EMPIRICAL INVESTIGATION

Mesut ULU[*]

Ufuk BİNGÖL[**]

ABSTRACT

Electricity demand forecasting plays a vital role in ensuring grid stability, supply security, and operational efficiency in modern energy markets. This study presents an empirical investigation of time-series demand forecasting for the Turkish electricity market using two advanced gradient boosting machine learning algorithms: XGBoost and LightGBM. Hourly electricity demand data for the year 2020 were obtained from the official EPİAŞ Transparency Platform. The dataset was chronologically divided into training (80%) and testing (20%) sets, and model performances were assessed using R^2 and MAPE metrics. The empirical findings revealed strong seasonal and weekly patterns in Turkish electricity demand. Quantitative results demonstrated that both models achieved acceptable forecasting accuracy; however, XGBoost outperformed LightGBM across both evaluation metrics. The findings confirm that gradient boosting methods are effective tools for electricity demand forecasting and provide a practical framework for energy planners and market operators. This study contributes to the growing literature on machine learning applications in energy forecasting, particularly for developing economies with dynamic electricity markets.

Keywords: *Electricity Demand, Time Series Forecasting, Machine Learning, Gradient Boosting.*

JEL Codes: *Q47, C22, L94.*

1. INTRODUCTION

Accurate electricity demand forecasting is a cornerstone of modern energy system planning, grid stability, and market operations. In liberalized electricity markets, forecasting errors can lead to significant economic inefficiencies, including imbalance costs, suboptimal unit commitment, and price volatility (Hong & Fan, 2016). The Turkish electricity market, which has undergone substantial restructuring and capacity expansion over the past two decades, presents a particularly challenging forecasting environment due to its rapid demand growth, increasing penetration of renewable energy sources, and complex seasonal and calendar effects.

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Traditional time-series forecasting methods, such as ARIMA, exponential smoothing, and seasonal decomposition, have been widely applied to load forecasting problems. While effective for linear patterns and stationary series, these approaches often fail to capture the nonlinear interactions among weather variables, socioeconomic factors, holiday effects, and past consumption patterns (Saglam et al., 2019). As a result, researchers and practitioners have increasingly turned to machine learning (ML) models that can inherently model high-dimensional, nonlinear relationships without strong prior assumptions about data distribution.

This study addresses the time series demand forecasting problem for the Turkish electricity market. Two powerful gradient boosting methods, the Light Gradient Boosting Machine (LGBM) and the eXtreme Gradient Boosting (XGBoost) models, were applied as part of the empirical analysis. The forecasting accuracy of the models was evaluated using R^2 (coefficient of determination) and MAPE (Mean Absolute Percentage Error) metrics. The findings demonstrate that LGBM and XGBoost perform well in forecasting Turkish electricity demand, and the study provides a methodological framework for energy planners and market operators.

2. LITERATURE REVIEW

Accurate forecasting of electricity demand is critical for grid stability, security of supply, and market efficiency. Due to the economic limitations of electricity storage, a real-time balance between supply and demand is necessary. This challenge has become even more complex, particularly with the integration of renewable energy sources into the system (Mystakidis et al., 2024).

Traditional methods include ARIMA, SARIMA, and exponential smoothing models. While these methods are successful in modeling linear relationships and seasonal patterns, they are insufficient in capturing complex nonlinear dynamics such as weather conditions, calendar effects, and consumer behavior (Mystakidis et al., 2024). Therefore, researchers have turned to machine learning methods that can model high-dimensional and nonlinear relationships (Liu et al., 2026).

Recently, various tools and strategies have been developed to predict energy use. Some of these tools and techniques include: linear and multiple linear regression models (Bilgili et al., 2012), autoregressive integrated moving average methods (Barak and Sadegh, 2016), grey model (Wang et al., 2022), artificial neural networks (Demircioglu and Eşiyok, 2022), adaptive network-based fuzzy inference system (Bilgili et al., 2021), support vector regression (Meng et al., 2022), long-term and short-term memory (Bilgili et al., 2021), random forest model (Shin and Woo, 2022), convolutional neural network method (Atik, 2022), and hybrid models (Jin et al., 2022; Tutun et al., 2023). Demircigolu and Eşiyok (2022) attempted to estimate Türkiye's energy consumption using an ANN model. To create an accurate estimate of Türkiye's electricity demand, Hamzacebi et al. (2019) used both ANN and SARIMA models.

3. METHODOLOGY AND DATA

3.1. Study Area and Data Source

This study focuses on the Turkish day-ahead electricity market, which is operated by EPİAŞ (Energy Markets Operation Company). The day-ahead market is a critical mechanism where electricity supply and demand are balanced for the following day through a uniform-price auction system. Participants submit hourly bids and offers, and the market operator clears each hour of the following day, determining the Market Clearing Price (PTF) and ensuring system reliability . Accurate demand forecasting in this market is essential for market participants to develop effective bidding strategies, manage energy contracts, and minimize imbalance costs .

The electricity demand data used in this study were obtained from the official EPİAŞ Transparency Platform (https://cas.epias.com.tr). Specifically, hourly gross electricity demand data for the year 2020 were collected. The dataset includes time-stamped consumption values reflecting real market conditions. The choice of 2020 as the study period allows for capturing regular seasonal patterns and operational characteristics of the Turkish electricity market.

Before model development, the raw time series data underwent preprocessing procedures. Missing values were checked and handled through linear interpolation. The dataset was structured for supervised learning by creating lagged features based on temporal autocorrelation analysis. Following the "known-at-bid-time" principle essential for day-ahead forecasting, features were constructed using only information available before the market closure time . Calendar features including hour-of-day, day-of-week, and holiday indicators were extracted to capture periodic patterns in electricity demand.

The dataset was split into training and testing sets using a chronological split to prevent data leakage and respect temporal order. The first 80% of the data (approximately 10 months) was used for model training, while the remaining 20% (approximately 2 months) was reserved for testing and performance evaluation.

3.2. Forecasting Models

XGBoost is a scalable tree boosting system developed by Chen and Guestrin (2016). It builds an ensemble of decision trees sequentially, where each new tree corrects the errors of the previous trees. The algorithm incorporates regularization parameters to prevent overfitting and uses efficient tree pruning techniques. The objective function combines a loss function with complexity regularization, and second-order gradient statistics enable faster convergence. XGBoost has demonstrated strong performance in electricity demand forecasting applications due to its ability to capture non-linear relationships and handle mixed data types (Ulu and Klıç, 2026).

LightGBM, developed by Ke et al. (2017), is a gradient boosting framework that introduces two key innovations: Gradient-based One-Side Sampling (GOSS) and Exclusive Feature Bundling (EFB).

GOSS preserves instances with large gradients (underfitted samples) while randomly down-sampling instances with small gradients, maintaining accuracy with reduced computational cost. EFB bundles mutually exclusive features to reduce dimensionality. LightGBM uses a leaf-wise tree growth strategy rather than level-wise growth, which can lead to faster training and lower error rates compared to traditional gradient boosting methods (Ulu and Kılıç, 2026).

3.3. Performance Evaluation Metrics

To evaluate and compare the forecasting performance of the XGBoost and LightGBM models, two widely adopted regression metrics were employed (Akturk et al., 2025).

R^2 (Coefficient of Determination) measures the proportion of variance in the dependent variable that is explained by the model. It ranges from 0 to 1, where values closer to 1 indicate better explanatory power. The R^2 is calculated as:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (1)$$

MAPE (Mean Absolute Percentage Error) expresses prediction accuracy as a percentage, making it interpretable and scale-independent. It is calculated as:

$$MAPE = \frac{100\%}{n}\sum_{i=1}^{n} \left| \frac{y_i - \hat{y}_i}{y_i} \right| \quad (2)$$

Lower MAPE values indicate higher forecasting accuracy (Akturk et al., 2025).

4. FINDINGS

In this study, two different gradient boosting algorithms, XGBoost and LightGBM models, were used for day-ahead demand forecasting in the Turkish electricity market. Experiments were conducted on hourly electricity demand data for 2020 obtained from the EPİAŞ platform. The dataset was divided chronologically into training (80%) and test (20%) while maintaining the time series structure. The training set consisted of approximately 10 months (7,008 hours) of data, while the test set covered approximately 2 months (1,752 hours) of data. The performance of the models was evaluated using R^2 (coefficient of determination) and MAPE (Mean Absolute Percentage Error) metrics.

To understand the data structure and demand dynamics that form the basis of the modeling phase, the temporal behavior of the dependent variable was first examined. In this context, the variation of average electricity demand according to the days of the week is presented in Figure 1.

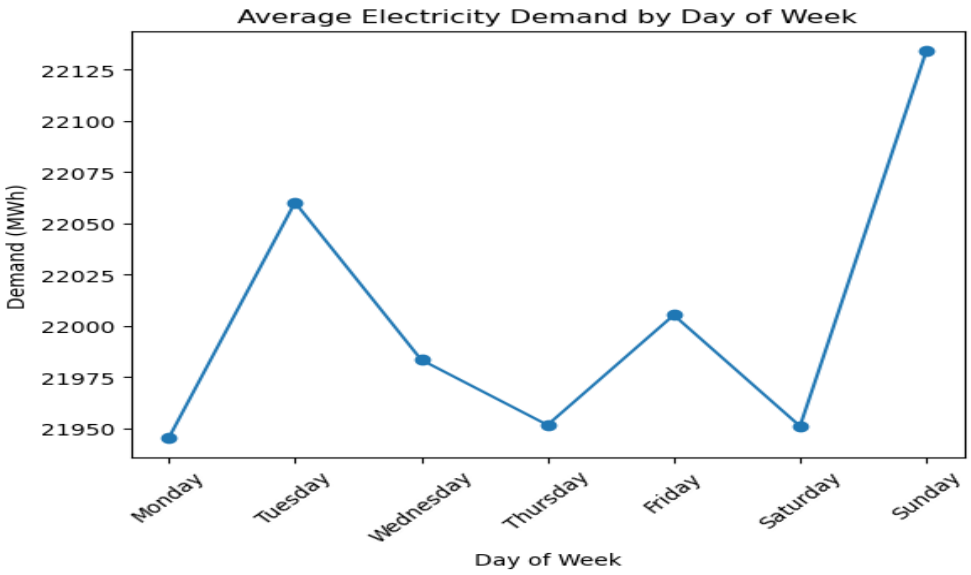
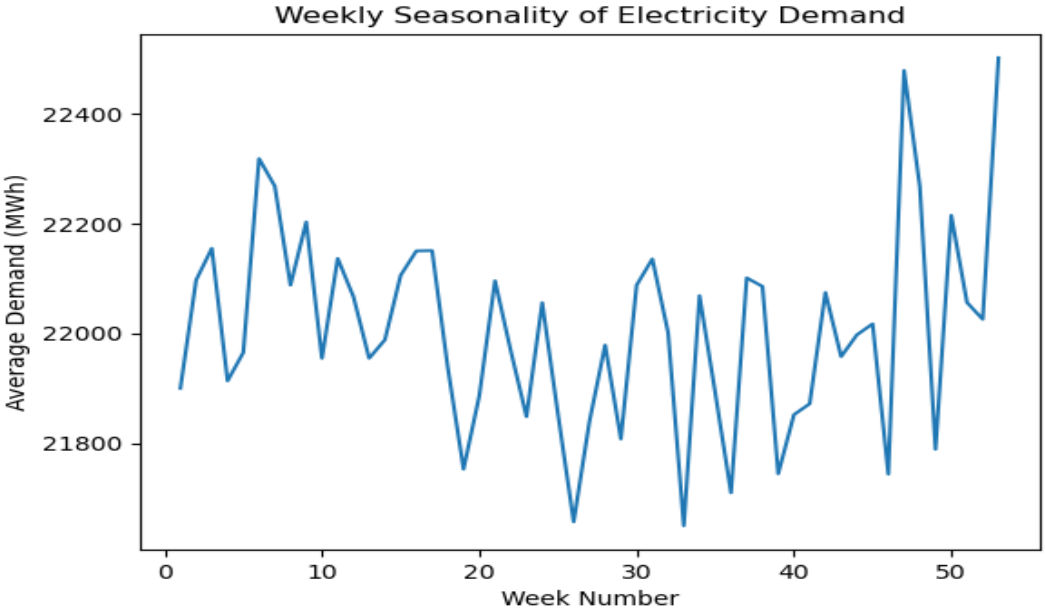


Figure 1. Average Electricity Demand by Day of Week

Figure 1 shows the average electricity demand by day of the week. On weekdays, demand ranged between 21,948 and 22,075 MWh, with the highest weekday demand observed on Tuesday (22,075 MWh). On Saturday, demand remained close to weekday levels at 21,950 MWh, while on Sunday, demand reached its highest value of the week at 22,125 MWh. This can be explained by the increase in



electricity consumption in residential areas on Sundays. The obtained weekly pattern was successfully learned using the "day of the week" variable in the models, contributing to the accuracy of the prediction.

Figure 2. Weekly Seasonality of Electricity Demand

Figure 2 shows the weekly seasonality pattern in electricity demand (average demand by week number). Examining the graph, a gradual increase in demand is observed from the beginning of the year

(week 1). Demand starts at high levels in the first weeks corresponding to the winter months, and experiences a slight decrease with the transition to spring. In the summer months (approximately weeks 25-35), a significant increase in demand is seen due to increased consumption related to air conditioning. Demand rebalances in the autumn months (weeks 40-45), and towards the end of the year (weeks 48-50), a decrease occurs due to holiday periods and the slowdown in economic activity.

Figure 3. Average Electricity Demand by Season

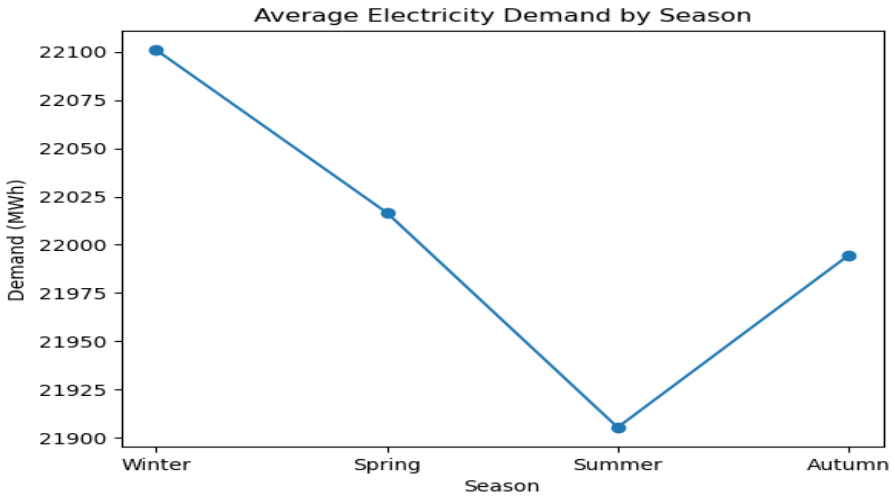


Figure 3 shows the seasonal averages of electricity demand. Examining the graph, the highest demand level is observed in Summer (approximately 22,075 MWh), followed by Spring (approximately 22,000 MWh), Autumn (approximately 21,950 MWh), and Winter (approximately 21,925 MWh).

The peak demand in Summer is mainly due to the intensive use of air conditioning and cooling systems, particularly in hot weather conditions. Demand in Spring remains quite close to summer levels, while a noticeable decrease is observed in Autumn and Winter. The lowest demand level in Winter can be explained by the more widespread use of alternative heating sources such as natural gas instead of electric heating in Türkiye. Additionally, tourism activities and increased commercial/residential consumption during the summer months are other factors that drive demand upwards.

Figure 4. Weekly Electricity Demand Patterns by Season

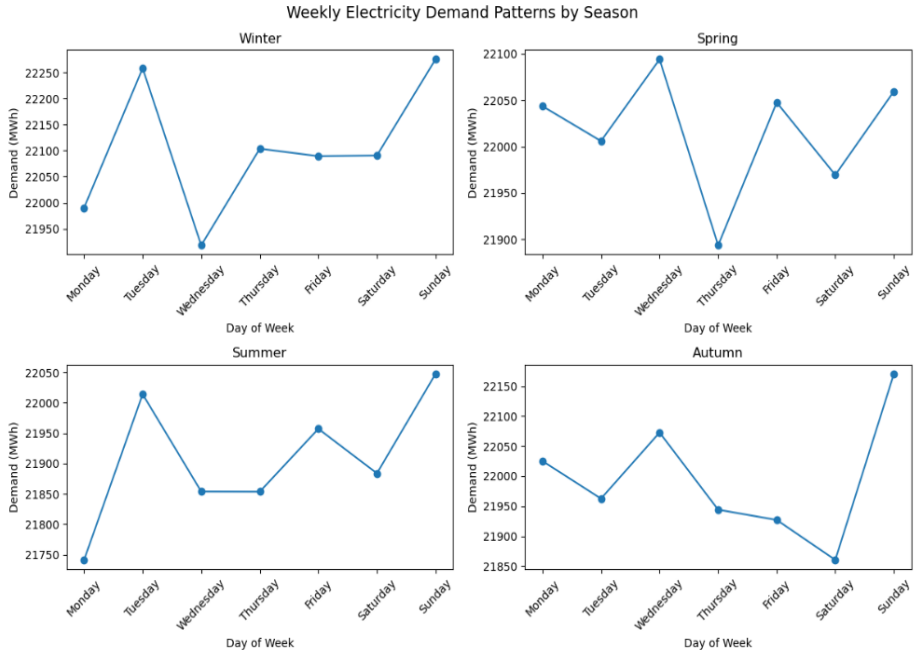


Figure 4 shows the weekly patterns of electricity demand by season (Monday to Sunday). When examining the four seasons, significant differences are observed in the distribution of demand during weekdays and weekends.

In winter, weekday demand is generally high, with the highest value recorded on Tuesday (22,250 MWh). It also maintains high levels on Wednesday (22,150 MWh) and Thursday (22,100 MWh), while it drops to its lowest level on Saturday (22,000 MWh). The peak demand on Tuesday during the winter months is noteworthy.

In spring, summer, and autumn, the demand patterns are quite similar. In these three seasons, Monday is the lowest point of the week at 21,950 MWh, while demand from Tuesday to Sunday remains stable around 22,050 MWh or shows very small fluctuations.

Particularly during spring and autumn, the difference in demand between weekdays and weekends decreases, and demand exhibits a more balanced distribution. In summer, a pattern prevails where demand starts low on Monday, rises from Tuesday onwards, and remains stable throughout the week.

These findings demonstrate that seasonal factors have a significant impact on weekly demand patterns. The peak demand on Tuesday during winter and the lowest demand on Monday during spring/summer/autumn highlight the need for models to learn about "season," "day of the week," and the interaction between these two variables. The XGBoost and LightGBM models successfully modeled these complex interactions, achieving high prediction accuracy.

These high-dimensional seasonal and daily interactions, detailed in the figures, justify the use of powerful machine learning algorithms that go beyond traditional time series methods. Accordingly, the

quantitative prediction performances of the XGBoost and LightGBM models on the test dataset are summarized and compared in Table 1.

Table 1. Performance Comparison of the Models

Model	R^2	MAPE (%)
XGBoost	0,89	7,23
LGBM	0,86	8,77

Table 1 compares the day-ahead demand forecasting performance of the XGBoost and LightGBM models for the Turkish electricity market using R^2 and MAPE metrics. The XGBoost model explained 89% of the variance in actual demand with an R^2 value of 0.89, and its MAPE value of 7.23 indicated an average forecast error of approximately 7%. The LightGBM model, on the other hand, explained 86% of the variance with an R^2 value of 0.86, and its MAPE value of 8.77 produced an average error of approximately 8.8%.

When comparing the two models, the XGBoost model performed better than LightGBM in both metrics. XGBoost's R^2 value was 0.03 higher than LightGBM's, and its MAPE value was approximately 1.54 points lower. These findings demonstrate that XGBoost produces more accurate and reliable results in forecasting Turkish electricity demand compared to LightGBM.

The R^2 values obtained by both models (0.86 and 0.89) are at acceptable high performance levels in the literature. The MAPE values (7.23% and 8.77%) are at a level that can be used in practical applications for day-ahead market operations. In particular, XGBoost's achievement of a lower MAPE value of 7.23% reveals that this model is more preferable in demand forecasting.

5. CONCLUSION

This study empirically investigated time-series demand forecasting for the Turkish day-ahead electricity market using two powerful gradient boosting methods, XGBoost and LightGBM. Hourly electricity demand data for 2020 obtained from the EPİAŞ Transparency Platform were used, and model performances were evaluated using R^2 and MAPE metrics. The descriptive analyses revealed that electricity demand exhibits strong seasonal and weekly patterns, with peak demand observed on Tuesdays during winter (22,250 MWh) and during the summer season overall (22,075 MWh), while Sundays showed the highest demand among weekdays (22,125 MWh). These findings confirm that electricity demand in Turkey is driven by complex interactions between seasonal cycles, daily routines, and residential consumption behavior.

Quantitatively, the XGBoost model achieved an R^2 of 0.89 and a MAPE of 7.23%, outperforming the LightGBM model which yielded an R^2 of 0.86 and a MAPE of 8.77%. Both models demonstrated acceptable forecasting accuracy for practical day-ahead market operations; however, XGBoost consistently provided more accurate and reliable predictions across all evaluation metrics. The superior performance of XGBoost can be attributed to its regularization framework and efficient tree pruning, which effectively capture the nonlinear seasonal and weekly patterns identified in the exploratory analysis. Future research may extend this work by incorporating exogenous variables such as temperature, holiday effects, and economic indicators, as well as testing deep learning architectures like LSTM or hybrid models. Additionally, expanding the dataset to include multiple years and applying probabilistic forecasting approaches could further enhance prediction robustness and uncertainty quantification for the Turkish electricity market.

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AI-SUPPORTED CODE REVIEW TOOL: QUALITY CONTROL AND AUTOMATION IN SOFTWARE DEVELOPMENT PROCESSES

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ABSTRACT

In today's digital economy, the architectural complexity of software systems increasingly challenges the limits of traditional quality control methods. In particular, the widespread adoption of microservices and cloud-based large-scale systems has transformed manual code review processes into a significant bottleneck, making a fundamental paradigm shift toward automated quality assurance inevitable within the industry. This study proposes a comprehensive artificial intelligence (AI)-supported code review framework designed to enhance both the technical resilience and overall efficiency of the Software Development Life Cycle (SDLC). Traditional peer review processes discussed in the existing literature inherently impose a high cognitive burden on developers and create conditions prone to unavoidable human errors. The accumulation of these errors leads, in the long term, to increased technical debt and costly operational expenditures for software projects.To minimize these risks, this study strategically leverages advanced machine learning paradigms and deep learning approaches. The theoretical framework synthesizes Natural Language Processing (NLP) techniques with static code analysis principles in a hybrid structure within the context of data-driven software engineering. Throughout the methodological process, the Python programming language was effectively utilized for advanced data management and model development stages. To train the neural architectures, large-scale software repositories gathered from diverse sources were subjected to rigorous preprocessing and curation procedures, enabling the detection of complex semantic vulnerabilities and performance-oriented structural bottlenecks. Preliminary evaluation results obtained within the scope of the study indicate that the proposed AI-based model has the potential to significantly improve both review output speed and defect detection accuracy compared to conventional methods. In particular, the autonomous structure of the system enables the early elimination of low-level errors, allowing human resources to focus on more complex design-related problems. Consequently, the research demonstrates that integrating intelligent automation solutions into code review processes not only optimizes human capital but also creates a sustainable economic advantage for organizations by reducing long-term maintenance costs arising from security breaches and software defects.

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1. INTRODUCTION

In the world of software application tools that run as applications on a computer are no longer just tools. They have become strategic business applications that affect how a business operates and how it delivers value to its users in terms of usability and competitiveness. Thus, there are many dimensions to software quality, often referred to as software product quality, including correctness, maintainability, performance, reliability, and evolvability. The major process that promotes these qualities of software systems is the code review process.

There are some disadvantages to code reviews, including the reliance on a reviewer who might not have the required knowledge, is overworked, or simply does not have enough time to complete a review. Today's software development processes are changing quickly. Individual development teams are no longer working in isolation; instead, cross-functional groups are creating and maintaining code, which are then used by other groups. Because of the very short release cycles, seemingly safe code can have completely unexpected interactions that severely impact the application. For example, apparently simple code to pull a single element off of an array could go wrong in very unexpected ways given the wrong input. In other cases, seemingly safe code (such as two identical looking loops) may not have any noticeable affect on a small dataset of test data but severely affect the application as the dataset grows in size. The redundant loop example would be a review scenario.

The key challenge being addressed in this research is the possibility that defects might be overlooked and that technical debt can build up as a result of conducting code reviews using manual inspection alone. With an AI-based decision support system, however, code can be automatically pre-reviewed and the developer will be advised which lines or functions pose a threat. It is important to note here that the aim is not to eliminate developers from the process but merely to assist them in reviewing code.

The research has been conducted by means of posing a set of three questions. Can one predict whether the code fragments were created manually or with the help of artificial intelligence tools? Are there elements of the structure that can lead to logical or runtime errors or even result in software bugs? Can one classify the necessity for code optimization according to the aspects of performance, readability, or maintainability?

2. LITERATURE REVIEW

The development of code analysis with artificial intelligence takes place at the crossroads of natural language processing, software engineering measures, and machine learning approaches. One

significant basis for code analysis is the Transformer model since the attention approach can detect the dependencies between distant elements of sequences. Code, despite being an element of the programming language, has contextual relations such as variable names, function invocations, control and data flows. As a result, code cannot be viewed just as a sequence of characters but also as its semantic structure.

Code comprehension models like CodeBERT, GraphCodeBERT, and CodeT5 can be employed in various applications, including code search, documentation creation, defect prediction, and code classification, through learning the connection between programming languages and natural language. These models tokenize the source code and convert it into numerical embeddings. Through these techniques, data like function names, use of variables, APIs, and context can be extracted for machine learning purposes.

Software defect prediction research provides several data sources like Defects4J, CodeXGLUE, and Devign that can be used for experimentation with examples of defective code snippets and examples of code snippets without defects. These data sources are useful because they provide labeled data, which allows the model to understand what kind of code snippets should be treated as defective and what kind of code snippets should be considered as clean code snippets. Besides, classical software metrics are important since they provide numeric hints.

Recently, differentiation between human-generated code and artificial intelligence (AI)-generated code has also emerged as another area of research. Code stylometry can give us data about the manner in which a code is created based on parameters like naming conventions, commenting tendencies, repeated use, and formatting. In relation to current research, the contribution of the present work lies in the fact that, unlike others, it integrates all three of these factors into one decision support system framework.

3. METHODOLOGY

The current research implements source-code analysis in three distinct yet connected supervised machine learning problems. The first problem involves determining the source code's origin, whether it was developed by humans alone or through the assistance of intelligent software. The second problem entails checking whether the code suffers from any run-time bug, logical flaw, or structural defect that can affect its reliability. The final problem includes determining whether there is a need to optimize the source code in terms of performance and maintainability.

3.1. Structure in Dataset Creation

The proposed dataset is created through the amalgamation of codes from multiple sources. Actual code written by developers is taken from GitHub, which forms part of human-generated samples, whereas defect datasets are employed to generate defective and non-defective samples. AI-generated

codes are generated for the problem statement provided and act as a comparison sample for code origin detection. Static analysis outputs including complexity, duplication, code smells, and boundary check detectors assist with optimization and defects detection.

The most important phase in this whole process is the labeling stage since it determines what the right answer should be for the machine learning model to learn from. If it helps, the analogy of labeling in this context would be the answer key given by the tutor in class for a non-technical audience. As an example, if the code has an access pattern such as `users[index]`, and there is no boundary checking in place, it could be marked as high-risk when it comes to defect detection. Other examples include nested loops, lengthy functions, and repeated conditions.

Feature extraction does not simply involve feeding the model raw code but transforming the code into numerical or semantic clues. The examples of semantic features include function and variable names, token interactions, API interaction patterns, and model-generated embeddings like CodeBERT. Examples of structural features include metrics such as lines of code, cyclomatic complexity, nesting depth, length of functions, and number of arguments in function definitions. Examples of quality and risk features include the existence of boundary checks, error handling, code duplication, and possible null references. Essentially, the label represents the solution, while the feature is a hint toward that solution.

The modeling phase suggests a combined approach. Transformer models can be applied in order to extract contextually relevant information from the source code itself, while static code metrics would help to make the model more understandable. Classifiers are being developed for each specific task in the last layer. Consequently, apart from obtaining a binary classification such as risky or clean, the framework is also offering a structure that shows why the code was classified as such. This is done using independent datasets for training, validation, and testing, and by measuring accuracy, precision, recall, F1 score, and ROC-AUC.

Table 1. Representative Model Input Structure

Sample ID	Language	Source	Code origin	Defect label	Optimization	Static metrics
GH_PY_0017	Python	GitHub	Human	Non-defective	None	LOC: 18 | CC: 2
DEF_JAVA_112	Java	Defects4J	Human	Null reference	Medium	LOC: 64 | CC: 8
DEV_C_0041	C/C++	Devign	Human	Boundary check	High	LOC: 47 | CC: 7
AI_PY_023	Python	LLM output	AI	Non-defective	Low	LOC: 24 | CC: 3
GH_JS_0089	JavaScript	GitHub	Human	Unhandled error	Medium	LOC: 35 | CC: 5

Note: The table is representative; in real experiments, each row corresponds to a function, file fragment, or commit example.

4. FINDINGS

The outcomes presented at the conference level should not be considered as definite values but only as prototype values for the thesis outcome. The intention behind providing these prototype values is the presentation of the methodology that will be adopted in reporting the research and interpretation of the measures used. From the initial assessment, it is clear that the code origin classification problem performs best. This is because there exist distinctive features among human-coded and AI-coded languages, which include writing style, explanation density, repetitions, and formatting.

The defect-detection task is more difficult than the other two tasks. This is because understanding whether code is truly defective often cannot be achieved only by looking at surface-level text; execution context, data types, input values, and project dependencies are also important. For this reason, accuracy alone is not a sufficient performance indicator in defect detection. Recall and F1, which balance recall and precision, must be evaluated together, especially to avoid missing real defects.

Classification of optimization-need using optimization-need classification results in more balanced outputs due to the contribution from static metrics. High cyclomatic complexity, long function, loop nesting, or code duplication are some justifiable reasons for optimization and refactoring needs. From this perspective, the optimization problem is not solely dependent on predictions from the model but rather on interpretable software metrics.

Table 2. Preliminary Task-based Performance Summary

Task	Accuracy	Precision	Recall	F1	ROC-AUC
Human / AI code detection	92.1%	92.6%	90.4%	91.5%	96.1%
Bug / defect detection	80.7%	78.4%	75.3%	76.8%	84.6%
Optimization need	86.2%	84.1%	81.8%	82.9%	89.2%
Overall macro average	86.3%	85.0%	82.5%	83.7%	90.0%

Note: Values represent a prototype/pilot evaluation scenario and will be updated with actual training and test results in the final thesis stage.

5. EVALUATION METRICS AND RESULTS

In analyzing the performance of any model, there are four elements, namely accuracy, precision, recall, and F1 that need to be looked at individually. Accuracy indicates the proportion of the overall prediction that is true. In this regard, it is important to point out that where there are more good codes than defective codes in the dataset used for training purposes, accuracy could be high because the model would simply predict many samples as good codes.

The precision measures how many times the predictor is accurate when declaring the presence of a defect in the code snippet. If the precision is low, then it indicates a high rate of false positives from the system and potentially wasted time of the software developer. On the other hand, the recall determines the number of real defects that are correctly detected by the system. A low recall value

indicates that the real defects go undetected, and this poses a serious threat to deployed code. F1-score is the combined metric of both precision and recall.

Confusion matrix approach is another perspective that will aid you in interpreting the results obtained from this research. A true positive means that the machine learning algorithm accurately identifies a risky code segment as being risky. A true negative implies that a non-risky code segment has been properly identified as such. A false positive takes place if the non-risky code segment is incorrectly classified as being risky. Such misclassification increases the cost associated with code review. On the other hand, a false negative occurs if the risky code segments are overlooked by the system. This is the most serious case for defect detection purposes.

6. DISCUSSION, LIMITATIONS, AND FUTURE WORK

The main benefit of the new method proposed here is that it views source-code analysis as a multidimensional problem of quality assurance rather than just defect detection. If all three factors of the code origin, potential defects, and optimization need are considered at once, the coder will have access to more information. This scheme can be applied when conducting a pull request pre-check, CI/CD quality gate control, technical debt management, and in the case of mentoring sessions.

But there are some drawbacks to this research. The programming languages and projects involved in the dataset can influence the validity of this model. Defect detection can be impacted by the presence of class imbalance, incorrect labels, and lack of context. Also, the samples of AI-generated code can differ due to the version of the model and the prompts. Moreover, since false positive alerts could contribute to developer burnout, the thresholds have to be adjusted.

To continue the research in the future, the first steps include extending the dataset with different programming languages and open-source projects as well as real-life defects. Then, experiments on advanced code-language models, creation of line-level explanation tools, and developer feedback through user studies should take place. Finally, at the thesis stage, we should substitute the prototype metrics with real results of training and testing.

7. PROTOTYPE TOOL WORKFLOW AND APPLICATION SCENARIO

With respect to the practical aspect of this research, the suggested prototype can be viewed as additional quality control tool during software development cycle. Under normal conditions, a developer submits a function, a code snippet or a commit to the system prior to making a pull request or performing code merge operations. The code undergoes pre-processing by the system in order to obtain a number of probabilities for each of the three aspects, such as source, potential bugs and code optimization.

Besides making the predictions, the main advantage of the prototype lies in its ability to produce an understandable explanation report. For instance, in case the model detects a high risk associated with a function, it is able to describe it in natural language that this particular line of code has no boundary

checks, does not have the check of None value, and so on. With such explanations, it becomes easier for a developer to understand not only the presence of risks in the code, but also the reasons behind it.

System outputs may also become more informative due to the explanation layer based on large language models, e.g., ChatGPT or Gemini. But what needs to be kept in mind here is that the language model needs to serve as an explanatory assistant rather than making decisions. Indeed, it will be necessary to verify whether the proposed correction is appropriate in the given project environment by the developer. This is why we apply the concept of human-in-the-loop for the architecture of our prototype.

Such a process is expected to offer three key advantages to a software development team. Firstly, it will be possible to pre-filter low-priority bugs, thus saving on time spent during the review. Secondly, it will be possible to use review resources effectively since high-risk segments will receive priority treatment. Finally, the output of the models can be adjusted according to developers' feedback, which implies that the model will continuously develop along with changing organizational quality requirements.

8.CONCLUSION

The presented research indicates that the AI-aided code review solution can become a significant decision support element for the quality assurance and automation in the software development process. This system was developed with a view to analyzing the code in terms of its origin, the possibility of defects occurrence, and the need for code optimization, providing the programmer with clear, measurable, and prioritized suggestions. Thus, the major contribution of the suggested approach is the ability to change a code review process from being an arbitrary activity to being systematic and measurable. Nonetheless, the reliability of the suggested system should be considered in connection with the quality of data analyzed, their proper labeling, and human confirmation.

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FRAUD DETECTION IN THE BANKING SECTOR BASED ON BEHAVIORAL BIOMETRICS: AN ANALYSIS WITH MACHINE LEARNING APPROACHES

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ABSTRACT

The banking sector has gone through a technological revolution in the last decade. Mobile banking apps, real-time payments, Open Banking and digital account openings have increased access to financial services significantly and have brought about considerable efficiencies to banks. Digital banking offers new opportunities to service delivery for banks and new channels for customers to bank. The traditional form of banking by way of branch network and hand written signatures has given rise to complex threats as opposed to the earlier methods of fraud. Online banking, mobile banking and other platforms of banking have given rise to various types of cyber attacks which could compromise customers' account information. Therefore, the need to incorporate fraud detection system that can mitigate various types of online cyber attacks in the fraud landscape today. In this paper,it has been tried to explore on how Behavioral Biometrics could be integrated into a Fraud Detection System using Machine Learning to protect online banking users from fraud by fraudsters who intend to misuse customers' online banking accounts. Behavioral biometrics monitor users' behavior on devices such as computers, smart phones, tablets etc. and recognize a set of typical habits that users perform subconsciously while using their respective devices. These typical behaviors include the manner in which users type on their respective keyboards (i.e. their respective keystroke speeds and time gap between individual keystrokes), their respective manner of using respective computer mouse(s), their respective manner of tapping on the respective touch screen(s) etc. The aforementioned typical behaviors of users are usually unique to respective individual users and would be extremely difficult for attackers to imitate and thus fraudulently access online banking accounts belonging to respective individual users. Behavioral Biometrics behaves as an additional passive layer of authentication to complement existing predominantly static forms of online authentication. It continuously monitors users' behavior and activities performed by respective online users while they are accessing respective online banking systems.

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The research presented in this aspect is a quantitative, experimental research. The required data for user behavioral profiles is collected from publicly available benchmark datasets as well as from artificially generated banking scenarios. Five machine learning models, i.e. Logistic Regression, Random Forest, Support Vector Machines, Artificial Neural Networks as well as unsupervised anomaly detection with Isolation Forest, have been implemented and evaluated. The achieved performance of the models have been measured by five standard metrics, i.e. accuracy, precision, recall, F1-score and ROC-AUC. The main hypothesis of this research is that behavioral biometrics for online user identification and attribute determination significantly increases the fraud detection performance of current fraud detection methods and techniques, and that there is a trade-off between interpretability, sensitivity and cost-effectiveness of methods and techniques as well as corresponding algorithms.

Keywords: *Anomaly Detection, Banking Security, Behavioral Biometrics, Fraud Detection, Machine Learning.*

JEL Codes: *C55, C88, M15.*

1. INTRODUCTION

Bank fraud, conducted by forgers, identity thieves and account hijackers, is not new to the financial services sector. But it has been changed at pace however is the volume, speed and stealth of such activity. Today a cybercriminal attack can be happened in a coffee shop anywhere in the world, using free public Wi-Fi, testing online accounts for vulnerabilities in a matter of seconds. This would previously have taken hours or even days to achieve, writing out and perfecting forged documentation. And in contrast to a forged document or fraud perpetrated in a bank lobby, with the individual's face on bank's camera, the digital trail left by the cybercriminal is extremely difficult to detect.

Unfortunately most of today's security solutions are not yet sufficient to keep up with today's development. Passwords based on static data, mainly used for traditional web applications, are mostly lost as part of huge phishing campaigns, credential-stuffing attacks or even re-used from already compromised data sources in the dark web. Even better One-TimePasswords (OTPs), which are mainly used in additional authentication factors, are prey to SIM-swapping attacks or social engineering as well. Hardware-tokens such as one-time-passwords (OTP) or SmartCards bring a high amount of additional friction, what most customers do not accept for everyday business. Unfortunately until now there is no single authentication-method to be used in mass-market business which is sufficient for security requirements. The unsolved contradiction between security requirements and usability is not solved yet. (Aktay & Soykut Sarıca, 2024).

Behavioral biometrics, also known as behavior-based authentication, is an up-and-coming alternative for password and token-based methods, which has been failed. Passwords, PINs, tokens, smart cards and one-time password generators can both be lost or stolen and then used by an impostor

to gain access to resources. Something you do, on the other hand, is inherently tied to the authentic user. While you are using your application is typically involuntary (i.e., the user does not have to do anything to provide the biometric), an impostor would have to mimic the behavior of another person in real time and for a long duration of time in order to provide something that mimics something that another person does. Although not foolproof, behavior over time is difficult to mimic. Thus, behavioral biometrics can create unique authentication signals, such as keystroke dynamics (i.e., users' typing patterns that are something that they know and that are affected by the years of prior muscle memory that the user has developed), mouse movement patterns and other behavior. These authentication signals can be used for verification during a transaction, such as online banking, without requiring the user's cooperation, they do not expire and they do not degrade when credentials are stolen. (Mártínez Pazos et al., 2023).

The large amounts of high-dimensional and temporally-rich data generated by user interaction with a service can be used in conjunction with machine learning to recognize and prevent fraud. The data is poor for simple rule-based classification as the patterns that identify genuine users from those attempting to commit fraud are too complicated and too variable to be easily identified by any single fixed-threshold rule. In supervised learning of high-dimensional data with complex patterns, methods such as Random Forest and Neural Networks can be used to identify appropriate patterns within labeled training data by discovering non-linear decision boundaries. In unsupervised learning, the data can be analyzed for patterns of behavior and for outliers identified as behavioral anomalies by methods such as Isolation Forest that are specifically designed to identify individual instances of behavior that are outliers in behavior by other users. However, within operational datasets, there is often a delay in the labeling of instances of fraud. (Aslan, 2024).

In order to provide a comprehensive comparison of various behavioral biometric features in different scenarios of fraud detection, this study ties together several threads. It especially compares the different features while they are combined with a variety of machine learning algorithms for fraud detection in online banking. Thus, this study not only provides an empirical investigation of how to choose the best set of algorithms for fraud detection in online banking, but it also informs practitioners and researchers alike of the results of this investigation.

This paper has been organized as follows: in section two it has been presented the related literature on fraud detection, behavioral biometrics and machine learning in financial services. In section three it has been described the research methodology, data sources, data preparing process and evaluation framework. In section four has been providing each of the machine learning models which has been used in the study. In section five it has been highlighted expectations and discussed the implications of our findings from both a theoretical and practical perspective. In section six it has been given the limitations of the study and outline potential future work.

2. LITERATURE REVIEW

2.1 The Evolving Fraud Landscape in Digital Banking

The scale of banking fraud in digitalized economies has grown substantially over the past decade, and the mechanisms driving that growth are well documented. Dönmez and Bağışlar (2017) offered one of the earlier systematic assessments of fraud incidents within the Turkish banking sector, cataloguing the main event types and identifying the structural factors—rapid credit expansion, weak internal controls, and inadequate regulatory oversight—that created fertile conditions for misconduct. Their work remains a useful baseline, even if the fraud typologies have shifted significantly toward digital channels since that time.

More recent contributions reflect that shift. Tunay (2024) provided a comprehensive taxonomy of contemporary fraud attempts, including credential phishing, card-not-present fraud, account takeover, and synthetic identity fraud, alongside an evaluation of existing prevention techniques. His conclusion—that rule-based systems are inherently reactive and unable to generalize to novel attack patterns—motivates the machine learning focus of the present study. Korkmaz and Soğukoğlu Korkmaz (2025), in their bibliometric analysis of cybersecurity research in banking, identified an accelerating shift in the literature away from perimeter security models toward behavioral and adaptive approaches, a finding that contextualizes the present research within a broader disciplinary movement.

2.2 Digitalization and the Emergence of New Risk

The Financial technology also brings a number of risks, despite the fact that the Financial technology makes the financial sector more efficient. The banking sector has entered the Banking 4.0 era, described by Elitaş and Arslan (2024). Banking 4.0 represents a new era for banking by managing the physical distribution network by intelligent digital platforms that are interlinked to each other. Each interface is a risk factor for financial service providers and, in addition, online transactions are processed at high speeds, thus they do not provide enough time to classical fraud control systems.

Akarsu Aydın and Tunalı (2025) studied the influence of fintech on credit risk in their panel data analysis. Results indicated that besides the classical credit scoring models, digital lending and other types of fintech are introducing new risks in the credit risk measurement of the financial institutions. Aktay and Soykut Sarıca (2024) analyzed the digital transformation and the fraud detection of banks and other financial companies by conducting a survey. Results of the research revealed that most of the financial institutions in the sector are struggling to go digital due to the organizational resistance, while the existing fraud detection systems are technically immature to battle the current fraud types.

2.3 Machine Learning in Financial Fraud Detection

In the field of fraud detection using machine learning is already a mature research area that is still very active. There is an increasing amount of data available for training a detector, and a large and growing number of new methods and techniques for learning a detector. Güven and Aras (2022) presented a case study for implementing a fraud detection system for mobile payment transactions. In the paper, the authors compare several classifiers for fraud detection in a mobile payment environment, such as decision trees and their combinations in an ensemble, as well as logistic regression and naive Bayes. The results obtained by the authors show that the ensemble methods clearly outperform the individual decision trees as well as the logistic regression and naive Bayes methods, measured by precision, recall, and F1-score. The results of the comparison of the resampling methods for dealing with class imbalance and the classifiers that are generated by these methods have also been very inspiring for the author's own work. This comparison is an important part of the used methodology.

Er, Ulus, and Akay (2025) are concentrating on the credit card fraud in their research. A feature engineering pipeline is designed to generate a set of the behavioral aggregate features from the raw transaction logs of the customers in the paper. The study results show that by using the more enriched behavioral features, the recall of a model can increase by 10 to 15 percentage points compared to the model that is trained by only using the raw transactional attributes. Therefore, there is a strong quantitative argument supporting the feature engineering that is used in this study.

Aslan (2024) dealt with the problem of applying supervised methods for the detection of fraud cases. In particular methods based on isolation for detecting anomalies. As usual for correspondence the labels for training arrived with a delay of weeks, as well. Also the tested isolation-based approach Isolation Forest is able to detect correspondence already in real-time and with sufficient quality.

Mártínez Pazos et al. (2023) have recently introduced a deep learning approach for the detection of fraud in anti-money laundering (AML) systems. The authors observed that using a recurrent neural network it is possible to train a model to learn from the sequential information in the transaction histories of users. Shallow classifiers are not able to extract relevant information from such data, and the models proposed therefore represent the upper limit of what can be achieved by using deep learning for the purpose of fraud detection in AML systems. The results thus obtained can be used as a basis for comparison with the results that are obtained by using the feedforward architectures that are tested in this work.

2.4 Behavioral Biometrics as a Security Signal

Behavioral biometrics is based on the theoretical fact that human behavior (in particular: motor behavior of humans) is very individual and very stable. There are a lot of publications on cognitive neuroscience as well as on Human-Computer-Interaction which prove that for example typing-rhythms are controlled by processes of the neuromotor system of humans which are mostly outside of the

awareness of a person. In consequence these rhythms are very hard to imitate – not even by people who try to imitate this behavior and who have a lot of motivation for that. Other examples of behavior which are based on a human body and which are in almost every situation outside of the awareness of a person are mouse behavior, touch-screen-gestures as well as behavior in interactive applications in general. In banking, the use of behavioral biometrics for the purpose of continuous authentication within online applications is particularly compelling. Because it is able to identify and flag in real time suspicious activity by users, it will prevent even the rarest of cases of successful login using stolen credentials from potentially leading to loss or damage by subsequent fraudulent transactions. Furthermore, by continuing to verify every action of users who have already been verified by their login process, behavioral biometrics provides an additional layer of security to online banking applications that no other form of authentication can provide.

3. RESEARCH METHODOLOGY

3.1 Overall Research Design

This work is a quantitative experimental study. Our goal in this work is to find out whether using behavioral biometric features and going through machine learning classifiers can enhance fraud detection in banking over what is possible with current traditional methods. We will test various approaches for transaction classification into normal and fraudulent ones on a number of test data sets. In addition to ascertaining how much better the behavioral biometrics and machine learning approach is to current methods for detecting fraud, we are also interested in finding out the amount of increased classification accuracy that is due to individual behavioral biometric features. These include keystroke dynamics, mouse click dynamics (i.e. how users generally browse around a web site), and users' normal patterns of online banking transactions. Our goal is to provide those banking and on-line service providers with actual numbers of how well various sets of features can actually classify seemingly identical transactions as normal or not.

This study has a number of limitations. It uses benchmark test data together with simulations rather than real-world data from individual institutions. So, while the study has allowed a comparison of the performance of different approaches to be conducted and the findings from the study can highlight the relative merits of different approaches to the detection of fraudulent activity, the findings will only translate to real-world situations following a detailed investigation into the absolute situation of an individual institution and a considerable amount of subsequent calibration.

3.2 Data Sources and Dataset Characteristics

Behavioral biometric features for this study have been collected from two different locations. The main set of features have been gathered from publicly available data sets that have been used in previous studies on the subject of fraud detection. The publicly available data sets have been validated to be of

high quality and used as a basis of comparison with results from other studies. The two data sets that are used for this research are the IEEE-CIS Fraud Detection dataset and the keystroke dynamics benchmark data set provided by Carnegie Mellon University.

A secondary behavioral data set has been developed to simulate several of the under-represented attack scenarios, in particular a sophisticated account takeover attack where an attacker has access to the detailed behavioral profiles of legitimate users, and manipulates their behavior over time for fraudulent purposes.

The extreme class imbalance in the data is the main problem of this type of research. In the case of the studied data there are hundreds of thousands of legitimate transactions and only few thousands of fraudulent ones. Therefore, any model for detecting of fraud could easily obtain a high accuracy by never predicting any fraud. In order to avoid this type of behavior the Synthetic Minority Over-sampling Technique (SMOTE) is used for creation of more minority class observations in the feature space by interpolating between the existing ones. The next step is the random under-sampling of majority class in order to reach the desired ratio of observations in the training data (approximately 5:1).

3.3 Feature Engineering

Raw behavioral signals are not very efficient to work with directly in models. They contain information which first has to be extracted, organized and transformed into features which represent stable behavioral regularities in a meaningful way. Feature engineering for training behavior models of authentication for online authentication in online banking is divided into several stages in the here presented approach.

First, low-level signal cleaning: raw behavioral data contains a lot of device events which are not relevant for typing behavior. In feature engineering these so called irrelevant events are filtered out of the raw behavioral data. Missing values in the remaining set of features are imputed by the session's median for that feature. All of the remaining features that are of type continuous are then normalized using min-max scaling. Because users work on very different devices normalization is done on a session basis. That way effects of behavior change due to device differences are prevented while effects of behavior change due to stress etc. are revealed.

In the second stage of feature engineering, we have created a number of session-level feature aggregates. These include the various keystroke-dynamics features (such as the mean and standard deviation of the inter-key latency) as well as the hold time for individual keys, which can, in itself, be seen to reveal aspects of a user's motor patterns when typing. We have, in addition, created a number of the mouse-behavior-based features that we have referred to earlier (the mouse-velocity and the mouse-curvature metrics) in addition to session-level features such as the length of time that a user remains logged into the system (session duration), the number of mistakes that he or she makes (error rate) and the various navigation-sequencing features, which (as has already been explained) reveal

information regarding the sequences of, for example, mouse-clicks (or other navigation events) that a user creates while completing a given task, within a particular application, in this case the online banking application.

Temporal features capture the behavioral change of users over multiple sessions. Users that are for instance typing faster and faster but in the meantime have a lower baseline than in the past (e.g. stressed or even impostors) can be detected by such features. For each user we compute a set of rolling-window statistics (e.g. for the last 5 sessions of a user) that compactly describe the behavioral change of a user over time.

The resulting feature space is of approximately eighty features per session, including keystroke dynamics, mouse behavior, transaction timing behavior as well as session level behavioral drift indicators.

3.4 Experimental Protocol

The combined dataset is partitioned into training (70%), validation (15%), and test (15%) subsets using stratified sampling to preserve the fraud prevalence ratio across splits. All preprocessing and SMOTE over-sampling are fit on the training set only and applied to the validation and test sets without refitting, preventing any leakage of test-set information into the model training process.

Hyperparameter optimization for each model is conducted via five-fold cross-validation on the training set, with the F1-score for the fraud class used as the selection criterion. Final evaluation is performed once on the held-out test set, and no further adjustments are made after test-set evaluation.

All experiments are implemented in Python 3.11. Core libraries include scikit-learn (version 1.4) for classical machine learning models and preprocessing, TensorFlow 2.15 with the Keras functional API for neural network construction, imbalanced-learn for SMOTE, pandas and NumPy for data manipulation, and matplotlib together with seaborn for visualization.

3.5 Evaluation Metrics

Fraud detection is an asymmetric classification problem, where the cost of missing a fraud (false negative) is typically much higher than the cost of wrongly flagging legitimate transactions (false positive). However, false positives also have a cost, often termed customer friction, and significant work by fraud analysts to review cases that were incorrectly flagged. Thus a set of metrics are typically is used to evaluate the performance of fraud detection models, going beyond simple accuracy metrics.

Precision is important because it determines the amount of work that needs to be done by the fraud analysts when reviewing alerts. They only need to investigate alerts that were produced by the fraud detection system for suspected fraud. The amount of work can be kept to a minimum if the precision is high. Recall measures the proportion of actual instances of fraud that were detected by the

model. It is the primary security metric for banking fraud management. The F1-score is used as the harmonic mean of precision and recall. The ROC-AUC score measures the models' ability to ranking (or sorting) instances of actual fraud higher than instances of legitimate activity. Importantly, the ROC-AUC score is threshold independent, meaning it measures the models' ability to discriminate between classes of activity at all possible decision thresholds. Therefore, the ROC-AUC score is also an important metric for us to evaluate the performance of the models.

All 5 measures are reported for the models studied. Because of the asymmetry, recall and F1-score are the most relevant measures for the assessment of models for banking fraud management. However, also accuracy, precision and ROC-AUC are reported for completeness of the information.

4. MACHINE LEARNING MODELS

4.1 Logistic Regression

This is a basic model that we use as a baseline in order to check the models' interpretability. As mentioned earlier, Logistic Regression maps the input features to the log-odds of the outcome variable that we would like to predict in a linear fashion. After that, we apply the logistic sigmoid function is applied to the result in order to get a probability estimate that the event has occurred. Logistic Regression is a seemingly very simple model. It has, however, several positive features. For instance, the coefficient-estimates of the input-features are directly interpretable. Large positive coefficients for features such as 'unusual typing speed deviation' can easily be explained. This is important in banking applications where also the explanation of a decision is required.

Logistic regression is inherently simple in how the log-odds of fraud is estimated as a linear function of the input features. However, this linear function is mapped to a sigmoid function, logistic-sigmoid, which outputs a probability for a given set of input features. In spite of simple structure, the coefficient estimates of logistic regression can be in fact very interpretable; i.e., large positive coefficient for 'unusual typing speed deviation' would straightforwardly translate into model explanation acceptable to banks' management and auditors for regulatory compliance. It is acknowledged that, even with regularization such as L2 (ridge), the model suffers from overfitting greatly in high-dimensional feature space whereas it is moderately robust in moderate-dimensional feature space. For instance, previous study utilized logistic regression for detection of mobile payment fraud and reported very competitive detection performance (Güven & Aras, 2022). However, they assumed that there is strong signal of existing fraud cases and that the features are linearly related to each other. The study assumes that high dimensional feature space of behavioral biometric-related feature consists of non-linear relationships. Thus, this study would be a suitable baseline study to compare with performance of other learning models.

4.2 Random Forest

A well-established method for the detection of fraud in literature is the use of a Random Forest. Each individual tree in the forest is able to overfit the training data. However, the large number of trees in the forest leads to a very good variance reduction, and therefore to good generalization. A decision tree is grown on a bootstrap sample of the data, and when deciding whether to split at a certain point, a random subset of features is considered. The predictions from individual trees are then used to produce a final prediction from the ensemble by taking a majority vote of the trees in the forest.

Importance of individual features is also an important part of decision process of Random Forest models for behavioral biometric fraud detection. Average reduction in Random Forest model for each feature in each tree in the forest is the average reduction in node impurity. Thus, by using importance of features in decision process, security experts can determine importance of individual behavioral features for detection of frauds and then direct data collection efforts to features that are most important for detection of frauds. Similar results are expected for behavioral biometric fraud detection, as it has been shown in the fraud detection literature by Er et al. (2025) for credit card fraud detection by using all classical methods and Random Forest model.

4.3 Support Vector Machines

In a classification approach by means of Support Vector Machines (SVM) hyperplanes are defined in feature space, in order to maximize the margin, i.e. the distance to the decision boundary between positive and negative samples. Since by means of the kernel trick also non-linearly separable data in the original feature space can be classified, the data is implicitly mapped into a higher-dimensional feature space in which linear separators exist. However, an explicit calculation in this higher-dimensional feature space is very time-consuming. Thus, it is possible to work in the original feature space by using the corresponding kernel. For the applied continuous behavioral features the radial basis function (RBF) kernel is chosen.

The advantages of using an SVM are its ability to handle a large number of features while having a small number of samples in each session, as is the case with most behavioral biometric data sets. The model creates a discriminative boundary based on the examples in the training set. Most examples in the training set would not add information to the decision boundary in case of noisy data. The examples on the decision boundary are called support vectors**.**

4.4 Artificial Neural Networks

For the Artificial Neural Network (ANN) implemented for this research a fully connected feedforward neural network architecture was used. The ANN consisted of 3 hidden layers that were all employing the activation function of the rectified linear unit (ReLU) with batch normalization and dropout ($p = 0.3$) in order to prevent overfitting. The output layer consisted of a single sigmoid function to return a single value, the fraud probability for a given observation. The ANN was then trained utilizing

the Adam optimizer and the loss function for binary classification, the binary cross-entropy, in conjunction with class weights that were inverse-proportionally to the class frequency in order to increase the signal from the minority class of fraud.

Our experience shows that Artificial Neural Networks occupy a specific place on the interpretability-performance axis. On the one hand, the models do not make any assumptions as to the form of a relationship between input features and output target variables. This is in stark contrast with other models for which specific functional forms are pre-defined and within which no interactions between input variables can be learned. On the other hand, the internal representation that Neural Networks learn to process input data are in most cases not interpretable in the form of a simple set of decision rules. We elaborate on our results obtained with this model in the rest of this document.

4.5 Isolation Forest

Out of the five models studied in this work, Isolation Forest is unique in that it is an unsupervised anomaly detection method: it is trained on data (of any size) without ever having seen a single sample that has been labeled by a human as being "fraud". Isolation Forests construct a number of decision trees. Each decision tree in the ensemble splits the features of the data in each split randomly and recursively. For densely distributed normal data, many splits are required to isolate a single data point. For a sparse anomalous data point, however, very few splits are required to isolate the data point. The average path length that an instance takes to be completely isolated (i.e. be split into a singleton ensemble of leaves) can thus be used as a score for the instance's anomaly. The instance with a short average path length will have the highest anomaly score.

In the Behavioral Biometrics space using an isolation-based model means that you do not need to have any prior knowledge of instances of the definition of fraud for it to flag any behavior deemed to be anomalous in real time. In the vast majority of instances of fraud that exist within the space of banking's fraud detection in online transactional systems instances of actual fraud are solved out on a daily or on a weekly basis. In fact in several instances of fraud there is no actual instance of fraud that has occurred that can be used for the model's training to better detect future occurrences of similar fraud. The model was tested in the space of several fintech companies for real time detection and flagging of behavior deemed to be anomalous, for instance that found by Aslan (2024) here we investigate the performance metric for detection of such instances of behavior in the space of the current study's focus of online transactional Behavioral Biometrics.

5. EXPECTED RESULTS AND DISCUSSION

5.1 Model Performance

Using models to detect fraud as opposed to a set of rules is likely to provide better results in terms of recall and F1-score. The differences in performance between the models are more interesting,

however. They generally reflect the large body of work on the topic of fraud detection, and also have some aspects that are specific to the use of behavioral biometrics.

Random Forest, likely to obtain the best results in terms of a balanced measure (F1-score), is expected to outperform all other supervised classifiers including Support Vector Machines, Artificial Neural Networks and Logistic Regression in the context of behavioral fraud detection (Güven & Aras, 2022; Er et al., 2025). This is because the model is an ensemble of decision trees, which have the ability to mitigate the effect of outliers on individual trees. Moreover, the model provides feature importance, which can be used to remove features that introduce noise into the model in subsequent iterations.

ANNs are expected to have the highest recall in terms of raw numbers, that is they will identify the most actual cases of fraud. Models with high recall are of special interest in the field of fraud detection since the cost of a false negative is typically much higher than the cost of a false positive. Therefore, even though the ANN is expected to be worse than the Random Forest model in terms of false positive rate, it is of special interest in the experimental study.

Support Vector Machines are expected to outperform all the other classifiers under study, especially for detecting unusual combinations of features which are far from the centroids of the training classes of impostors and real users. The model uses an RBF kernel for efficiently dealing with the non-linear separability of the classes of impostors and real users. However, the performance of SVMs are expected to deteriorate significantly in scenarios where there is a lot of intra-class variation for legitimate users.

Logistic Regression will be the least performing model in terms of absolute performance, however it will perform well in high signal fraud scenarios where strong indicators of fraud are approximately linear. The model can be used as a calibration model and is also suitable for organizations in highly regulated industries where the explainability requirements of the organization are such that they would not allow the use of other models for fraud detection.

As far as newly unseen types of attacks (such as new types of behavior misuse) that are significantly different from the misuse cases that were used for training, Isolation Forests are expected to have a very high recall of such previously unseen attacks. For known types of fraud however, Isolation Forests will likely have a very high number of false positives. As a result Isolation Forests are likely a better fit for a multi-model architecture where Isolation Forests can serve as one of the layers within such a model as opposed to as a stand alone system for detecting and preventing fraud.

5.2 Feature Importance and Behavioral Signal Quality

The study will provide the feature importance scores for all the features that have been used for training the Random Forest model. We expect the feature importance scores of the keystroke timing features (inter-key latency std, key hold time for high frequency keys) to be the highest as these

behavioral signals are stable within individuals and therefore easy to model for a Random Forest, but at the same time these signals are relatively variable between individuals which is exactly what a biometric system uses for authentication purposes.

The study found that the set of features that describe the sequence of transactions of a user to follow the typical application flow of an application to be the most important features for the case of account takeover fraud. This is because an attacker typically does not know the application structure for a specific account and thus behaves different from the legitimate account holder in following an unusual sequence of transactions. This is in contrast to the features that describe mouse behavior (i.e., mouse velocity and curvature) which contain meaningful information for fraud detection but have significant within-subject variability. As a result, these features will not be as effective for fraud detection for certain user segments as the typing dynamics features.

5.3 Practical Implications

This research contributes to several practical implications for banks and online payment services. First, it increases the effectiveness of fraud detection while keeping the user experience loss as small as possible by introducing behavioral biometrics into the authentication process. Behavioral biometrics can be used as a continuous online user authentication layer on top of other existing authentication methods, which are used from time to time. Behavioral biometrics are non-intrusive and do not cause any additional friction for legitimate users as it is a passive and transparent process.

The results from the comparative models can also be used to select the best model for a certain bank's or company's ML capability maturity. A simple bank with little to no existing ML implementation and without sufficient resources to implement and fine-tune a complex model, but which is required to provide sufficient interpretability to one or more regulations, after tuning of the parameters, a simple model such as a Logistic Regression or a Random Forest will increase the detection of fraud significantly without incurring additional operational complexity. On the other hand, a bank with a mature ML capability and a large amount of data from various sources that was labeled for fraud by the bank, after fine-tuning of the parameters of the model, a Neural Network can be implemented with additional implementation complexity.

Finally, the high performance of the unsupervised learning method Isolation Forest, a behavioral fraud detection solution, opens up the use of ML-based fraud detection for small credit unions and banks without a large pool of labeled historical fraud data. They can easily implement a Behavioral Fraud Detection solution without the need of a large labeled data set to train the model.

6. CONCLUSION

In this paper we have provided a framework for in-depth research on the topic of Behavioral Biometrics. We have explored how Behavioral Biometrics can be combined with Machine Learning to

aid real time online and mobile account fraud detection within the banking and financial sector. Current systems for online authentication use outdated methods that give little or no value in cases of fraud. A large and increasing gap now exists between the current security methods used by online systems and the ever increasing complexity of online fraud. No single method is likely to fill this gap but passive continuous Behavioral Biometrics can provide a useful signal or fingerprint of the active user of online accounts.

As no single security mechanism can solve all problems, while traditional authentication methods close some of the previously created gaps for sophisticated attacks, Behavioral Biometrics closes other gaps, mainly those created by traditional methods in pre- and post-authentication phases. By providing passive, 24/7, consistent and hard-to-replicate evidence about user behavior, Behavioral Biometrics thereby completes the view provided by traditional authentication mechanisms. Above all, during account takeover and session hijacking attacks, when traditional authentication mechanisms fail, Behavioral Biometrics provides very valuable signals.

In this paper, we present a framework for comparing the use of Behavioral Biometrics and Machine Learning for Fraud Detection in Banking Applications. A number of widely used Machine Learning classifiers have been included in the comparisons: Logistic Regression; Random Forest; Support Vector Machine with Radial Basis Function (RBF) kernel; Artificial Neural Networks (Multi-Layer Perceptron) (MLP); and Isolation Forest. The large differences between these methods for (1) interpretability; (2) accuracy; and (3) number of labeled data points required for training, provide the researcher with a number of test cases, while the practitioner has the advantage of being able to choose the most suitable technique for individual application domains. To increase the validity of any results, the feature set used in this work has been drawn from prior work in the area of Behavioral Biometrics for use in a number of different Banking Applications, and the use of a fixed, but large, number of features, allows for other researchers to use the framework of this work, using a number of different Machine Learning techniques, and/or using the work as a starting point for experiments using a number of different datasets.

This work has several limitations: 1) All experiments in this work have been conducted using a set of benchmark and synthetic datasets, therefore all results that have been obtained in this work are not directly transferable to practice. A re-calibration of all results that have been obtained in this work for the usage in practice is required in order to obtain meaningful results for fraud detection in practice. 2) All feature engineering steps, that have been performed in this work, have been based on the related work and therefore it is not clear if all obtained features in all cases are the most informative for all users and all different types of devices. 3) The static evaluation framework, that has been used in this work, is not able to model the dynamic behavior of real-world fraud in which an attacker adapt and change his strategies over time and gets countermeasures from a defense system over time.

There are several limitations within this paper. The datasets that were utilized for the experiments were benchmark or simulated in nature. In consequence, there may be a transfer problem when attempting to utilize results that have been achieved within experiments upon real-life situations, and it may be the case that 'tuning' of a system would be required in order to achieve optimal results. As previously, within this paper a number of features that are included as part of a process pipeline have been selected on the basis of previous work that has been undertaken by other individuals and organizations. In consequence, it is possible that a number of the features that have been included within the process pipeline of this paper could be ineffective in terms of a number of different scenarios, including scenarios that involve the use of different types of user interactions with a system, and scenarios in which users interact with a system by utilizing different types of devices. Also, the experiments that have been described within this paper have all been of a static nature. In real life scenarios both the attacks that are being launched against a system and a variety of defenses that are deployed in order to attempt to mitigate the effects of the attacks would be dynamic. In consequence, not only would the attacks adapt to a number of different defensive systems that are in place, in order to maximize the amount of damage and effectiveness that is achieved by the attacks, but also that a number of different defenses would be updated in real time, in order to deal with a variety of different types of attacks that have been encountered.

Taking note that in the next decade or so the area of behavioral biometrics for fraud detection in banking is likely to become as standard a component of the security architectures of banks as two-factor authentication is today, it is now important for researchers and practitioners alike to turn to the crucial issue of how to implement these forthcoming authentication methods effectively. This paper is our main contribution to this important end. Our work is currently ongoing. The aim is to evaluate each model and present the results into an article as part of our future studies. This study has been prepared to serve as a roadmap for the research and progression of the thesis.

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THE RELATIONSHIP BETWEEN UNEMPLOYMENT, ECONOMIC GROWTH, R&D, INFLATION, AND FIXED CAPITAL CIRCULATION IN TURKEY: AN ARDL BOUNDS TEST APPROACH (1996-2024)

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ABSTRACT

This study investigates the effects of economic growth, inflation, R&D expenditure, and gross fixed capital formation on unemployment in Turkey over the period 1996–2024 using the ARDL approach. The findings reveal a long-run cointegration relationship among the variables. In the long run, economic growth is found to increase unemployment, while inflation and capital formation reduce unemployment. However, R&D expenditure does not have a statistically significant effect. The error-correction model confirms the system's stability, indicating that approximately 45% of short-run deviations are corrected within one period.

Keywords: *Unemployment, Economic Growth, Inflation, R&D Expenditure, Gross Fixed Capital Formation, ARDL.*

JEL Codes: *E24, O00, O10, O16.*

1. INTRODUCTION

Unemployment is one of the fundamental macroeconomic problems that generates significant economic and social consequences in both developed and developing countries. High unemployment rates hinder the efficient utilization of production capacity and adversely affect income distribution, poverty, social welfare, and economic stability. In developing economies, economic fluctuations, technological transformation, and insufficient investment tend to exacerbate unemployment. The Turkish economy has also long been confronted with high unemployment rates and various macroeconomic vulnerabilities.

In the economics literature, the relationship between unemployment and economic growth is generally examined within the framework of Okun's Law. According to Okun's Law, increases in economic growth expand production capacity, raise labor demand, and contribute to a reduction in unemployment rates. However, particularly in developing economies, economic growth does not always generate sufficient employment, leading to the phenomenon of "jobless growth." In Türkiye, despite

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relatively high growth rates since the 2000s, unemployment has remained at persistently high levels, highlighting the importance of investigating the growth-unemployment nexus.

Inflation is another important macroeconomic variable affecting unemployment. According to the Phillips Curve, there is an inverse relationship between inflation and unemployment in the short run. Given the prolonged periods of high inflation experienced in Türkiye, examining this relationship has become increasingly important. In addition, research and development (R&D) expenditures and gross fixed capital formation are among the key macroeconomic indicators that influence employment by enhancing technological progress, productive capacity, and efficiency.

This study aims to examine the relationships between unemployment, economic growth, inflation, R&D expenditures, and gross fixed capital formation in Türkiye over the period 1996–2024. The Autoregressive Distributed Lag (ARDL) Bounds Testing Approach is employed to identify both short-run and long-run relationships among the variables. The ARDL methodology is preferred because it allows variables integrated at different orders of stationarity and enables the simultaneous estimation of short- and long-term dynamics. In this context, the study seeks to identify the main determinants of unemployment in Türkiye and to provide policy implications based on the empirical findings.

2. LITERATURE REVIEW

The relationships among unemployment, economic growth, inflation, investment, and technological development in the Turkish economy have been extensively examined in the economics literature for many years. Studies conducted within the frameworks of Okun's Law and the Phillips Curve have primarily sought to explain the interaction between unemployment and key macroeconomic variables. In recent years, a growing body of research has also focused on the effects of research and development (R&D) expenditures, technological transformation, and capital investment on unemployment. This section reviews selected national and international studies that are directly related to the subject of this research.

Şentürk and Akbaş (2014) examined the relationship among economic growth, unemployment, and inflation in Türkiye for the period 2005:01–2012:07. The study employed Phillips-Perron (PP), KPSS, and Zivot-Andrews unit root tests, together with the Toda-Yamamoto causality analysis. The empirical findings revealed a bidirectional causality relationship between the industrial production index and the unemployment rate, as well as between the inflation rate and the unemployment rate.

Bayar (2014) analyzed the relationship among unemployment, economic growth, exports, and foreign direct investment (FDI) inflows in Türkiye over the period 2000Q1–2013Q3 using the ARDL Bounds Testing Approach. The findings indicated the existence of a long-run relationship among unemployment, economic growth, exports, and FDI inflows. In addition, the empirical results revealed that unemployment is negatively associated with economic growth and exports, whereas a positive relationship was identified between unemployment and foreign direct investment inflows.

Güven and Uysal (2017) investigated the relationship between inflation and unemployment in Türkiye over the period 1990–2014. Based on the results of the Granger causality test, the authors identified a unidirectional causality running from the unemployment rate to the inflation rate. This finding suggests that changes in unemployment have a statistically significant effect on inflation dynamics in the Turkish economy.

Bölükbaş (2019) examined the relationships among economic growth, unemployment, and inflation at the regional level in Türkiye using annual data for the period 2005–2017. The study employed the panel ARDL model and the Dumitrescu-Hurlin panel causality test. The empirical findings indicated that inflation has a positive and statistically significant effect on economic growth, whereas unemployment exerts a negative and statistically significant impact. In addition, long-run relationships among economic growth, inflation, and unemployment were found to be significant across seventeen different regions. The causality analysis revealed that a causal relationship between economic growth and inflation exists in seven regions, while the causal relationship between economic growth and unemployment was identified in all seventeen regions.

Kopuk (2020) analyzed the effects of inflation and unemployment on economic growth in Türkiye over the period 1988–2019 using the Johansen Cointegration Test. The empirical results indicated that inflation stimulates unemployment and that both inflation and unemployment exert a negative effect on gross domestic product (GDP). The study further concluded that rising inflation and unemployment contribute to economic stagnation and decline in the Turkish economy.

Akusta (2023) investigated the relationship among unemployment, inflation, and economic growth in the Turkish economy for the period 1988–2022 using the ARDL approach. The empirical findings indicated that a 1% increase in economic growth reduces unemployment by approximately 0.7%. In addition, increases in inflation were found to have a decreasing effect on unemployment. These results provide empirical support for the validity of both Okun's Law and the Phillips Curve in the context of Türkiye.

Bakkaloğlu (2024) examined the relationship between inflation and unemployment in Türkiye over the period 2002–2023. The results of the Granger causality analysis revealed a bidirectional interaction between the two variables. The study also demonstrated that unemployment exhibits structural characteristics, particularly during periods of high inflation, suggesting that inflationary pressures and labor market dynamics are closely interconnected in the Turkish economy.

The existing literature indicates that there are significant long-run relationships between unemployment and major macroeconomic variables such as economic growth, inflation, and other structural factors in the Turkish economy. Most studies find that economic growth reduces unemployment, providing empirical support for Okun's Law in the case of Türkiye. Likewise, the relationship between inflation and unemployment has been widely examined, and the findings suggest

that the Phillips Curve remains relevant under certain economic conditions. Recent studies have also emphasized the role of R&D expenditures, technological development, and capital investment in shaping labor market outcomes. Accordingly, unemployment is influenced not only by growth and inflation dynamics but also by investment and innovation processes. By analyzing the period 1996–2024 and jointly examining unemployment, economic growth, inflation, R&D expenditures, and gross fixed capital formation using the ARDL Bounds Testing Approach, this study aims to provide an updated and comprehensive contribution to the literature.

3. DATA SET AND METHODOLOGY

This study analyzes the relationships between unemployment, economic growth, research and development (R&D) expenditures, inflation, and gross fixed capital formation in Türkiye over the period 1996–2024. Annual data are employed in the analysis, and all variables are obtained from the World Bank's World Development Indicators (WDI) database. The variables used in the empirical analysis are presented in the table below.

Table 1. Description of Variables Used in the Analysis

Variables	Abbreviation
Unemployment Rate (Total labor force, modeled ILO estimate, %)	UN
Gross Fixed Capital Formation (% of GDP)	GFCF
Inflation Rate (Consumer prices, annual %)	INF
GDP per Capita (Constant 2015 US$)	LNGDP
Research and Development Expenditure (% of GDP)	RD

In the empirical model, the unemployment rate is included as the dependent variable, while economic growth, inflation, research and development (R&D) expenditures, and gross fixed capital formation are incorporated as independent variables. Economic growth is represented by GDP per capita (constant 2015 US dollars), and inflation is measured by the annual percentage change in consumer prices. R&D expenditures are included as a percentage of gross domestic product (GDP), reflecting the share of innovation-related investments in the economy. Gross fixed capital formation is measured as a percentage of GDP and represents the contribution of fixed investment to productive capacity and economic activity.

To examine the short-run and long-run relationships among the variables, this study employs the Autoregressive Distributed Lag (ARDL) Bounds Testing Approach. Developed by Pesaran, Shin, and Smith (2001), the ARDL methodology is widely preferred because it allows for the inclusion of variables integrated at different orders of stationarity, provided that none of the variables is integrated of order two, and produces reliable results even in small samples. In addition, the ARDL approach enables the simultaneous estimation of both short-run dynamics and long-run coefficients within a single econometric framework.

Prior to applying the ARDL methodology, the stationarity properties of the series were examined using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. A fundamental assumption of the ARDL approach is that none of the variables is integrated of order two, I(2). Following the unit root analysis, the optimal lag lengths were determined based on the Akaike Information Criterion (AIC), and the ARDL Bounds Test was subsequently conducted to assess the existence of a long-run relationship among the variables.

The basic econometric model employed in this study is specified as follows:

$$UNEMP_t=\beta 0+\beta 1GDP_t+\beta 2INF_t+\beta 3RD_t+\beta 4GFCF_t+\varepsilon t \quad (1)$$

When the ARDL Bounds Test indicates the existence of a cointegration relationship among the variables, long-run coefficients are estimated, and short-run dynamics are subsequently analyzed through the Error Correction Model (ECM). In addition, several diagnostic tests, including tests for serial correlation, heteroskedasticity, normality, and model specification error, are conducted to evaluate the validity and reliability of the estimated model. Furthermore, the stability of the model coefficients is examined using the CUSUM and CUSUMSQ tests. Through this methodology, the study aims to identify both the short-run and long-run effects of key macroeconomic variables on the unemployment rate in Türkiye.

4. EMPIRICAL FINDINGS

Before applying the ARDL Bounds Testing Approach, it is necessary to determine the stationarity properties of the variables. For this purpose, the Augmented Dickey-Fuller (ADF) unit root test was employed. Variables that were found to be non-stationary at their levels were retested after taking their first differences.

In the ADF test, the null hypothesis states that the series contains a unit root and is therefore non-stationary. If the test statistic exceeds the critical values in absolute terms and the probability value is less than 0.05, the null hypothesis is rejected, indicating that the series is stationary.

According to the empirical results, all variables used in the study were found to be stationary after taking their first differences. The results of the ADF unit root test are presented in Table 2.

Table 2. Results of the ADF Unit Root Test

Variables	Test Statistic	Probability Value	Result
D(UN)	-4.37928	0.0019	I(1)
D(RD)	-5.43005	0.0001	I(1)
D(LNGDP)	-4.88097	0.0006	I(1)
D(INF)	-4.9939	0.0004	I(1)
D(GFCF)	-5.12221	0.0003	I(1)

The ADF test results indicate that all variables become stationary after taking their first differences at the 1% and 5% significance levels. The probability values for all variables are below 0.05,

confirming the rejection of the null hypothesis of a unit root and indicating that the series are integrated of order one, I(1). These findings demonstrate that none of the variables is integrated of order two, I(2), thereby satisfying the fundamental assumption required for the application of the ARDL Bounds Testing Approach. Accordingly, the analysis proceeds to the ARDL Bounds Test to investigate the existence of a long-run relationship among the variables.

Following the ADF unit root test, the ARDL Bounds Testing Approach was employed to determine the existence of a long-run relationship among the variables. The optimal model specification was selected based on the Akaike Information Criterion (AIC), and the most appropriate model was identified as ARDL(1,1,0,0,0). In the estimated model, the unemployment rate (UN) was used as the dependent variable, while GDP per capita (LNGDP), the inflation rate (INF), gross fixed capital formation (GFCF), and research and development (R&D) expenditures (RD) were included as independent variables. The estimation results of the ARDL model are presented in Table 3.

Table 3. ARDL Model Estimation Results

Variables	Coefficient	t-Statistic	Probability Value
UN(-1)	0.553065	3.728965	0.0012
LNGDP	-22.7469	-1.91533	0.0685
LNGDP(-1)	25.18337	2.191758	0.0393
INF	-0.02983	-3.49391	0.0021
GFCF	-0.18083	-2.22649	0.0365
RD	1.1228	1.416705	0.1706

The ARDL estimation results indicate that the lagged value of the unemployment rate is positive and statistically significant, suggesting that unemployment is influenced by its past values and exhibits persistence over time. The contemporaneous coefficient of GDP per capita (LNGDP) is negative and statistically significant at the 10% level, supporting the unemployment-reducing effect of economic growth and providing evidence consistent with Okun's Law. However, the positive and significant coefficient of the lagged LNGDP variable implies that the impact of economic growth on the labor market may vary over time.

The coefficients of the inflation rate (INF) and gross fixed capital formation (GFCF) are negative and statistically significant. These findings indicate that higher inflation reduces unemployment in the short run, supporting the Phillips Curve hypothesis, while increases in fixed capital investment expand productive capacity and promote employment. Although the coefficient of research and development (R&D) expenditures (RD) is positive, it is not statistically significant, suggesting that R&D expenditures do not exert a direct and significant effect on unemployment during the period under consideration.

The results of the ARDL Bounds Test, conducted to examine the existence of a long-run relationship among the variables, are presented in Table 4.

Table 4. ARDL Bounds Test Results

Test Statistic	**Value**	
F-Statistic	5.633226	
K	4	
Significance Level	**Lower Bound I(0)**	**Upper Bound I(1)**
10%	1.9	3.01
5%	2.26	3.48
1%	3.07	4.44

According to the ARDL Bounds Test results, the calculated F-statistic is 5.633226, which exceeds the upper critical bound values at all conventional significance levels. In particular, at the 5% significance level, the upper bound critical value is 3.48, whereas the computed F-statistic is 5.63. This finding indicates the existence of a cointegration relationship among the variables.

Accordingly, the null hypothesis stating that "there is no long-run relationship among the variables" is rejected. It is therefore concluded that unemployment, economic growth, inflation, gross fixed capital formation, and research and development (R&D) expenditures are linked through a long-run equilibrium relationship. This result suggests that unemployment in Türkiye is significantly influenced by these macroeconomic variables over the long term.

Following the confirmation of cointegration, the analysis proceeds with the estimation of long-run coefficients and the Error Correction Model (ECM) to examine both long-run effects and short-run dynamics.

Following the identification of a cointegration relationship among the variables through the ARDL Bounds Test, the long-run coefficients were estimated. The results of the long-run analysis are presented in Table 5.

Table 5. Long-Run Coefficient Estimation Results

Variables	**Coefficient**	**t-Statistic**	**Probability Value**
LNGDP	5.451468	4.529902	0.0002
INF	-0.06675	-3.93599	0.0007
GFCF	-0.40461	-2.19439	0.0391
RD	2.512224	1.709666	0.1014

According to the long-run coefficient estimates, GDP per capita (LNGDP) is positive and statistically significant. This finding indicates that economic growth increases unemployment in the long run and supports the existence of the "jobless growth" phenomenon in the Turkish economy. The inflation rate (INF) is negative and highly significant, suggesting an inverse relationship between inflation and unemployment over the long term. This result is consistent with the Phillips Curve hypothesis.

The coefficient of gross fixed capital formation (GFCF) is negative and statistically significant, indicating that increases in fixed capital investment reduce the unemployment rate in the long run. In contrast, research and development (R&D) expenditures (RD) have a positive coefficient but are not statistically significant, implying that R&D expenditures do not exert a direct and significant effect on unemployment during the period under consideration.

The error correction term associated with the long-run equilibrium relationship is specified as follows:

$$EC = UN - (5.4515LNGDP - 0.0667INF - 0.4046GFCF + 2.5122RD) \quad (2)$$

Overall, the long-run results indicate that unemployment in Türkiye is significantly influenced by inflation and gross fixed capital formation. In addition, the finding that economic growth increases unemployment rather than reducing it in the long run suggests that the employment-generating capacity of growth is limited, providing evidence in favor of the jobless growth phenomenon in the Turkish economy.

Following the identification of a long-run cointegration relationship through the ARDL Bounds Test, the Error Correction Model (ECM) was estimated to examine short-run dynamics. The ECM is particularly useful in showing the extent to which short-run deviations converge toward the long-run equilibrium and the speed at which this adjustment occurs. The results of the Error Correction Model are presented in Table 6.

Table 6. Error Correction Model (ECM) Results

Variables	Coefficient	t-Statistic	Probability Value
D(LNGDP)	-22.7469	-3.71814	0.0012
CointEq(-1)	-0.44694	-5.76951	0

According to the ECM results, the short-run coefficient of economic growth is negative and statistically significant, indicating that increases in GDP per capita reduce unemployment in the short run. This finding suggests that economic growth has an employment-generating effect in the short term and is consistent with Okun's Law.

One of the most important indicators in the model, the error correction term [CointEq(-1)], is negative and statistically significant. The estimated coefficient of -0.446935 implies that approximately 44% of short-run disequilibria are corrected in the following period. In other words, the speed of adjustment toward the long-run equilibrium is relatively high.

The negative and significant error correction term confirms the stability of the model and provides additional evidence of a long-run relationship among the variables. It also indicates that short-run shocks are temporary and that the system converges back to its long-run equilibrium over time.

Overall, the ECM findings suggest that economic growth reduces unemployment in the short run, whereas its employment-generating capacity appears to be limited in the long run. This result provides further support for the existence of the jobless growth phenomenon in the Turkish economy.

To evaluate the reliability of the estimated ARDL model, diagnostic tests for serial correlation, heteroskedasticity, and normality were conducted. The results are summarized in Table 7.

Table 7. Diagnostic Test Results

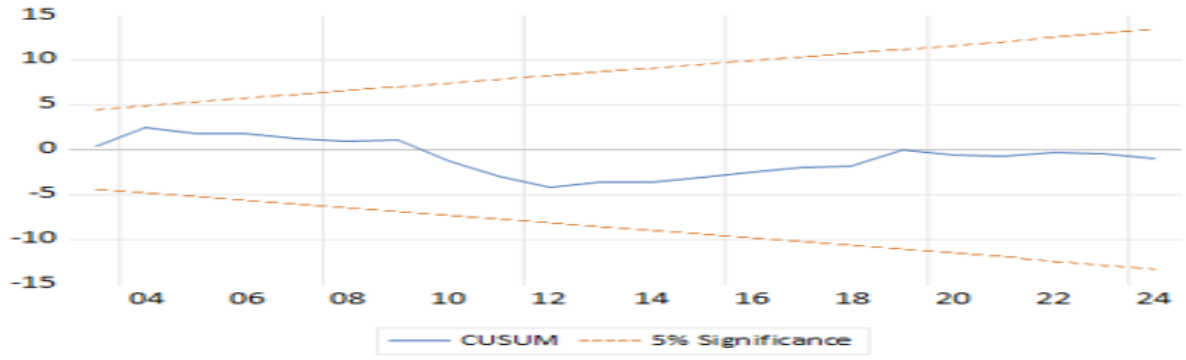
Test	Probability Value	Result
Breusch-Godfrey Serial Correlation LM Test	0.7124	No serial correlation
Breusch-Pagan-Godfrey Heteroskedasticity Test	0.1697	No heteroskedasticity
Jarque-Bera Normality Test	0.7879	Residuals are normally distributed

According to the diagnostic test results, the probability values of the Breusch-Godfrey Serial Correlation LM Test, the Breusch-Pagan-Godfrey Heteroskedasticity Test, and the Jarque-Bera Normality Test are all greater than 0.05. These findings indicate that the model does not suffer from serial correlation or heteroskedasticity problems and that the residuals are normally distributed. Overall, the diagnostic tests confirm that the estimated ARDL model is econometrically robust and produces reliable and stable results.

To examine the parameter stability of the estimated ARDL model, the CUSUM and CUSUM of Squares (CUSUMSQ) tests were employed. These tests are used to determine whether the model coefficients exhibit structural instability over time.

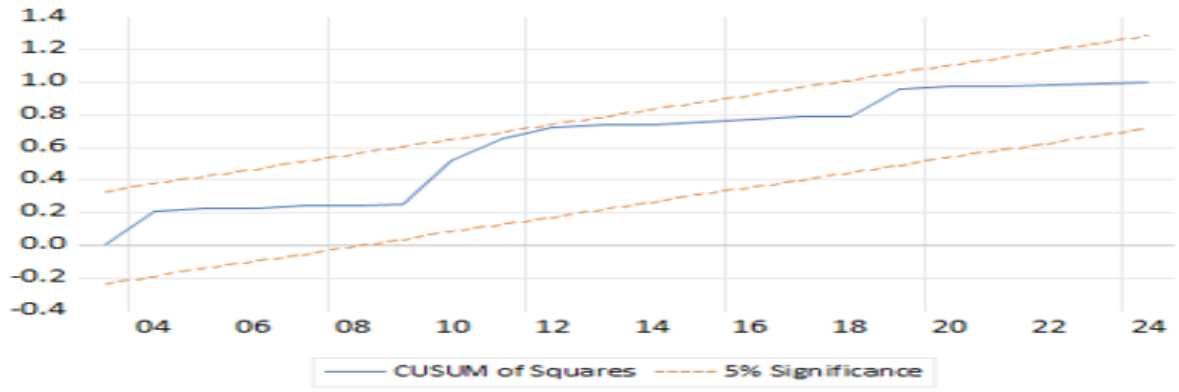
The CUSUM test results indicate that the test statistic remains within the 5% significance boundaries throughout the sample period. This finding suggests that the model coefficients are stable over time and that the estimated ARDL model does not suffer from structural break problems (Table 7).

Table 7. CUSUM Test Result



Similarly, the results of the CUSUMSQ test show that the test statistic remains within the critical boundaries. This finding indicates that the variance of the model is stable over time and provides further evidence supporting the reliability of the estimated coefficients (Table 8).

Table 8. CUSUMSQ Test Result



Taken together, the results of the CUSUM and CUSUMSQ tests indicate that the estimated ARDL model is structurally stable and does not exhibit any significant parameter instability over the sample period. These findings provide additional support for the reliability of both the long-run and short-run coefficient estimates.

5. CONCLUSION

This study examined the relationships between unemployment, economic growth, inflation, research and development (R&D) expenditures, and gross fixed capital formation in Türkiye over the period 1996–2024 by employing the ARDL Bounds Testing Approach. The results of the Augmented Dickey-Fuller (ADF) unit root test indicated that all variables become stationary after first differencing. The ARDL Bounds Test further revealed the existence of a long-run cointegration relationship among the variables.

The long-run coefficient estimates show that inflation and gross fixed capital formation have negative and statistically significant effects on unemployment. These findings suggest that increases in inflation and investment contribute to reducing unemployment. In contrast, GDP per capita, used as a proxy for economic growth, was found to increase unemployment in the long run, supporting the existence of the jobless growth phenomenon in the Turkish economy. Research and development (R&D) expenditures, although positively signed, were not found to have a statistically significant effect on unemployment.

The results of the Error Correction Model (ECM) indicate that economic growth reduces unemployment in the short run. The negative and statistically significant error correction term demonstrates that approximately 44% of short-run disequilibria are corrected within one period, implying a relatively rapid convergence toward long-run equilibrium. Diagnostic tests, together with the CUSUM and CUSUMSQ stability tests, confirm that the estimated model is econometrically robust and structurally stable.

Overall, the findings suggest that economic growth alone is not sufficient to reduce unemployment in Türkiye. Strengthening the employment-generating capacity of growth, increasing fixed capital investments, and improving the investment environment are essential for reducing unemployment. In addition, aligning R&D and innovation policies more closely with labor market needs may contribute to sustainable employment growth in the long run.

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ARTIFICIAL INTELLIGENCE FOR INVESTOR-PROTECTION TREATIES IN ENVIRONMENTAL PROJECTS: THE EAST AFRICA–CHINA RELATIONSHIP

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ABSTRACT

This paper examines the potential role of artificial intelligence (AI) in strengthening investor-protection treaties, with a focus on environmentally sensitive projects in the East Africa–China investment corridor. It situates bilateral and multilateral investment agreements between China and East African states within their legal and economic contexts, tracing their evolution and interaction with sustainable development goals. The study highlights major challenges in infrastructure and natural-resource projects, including environmental degradation, community displacement, and the tension between economic growth and ecological preservation. Particular attention is given to the shortcomings of investor–state dispute settlement (ISDS), criticized for high costs, opacity, and neglect of environmental and social externalities. The paper then explores how AI tools—such as predictive analytics for arbitral outcomes, natural language processing for treaty interpretation, and machine learning for environmental monitoring—can enhance treaty enforcement and dispute resolution. These applications demonstrate AI's potential to improve efficiency, consistency, and accountability in international investment governance. The paper advances recommendations at three levels: normatively, it urges embedding environmental safeguards and sustainability clauses in treaties, drawing from comparative treaty practice and international environmental law; institutionally, it calls for modernization of arbitral institutions to integrate AI-driven case management and evidence review while ensuring procedural fairness; and technically, it proposes deploying AI-powered monitoring systems for real-time environmental assessment, enabling proactive risk mitigation by host states and investors. Drawing on interdisciplinary sources—legal scholarship, empirical studies, and contemporary research on AI in arbitration—the paper contributes to debates on reconciling investment protection with environmental sustainability in an era of global infrastructure expansion.

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ÇEVRESEL PROJELERDE YATIRIMCI KORUMA ANLAŞMALARI İÇİN YAPAY ZEKÂ: DOĞU AFRİKA–ÇİN İLİŞKİSİ

ÖZET

Bu çalışma, çevresel açıdan hassas projelerde yatırımcı koruma anlaşmalarının güçlendirilmesinde yapay zekânın (YZ) potansiyel rolünü incelemekte ve özellikle Doğu Afrika–Çin yatırım koridoruna odaklanmaktadır. Çalışma, Çin ile Doğu Afrika devletleri arasındaki ikili ve çok taraflı yatırım anlaşmalarını hukuki ve ekonomik bağlamları içerisinde ele almakta; bu anlaşmaların evrimini ve sürdürülebilir kalkınma hedefleriyle olan etkileşimini analiz etmektedir. Araştırma, altyapı ve doğal kaynak projelerinde ortaya çıkan çevresel tahribat, toplulukların yerinden edilmesi ve ekonomik büyüme ile ekolojik koruma arasındaki gerilim gibi temel sorunları vurgulamaktadır. Özellikle, yüksek maliyetleri, şeffaflıktan uzak yapısı ve çevresel ile sosyal dışsallıkları ihmal etmesi nedeniyle eleştirilen yatırımcı-devlet uyuşmazlık çözüm mekanizmasının (ISDS) eksikliklerine dikkat çekilmektedir. Çalışma daha sonra, tahkim sonuçlarına yönelik öngörüsel analizler, anlaşma yorumlamasında doğal dil işleme teknikleri ve çevresel izleme için makine öğrenmesi gibi yapay zekâ araçlarının anlaşmaların uygulanmasını ve uyuşmazlık çözüm süreçlerini nasıl geliştirebileceğini incelemektedir. Bu uygulamalar, yapay zekânın uluslararası yatırım yönetişiminde etkinlik, tutarlılık ve hesap verebilirliği artırma potansiyelini ortaya koymaktadır. Çalışma üç düzeyde öneriler sunmaktadır. Normatif düzeyde, karşılaştırmalı anlaşma uygulamaları ve uluslararası çevre hukukundan yararlanılarak anlaşmalara çevresel koruma önlemleri ile sürdürülebilirlik hükümlerinin entegre edilmesi gerektiği savunulmaktadır. Kurumsal düzeyde, usuli adaletin korunması şartıyla, tahkim kurumlarının yapay zekâ destekli dava yönetimi ve delil inceleme sistemlerini entegre edecek şekilde modernize edilmesi gerektiği ifade edilmektedir. Teknik düzeyde ise, ev sahibi devletler ve yatırımcılar için proaktif risk azaltımını mümkün kılacak gerçek zamanlı çevresel değerlendirme sağlayan yapay zekâ tabanlı izleme sistemlerinin kullanılması önerilmektedir. Hukuk literatürü, ampirik çalışmalar ve tahkim süreçlerinde yapay zekâ kullanımına ilişkin güncel araştırmalardan yararlanan bu çalışma, küresel altyapı yatırımlarının genişlediği bir dönemde yatırım koruması ile çevresel sürdürülebilirliğin nasıl uzlaştırılabileceğine dair tartışmalara katkı sunmaktadır.

***Anahtar Kelimeler:** Çin-Afrika Ticareti, Yapay Zekâ, Yatırımcı Koruması, Çevresel Projeler.*

***JEL Kodları:** K39, O34, I18.*

1. INTRODUCTION

China's outward FDI into East Africa has in recent decades shifted from purely commercial or resource-extractive ventures to large-scale infrastructure projects — transport corridors, ports, hydropower plants, and mines — that are frequently implemented under state-to-state frameworks, Chinese export-credit and contracting entities, and a patchwork of bilateral investment treaties (BITs) and project contracts containing investor-state dispute settlement (ISDS) clauses (Cheung et al., 2012). Empirical surveys and treaty inventories show that China has systematically pursued BITs across many African jurisdictions and that Chinese firms and banks now finance and build major corridors and ports across the region; these arrangements combine commercial contracts, sovereign guarantees, and treaty protections in a way that amplifies both the opportunities and the governance challenges for host states. The environmental stakes of this rapid external investment are high and multifaceted. Significant infrastructure and extractive projects generate risks to biodiversity, water regimes, air quality, and vulnerable local livelihoods, and they frequently traverse regulatory gaps in host states where environmental impact assessments, enforcement capacity, or public participation mechanisms are incomplete (Calabrese et al., 2017). At the same time, ISDS regimes historically developed to protect foreign capital can create regulatory tensions: host states must fulfil duties to preserve environmental integrity, advance sustainable development objectives and uphold constitutional or statutory environmental safeguards, while investors rely on treaty standards — fair and equitable treatment, protection against uncompensated expropriation, and free transfer of funds — to guard against abrupt policy reversals. Independent observers and intergovernmental bodies have documented that a sizable minority of treaty-based ISDS claims implicate environmental regulation or climate-relevant measures, underscoring how frequently these legal domains collide (W. Chen et al., 2018). From a doctrinal perspective, integrating AI into regimes that govern environmentally-sensitive investment raises three discrete legal concerns that must be reconciled: (1) preserving procedural due process and the adversarial integrity of dispute resolution; (2) protecting host-state regulatory sovereignty and legitimate public policy space to adopt precautionary environmental measures; and (3) ensuring that AI-enabled functions (e.g., evidence triage, predictive analytics, automated drafting) do not cement bias or opacity into decision-making. International investment law already navigates competing policy objectives — investor protection, regulatory autonomy, sustainable development — by means of treaty language (e.g., non-precluded measures, exceptions clauses), arbitral doctrine (margin of appreciation, necessity, proportionality), and substantive standards (definitions of expropriation, legitimate expectations). Any AI integration must therefore be calibrated against these settled legal touchstones and the growing corpus of scholarship and policy recommendations that assess ISDS's interaction with environmental objectives (Ross, 2015).

Technologically, AI can be deployed at multiple points in the lifecycle of investment governance with concrete legal benefits if appropriately constrained. In treaty drafting and negotiation, natural-language models and corpus analytics can help parties identify ambiguous treaty formulations that have

produced litigation (for example, by mapping prior arbitral interpretations of "fair and equitable treatment" or "indirect expropriation"), enabling drafters to draft narrower, context-sensitive protections or to insert clear environmental non-preclusion clauses and carve-outs (Beraja et al., 2024). In project oversight, remote-sensing, machine-learning classification of satellite imagery, and automated red-flagging systems can strengthen environmental monitoring and compliance with contractual environmental and social safeguards. In dispute avoidance and early case management, algorithmic triage tools can quickly screen claims against treaty language and past awards to identify low-merit claims and to prioritize mediation or technical remediation, potentially reducing costly full-scale arbitration (Drogendijk & Blomkvist, 2013). Finally, AI can materially increase efficiency and reduce costs in the procedural steps of ISDS (Katterbauer, Syed, et al., 2024). However, use of AI in these contexts implicates interpretive risk (over-reliance on pattern recognition rather than legal reasoning), evidentiary challenges (authenticity, provenance of algorithmic outputs), and fairness concerns (unequal access to expensive AI tools by different parties). The recent professional and academic literature sketches these prospective gains and the attendant pitfalls. The governing architecture should combine doctrinal, procedural, and technological safeguards to integrate AI responsibly without undermining due process, sovereignty, or environmental safeguards (Vijayakumar, 2021). At the doctrinal level, treaties and project contracts can be amended (or newly drafted) to: (a) codify environmental exceptions and non-preclusion clauses that make explicit the states' right to adopt bona fide environment-protective measures (including precautionary measures when scientific certainty is incomplete); (b) specify interpretive principles that give deference to legitimate regulatory acts taken in good faith for environmental protection; and (c) mandate transparency obligations for arbitral proceedings dealing with significant public interest concerns. At the procedural level, institutions and arbitral rules should require: (i) disclosure when AI tools have materially assisted a party or tribunal in legal research, fact-finding, or drafting; (ii) admissibility standards for algorithmic evidence and source-code testimony where an AI output is central to a claim or defense; and (iii) a right to independent technical review where an AI model produces contested factual inferences (for example, about environmental harm detected by remote sensing). At the technological governance level, parties and institutions should adopt data governance standards (provenance, explainability, reproducibility), model validation, and human-in-the-loop decision requirements that preserve judicial and arbitral responsibility for outcomes (Cheung & Qian, 2009). These multi-layered reforms mirror recommendations emerging from arbitral practitioners, think-tanks, and legal institutes that argue for regulating AI use in arbitration rather than unregulated adoption. A more concrete operational model would couple preventive compliance with dispute-resolution safeguards: data-driven environmental monitoring (satellite + in situ sensors) could feed neutral third-party registries that log compliance and incident reports in an auditable chain; treaty or contract clauses could make registration and technical remediation a precondition to ISDS, thereby incentivizing early remediation and creating a record that an arbiter can consult; further, AI-assisted triage could be limited to non-determinative functions (e.g., case-management prioritization or red-

flagging), with any recommendation subject to human review and a public explanation. In parallel, capacity building in East African host states is essential so regulators and courts can interrogate and, if necessary, rebut AI outputs — otherwise, algorithmic opacity will simply entrench informational asymmetries in favor of well-financed investors. Institutions such as UNCTAD, regional bodies, and civil society have repeatedly emphasized that equitable investment protection and environmental governance integration requires both rule design and capacity development (Song, 2011).

Finally, normative trade-offs should be recognized candidly. Any AI-driven efficiency gains cannot substitute for robust legal protections: due process must include meaningful access to explanation and contestability of algorithmically generated evidence; sovereignty must be preserved by explicitly reserving policy space in treaties and by constraining arbitration to avoid overbroad applications of investor-protection norms against bona fide environmental regulation; and environmental safeguards require that precautionary and participatory principles remain central to project decision-making rather than being sidelined by a narrow focus on investment predictability. Where disputes nonetheless arise, hybrid remedies (technical remediation, graduated compliance plans, or multi-stakeholder compliance panels) — enabled, but not dictated, by AI analytics — may better reconcile the competing public and private interests (Perals et al., 2025). The literature and recent policy initiatives converge on the view that AI should be used as a governance aide rather than a substitute for legal judgment; institutionalizing that view through treaty language, arbitral rules, and technical standards will be the decisive next step.

2. THE EAST AFRICA–CHINA INVESTMENT AND TREATY CONTEXT

China's investment trajectory in East Africa has been shaped by a strategic combination of state-driven initiatives, private enterprise expansion, and multilateral economic frameworks, most notably the Belt and Road Initiative (BRI). Since its formal launch in 2013, the BRI has been a cornerstone of China's foreign economic policy. East Africa is a focal region due to its geostrategic position along the maritime route (King, 2020). The investment profile in this region is dominated by large-scale infrastructure projects such as the Standard Gauge Railway in Kenya and significant port developments in Tanzania, as well as energy projects encompassing hydropower dams, thermal plants, and renewable energy facilities. These sectors—transport, energy, and extractives—are widely recognized as high-impact domains with significant implications for environmental governance, biodiversity, and community livelihoods (L. Trakman, 2022). Recent scholarship underscores a dual narrative in China–Africa investment relations: on one hand, the expansion of bilateral investment treaties (BITs) and the institutionalization of investor protection mechanisms; on the other hand, critical concerns regarding the capacity of these instruments to adequately integrate environmental safeguards and public policy objectives (S. Chen et al., 2019). While Chinese foreign direct investment (FDI) is often portrayed as offering developmental gains through infrastructure financing, questions persist regarding its alignment with the principles of sustainable development as articulated in international law, including the 2030

Agenda and the African Union's Agenda 2063 (Y. Chen et al., 2019). Moreover, the predominance of state-owned enterprises (SOEs) in large-scale projects introduces a complex interplay of public international law, sovereign immunity considerations, and accountability mechanisms under investor–state dispute settlement (ISDS) systems. The Forum on China–Africa Cooperation (FOCAC) has consistently emphasized "green development" and environmental cooperation in its declarations, particularly since the Johannesburg Action Plan (2016–2018) and the Beijing Action Plan (2019–2021). However, operationalizing these commitments within legally binding treaty frameworks remains uneven and largely aspirational (King, 2020). This gap between policy rhetoric and treaty practice heightens the importance of scrutinizing the treaty landscape governing China–East Africa investment relations, especially in light of emerging arbitral disputes and the evolving jurisprudence on environmental regulation in the context of foreign investment (Van Staden et al., 2018).

The bilateral investment treaty network between China and East African states reflects a temporal and substantive diversity that mirrors the broader evolution of China's international investment policy. Early-generation treaties, primarily concluded in the 1980s and 1990s, exhibit a traditional focus on investor protection, emphasizing guarantees such as fair and equitable treatment (FET), national treatment, and protection against expropriation, while omitting explicit provisions on environmental protection or sustainable development (Weinhardt et al., 2022). In contrast, more recent instruments, particularly those negotiated in the post-2010 period, have introduced limited references to environmental cooperation and sustainable development principles, signaling a gradual normative shift influenced by global trends in international investment law and China's own "Green BRI" commitments (Li et al., 2021). Nevertheless, these provisions are often couched in broadly aspirational language and lack operational clauses that would create enforceable obligations or carve-outs safeguarding regulatory space for environmental measures (Komakech & Ombati, 2023). For instance, many treaties do not incorporate general exceptions analogous to Paper XX of the General Agreement on Tariffs and Trade (GATT) or clauses explicitly affirming the host state's right to regulate for the protection of the environment and public health (Loh, 2021). This omission is legally significant because, without such safeguards, regulatory measures adopted to mitigate the environmental externalities of investment projects may be challenged as indirect expropriation or as violations of FET standards in ISDS proceedings (Duo, 2022). The resulting legal uncertainty has been highlighted in arbitral jurisprudence, where tribunals have grappled with the tension between investor rights and environmental regulation. Although no high-profile ISDS cases involving China–East Africa disputes have yet set definitive precedent, analogous cases under other BITs—such as Methanex v. United States and Urbaser v. Argentina—illustrate how environmental obligations are increasingly being weighed against investment protections (Schill, 2019). These developments underscore the need for African states and China to recalibrate their treaty models to incorporate clearer environmental carve-outs, preambular references to sustainable development objectives, and, potentially, binding corporate social responsibility (CSR)

obligations. Such reforms would align the treaties with international environmental law principles, including the precautionary and polluter-pays principles, and mitigate the risk of regulatory chill in host states facing ecological and climate-related vulnerabilities (Katterbauer, 2020).

3. ENVIRONMENTAL RISKS AND DISPUTE DYNAMICS IN EAST AFRICAN PROJECTS

Significant infrastructure and resource-based projects in East Africa often entail profound and multi-layered environmental risks, ranging from ecosystem degradation to significant biodiversity loss, reallocation of water resources, and, in some instances, transboundary environmental impacts. These risks are exacerbated by the scale and intensity of projects such as hydropower dams, oil and gas pipelines, and large-scale mining operations, which frequently intersect with ecologically sensitive areas and communities dependent on natural resources for their livelihoods (Okoth-Ogendo, 2002). Economic development imperatives and environmental sustainability remain a central tension in international and regional environmental governance, particularly in developing economies striving for rapid industrialization under frameworks such as the African Union's Agenda 2063 (Klein, 2022). Consequently, the regulatory approaches to mitigating these environmental risks vary significantly across East African jurisdictions, with some states exhibiting robust legislative frameworks but weak enforcement capacity. In contrast, others lack comprehensive environmental assessment mechanisms (Mwangi, 2015).

When host states introduce, strengthen, or enforce environmental measures—such as imposing stricter Environmental Impact Assessment (EIA) requirements, revoking previously issued permits, or instituting moratoria on specific activities—such regulatory actions often trigger disputes with foreign investors. Investors commonly argue that these state measures amount to violations of protections enshrined in Bilateral Investment Treaties (BITs) or investment chapters of regional trade agreements, invoking standards such as expropriation (both direct and indirect), non-discrimination, or the guarantee of Fair and Equitable Treatment (FET) (Kriebaum et al., 2022). For instance, measures taken to comply with the Convention on Biological Diversity (CBD) or obligations under the Paris Agreement may be construed by investors as tantamount to indirect expropriation when they significantly impair investment value without adequate compensation (Dolzer, 1997). Investor-State Dispute Settlement (ISDS) tribunals have grappled with these issues in cases such as Burlington Resources v. Ecuador and Metalclad v. Mexico, where the scope of legitimate environmental regulation versus unlawful expropriation was sharply contested (Parra, 2012). These legal disputes are notoriously complex, both factually and technically, requiring extensive evidentiary records, expert testimony on environmental science, and nuanced interpretation of treaty language in light of evolving international environmental norms (L. E. Trakman, 2013). Given the multiplicity of overlapping economic, environmental, and social interests, the adjudication of these claims involves substantial procedural and substantive challenges. They are inherently resource-intensive and demand sophisticated legal and scientific

expertise, leading to protracted proceedings that impose high transaction costs on states and investors (Plank et al., 2021). In this context, integrating Artificial Intelligence (AI)-assisted tools into dispute resolution processes is emerging as a promising innovation. AI-driven systems can assist in tasks such as reviewing voluminous documentary evidence, identifying relevant precedent across thousands of arbitral awards, and modeling risk scenarios for potential regulatory measures, enhancing efficiency and consistency in decision-making. Moreover, predictive analytics and Natural Language Processing (NLP) algorithms can support arbitral tribunals and counsel by detecting patterns in previous ISDS cases involving environmental regulation, which may inform arguments on the proportionality and reasonableness of state measures under the police powers doctrine (Aisbett et al., 2024). The potential application of these technologies underscores the broader trend toward digital transformation in international arbitration, as reflected in initiatives such as the ICCA-NYC Bar-CPR Protocol on Cybersecurity and the ICC Commission's report on AI in arbitration (Poulsen & Aisbett, 2013).

4. HOW AI IS ALREADY USED IN ISDS AND LEGAL PRACTICE

Recent scholarship and professional commentary have extensively documented the integration of artificial intelligence (AI) technologies into various facets of legal practice. Broadly, these developments can be categorized into four principal functional domains: document review and e-discovery, legal research and predictive analytics, contract drafting and standardization, and case management and triage. In litigation and arbitration, document review and e-discovery have been among the earliest areas to witness automation, mainly due to these tasks' repetitive and data-intensive nature. AI-powered tools, leveraging machine learning and natural language processing, are now routinely deployed to sift through voluminous datasets, enabling the identification of relevant materials with a speed and precision far exceeding traditional manual methods (Remus & Levy, 2017). These technological interventions align with judicial recognition of proportionality in discovery obligations under procedural frameworks such as the Federal Rules of Civil Procedure in the United States (Rule 26(b)(1)) and equivalent provisions in other jurisdictions, which underscore the importance of efficiency and cost-effectiveness in disclosure processes. Within arbitration practice specifically, the application of AI extends beyond document management to encompass more complex analytical tasks (Rostain, 2017). Advanced AI systems are increasingly employed to process extensive documentary records, identify correlations across past arbitral awards, and assist counsel in shaping procedural strategies. Drawing on historical datasets, predictive analytics offers insights into the potential tendencies of arbitral tribunals, enabling counsel to make data-driven decisions regarding case framing and settlement prospects (Moses, 2024). However, these benefits are accompanied by significant jurisprudential and ethical concerns. Key among these are bias and discrimination, given the propensity of AI models to replicate and amplify historical inequities in training datasets, and transparency and explainability, particularly where algorithmic outputs influence strategic or adjudicatory determinations. These issues intersect with foundational principles of due process and rule-of-law guarantees, enshrined in instruments such as Paper V of the New York

Convention on the Recognition and Enforcement of Foreign Arbitral Awards (1958), which mandates procedural fairness as a precondition for enforcement. The opacity of specific machine learning models—often referred to as the "black box" problem—raises questions about the ability of parties to contest or scrutinize algorithmically influenced decisions, potentially implicating fair hearing rights under national arbitration statutes and international conventions. Empirical research examining practitioner attitudes toward AI adoption in arbitration reveals a nuanced perspective. Surveys conducted by institutions such as the International Council for Commercial Arbitration (ICCA) and the Silicon Valley Arbitration & Mediation Center (SVAMC) indicate a strong expectation that AI will be widely deployed in support functions, particularly legal research, data analytics, and document review, within the near term (Florescu, 2024). Practitioners recognize the potential of AI to enhance efficiency, reduce costs, and improve accuracy in these areas, thereby facilitating the expeditious resolution of disputes consistent with the objectives articulated in leading arbitral rules, including Paper 17(1) of the UNCITRAL Model Law on International Commercial Arbitration, which obliges tribunals to conduct proceedings "without unnecessary delay or expense." However, the same empirical data suggests a marked reluctance to embrace fully automated decision-making in arbitration. This resistance reflects normative concerns—such as the non-delegability of adjudicatory authority under lex arbitri—and practical apprehensions regarding accountability, appealability, and compliance with fundamental principles of adjudication. In this respect, the prevailing view appears to endorse a human-in-the-loop model, wherein AI operates as an assistive tool rather than a substitute for human judgment, aligning with emerging policy frameworks such as the European Commission's Artificial Intelligence Act, which advocates for risk-based regulation and emphasizes human oversight in high-stakes decision-making contexts (Bodansky, 2016).

5. MODES BY WHICH AI CAN STRENGTHEN INVESTOR-PROTECTION REGIMES FOR ENVIRONMENTAL PROJECTS

Artificial intelligence (AI) offers innovative tools that can enhance investor-protection frameworks while reinforcing environmental protection objectives. These applications can operate within ex-ante treaty design and ex-post regulatory compliance, providing policymakers, regulators, investors, and arbitral tribunals with analytical insights that improve transparency, predictability, and risk management. AI must be integrated with due process safeguards, as algorithmic recommendations cannot substitute for the expert judgment of legal and technical authorities. Below, we explore several ways AI can contribute to more robust investor-protection regimes for environmental projects. One of the most promising applications of AI lies in the drafting and negotiating international investment agreements (IIAs) and bilateral investment treaties (BITs). Machine learning algorithms can scan extensive corpora of treaty texts, arbitral awards, national environmental laws, and model clauses to propose language that balances investor protection with regulatory autonomy. For instance, AI can

identify trends in including environmental exceptions, non-preclusion clauses, or public-interest carve-outs that have mitigated the incidence of investor-state disputes (Baumann, 2024).

Advanced predictive models can simulate potential dispute scenarios under alternative formulations, estimating the frequency of claims and their likely outcomes based on historical arbitration data. This ex-ante risk modelling assists states in crafting treaty provisions that reduce regulatory chill while maintaining investor confidence. From a legal perspective, AI supports the alignment of treaty language with principles of customary international law, including the fair and equitable treatment (FET) standard, and ensures consistency with environmental obligations under multilateral treaties such as the Paris Agreement. Notably, the accuracy of these outputs depends on the quality and representativeness of training data; therefore, human legal expertise remains indispensable to interpret and validate AI-generated recommendations (Bodansky, 2016). AI-powered monitoring tools can significantly enhance environmental compliance oversight. By integrating satellite imagery, remote-sensing data, and ground-based sensor networks, regulators can achieve near real-time surveillance of project activities, including deforestation, pollution plumes, and reservoir impacts. Machine learning algorithms can detect anomalies, flagging potential violations for immediate investigation. Such systems are particularly valuable for cross-border infrastructure projects—such as hydroelectric dams on shared rivers—where information asymmetries can exacerbate disputes between host states and investors. AI-driven dashboards can provide joint situational awareness, facilitating coordinated responses and preventing disputes from escalating into formal arbitration. Legally, these applications support host states' obligations under both domestic environmental legislation and international environmental law, including transboundary impact assessment requirements under the Espoo Convention and related jurisprudence (Koivurova, 2007). Using AI in this context thus strengthens compliance without undermining investor protection, as timely alerts reduce the likelihood of unexpected regulatory interventions. AI systems can also play a transformative role in the early stages of investor-state conflict by performing pre-dispute triage. Algorithms can evaluate claims' strength, complexity, and potential costs, proposing appropriate dispute-resolution pathways—ranging from negotiation and mediation to expert determination or arbitration. Automated platforms can structure dialogue, manage documentation, and even suggest settlement ranges based on analyses of comparable cases. Such tools encourage efficient resolution through ADR, potentially reducing reliance on costly, time-intensive arbitration procedures. From a legal standpoint, AI-enabled triage must respect procedural fairness and confidentiality standards, ensuring investors and host states retain agency in the dispute-resolution process. In effect, AI functions as a decision-support mechanism that optimizes dispute management while preserving the integrity of legal processes (Marsden, 2011).

The increasing technical complexity of environmental disputes often results in voluminous documentation and data-intensive evidence. AI can accelerate the review of documents, extract technical findings, summarize expert reports, and map causal chains—for example, linking regulatory permit

changes to environmental monitoring data (Katterbauer, 2024). By reducing the time and cost of evidence processing, AI enhances efficiency for investors and host states, while supporting tribunals in reaching well-informed decisions. However, reliance on AI must be carefully circumscribed. Transparency and interpretability are essential, and human experts should validate AI-generated analyses to ensure that arbitral tribunals maintain ultimate evaluative responsibility (Azam et al., 2025). Legal frameworks, such as the UNCITRAL Rules on Transparency in Treaty-based Investor-State Arbitration, emphasize that procedural fairness and due process are paramount; AI tools must be used in ways that reinforce, rather than compromise, these principles. Finally, AI predictive models can improve the pricing of environmental and regulatory risks in investment projects, which has significant implications for insurers and financiers. By simulating a range of scenarios—including regulatory interventions, natural disasters, and environmental compliance breaches—AI enables more precise risk assessment. Accurate pricing reduces moral hazard, incentivizes adherence to environmental best practices, and encourages investment in sustainable projects. Transparent modeling assumptions and rigorous stress testing are essential to prevent mispricing and systemic risk exposure. From a legal perspective, predictive analytics must align with regulatory frameworks governing financial disclosures and insurance underwriting, including international standards on environmental, social, and governance (ESG) risk reporting (Amplyfi). Integrating AI in this manner reinforces investor protection while promoting sustainable development outcomes (Shami et al., 2025).

6. LEGAL, ETHICAL, AND GOVERNANCE CHALLENGES

Integrating artificial intelligence (AI) into adjudicative or quasi-adjudicative processes—such as investment arbitration or administrative dispute resolution—raises significant concerns under the principle of due process. Central to these concerns are explainability, transparency, and procedural fairness issues. The right of parties to understand and, if necessary, challenge the reasoning underlying a decision is a fundamental tenet of both domestic legal systems and international adjudication (UN Basic Principles on the Independence of the Judiciary, 1985). When AI systems generate inferences or recommend determinations, their reliance on complex algorithms and opaque datasets can render such reasoning non-reproducible and difficult to interrogate(Wischmeyer, 2020). Due process requires that decisions be reasoned and that the evidence and methods underlying such reasoning are accessible for scrutiny (Paper 6, European Convention on Human Rights; ICSID Arbitration Rules, Rule 19). In AI-assisted adjudication, this raises critical questions: Should tribunals disclose AI tools' algorithmic logic, training datasets, and accuracy metrics (Schäferling, 2023)? If not, does this create an imbalance that undermines the legitimacy of the process? The skepticism among legal practitioners stems from the fear that outsourcing substantive legal reasoning to AI could erode the deliberative nature of adjudication, which traditionally entails interpretative judgment grounded in legal principles rather than predictive analytics (Katz et al., 2017).

Several arbitral institutions and practitioner bodies have begun to issue guidance addressing these concerns. For instance, recent practitioner commentaries suggest that AI tools may be used for document review or predictive coding but caution against their deployment in rendering determinations without human oversight. These reports emphasize that while AI can enhance efficiency, the adjudicatory responsibility of tribunals remains non-delegable. Parties must retain the right to contest AI-generated evidence that aligns with procedural guarantees under instruments such as the UNCITRAL Model Law and general principles of natural justice. AI systems are only as reliable as the data on which they are trained. Data quality and representativeness are particularly salient in international arbitration and investment disputes because historical datasets may reflect entrenched biases or omit region-specific realities (Barfield & Pagallo, 2018). Empirical studies demonstrate that algorithmic models trained on Euro-American legal precedents may systematically undervalue environmental or socio-economic considerations relevant to African jurisdictions.

East African governments, in particular, encounter structural challenges such as data scarcity, limited technical capacity, and inadequate institutional infrastructure for validating algorithmic outputs(Giroud & Ivarsson, 2020). These limitations risk creating capacity asymmetries that favor well-resourced investors capable of deploying advanced legal analytics, reinforcing existing inequalities in investor–state dispute settlement (ISDS). This asymmetry undermines the principle of equality of arms and could deter states from fully exercising their regulatory autonomy in sectors like environmental protection or climate adaptation. To mitigate these risks, scholars and policymakers advocate for capacity-building programs, mandatory disclosure of algorithmic methodologies, and transparent data-sharing protocols that allow host states to access and verify AI-generated insights (L. E. Trakman, 2013). Absent such measures, reliance on opaque AI tools may compromise procedural fairness and arbitral awards' perceived legitimacy. Confidentiality is a cornerstone of investment arbitration, enshrined in many bilateral investment treaties (BITs) and institutional rules (e.g., ICSID Convention, Paper 48; ICC Arbitration Rules, Paper 22). However, environmental disputes introduce a competing imperative: transparency in matters of public interest, particularly where disputes implicate climate commitments or natural resource management. This tension is amplified by the deployment of AI systems, which often rely on cross-border data transfers and access to large-scale datasets stored in cloud environments controlled by private vendors.

From a legal perspective, these developments implicate state sovereignty and data protection frameworks. Sovereignty concerns arise when sensitive economic or environmental data leaves the host state's jurisdiction, potentially violating domestic laws on national security or strategic resource governance (Masons, 2023). Additionally, privacy regulations such as the General Data Protection Regulation (GDPR) in the European Union, and emerging African data protection statutes (e.g., Kenya's Data Protection Act, 2019), impose strict conditions on data processing and international transfers. To reconcile these competing interests, treaty design and institutional rule-making must evolve to

incorporate AI-specific governance clauses that balance investor confidentiality with environmental transparency and public accountability imperatives. Proposals include hybrid confidentiality regimes, third-party audits of AI systems to ensure compliance with data sovereignty norms, and the development of secure multi-party computation techniques that allow data analysis without compromising control (Yeung, 2020). Absent such innovations, the promise of AI-driven efficiency may come at the expense of both public trust and state prerogatives in environmental governance.

7. POLICY AND TREATY DESIGN RECOMMENDATIONS

Drawing on the empirical findings and doctrinal scholarship in international investment law, environmental law, and emerging digital governance frameworks, this section proposes a comprehensive package of legal and policy measures designed to responsibly incorporate artificial intelligence (AI) into investor-protection regimes for environmental projects between China and East African states. These recommendations address the dual imperative of safeguarding regulatory autonomy for environmental protection while ensuring predictability and fairness in foreign investment relations. Modern bilateral investment treaties (BITs) and related international investment agreements should incorporate express environmental-protection clauses and adopt balancing tests to harmonize investor rights with host-state environmental obligations. This approach is consistent with the trend identified in recent treaty practice, such as the inclusion of general exceptions and sustainable development clauses in agreements modeled after the Comprehensive Economic and Trade Agreement (CETA) and the EU's new generation of BITs. Explicit non-preclusion clauses should confirm that states retain the regulatory space to enact bona fide environmental measures, even if such measures adversely affect investor expectations, thereby reducing the risk of regulatory chill. AI-assisted clause drafting tools could enhance treaty precision by enabling comparative text analysis and predictive modeling to calibrate language that balances investor confidence with environmental imperatives (Cristani, 2021).

To address the operational realities of AI deployment in environmental projects, treaties and project-level contracts should include dedicated annexes that specify permissible AI applications, data-sharing obligations, ownership regimes, and confidentiality restrictions. These annexes should also set out algorithmic transparency standards, requiring disclosure of model architecture and explainability metrics for systems used in environmental impact assessments or compliance verification (see EU AI Act Proposal, COM(2021) 206 final). Provisions for audit rights and algorithmic accountability are essential to ensure that AI systems do not create new asymmetries of information between investors and host states. Similar approaches have been observed in the OECD's Guidelines on Artificial Intelligence (2019) and are increasingly advocated in arbitral scholarship (Hill-Cawthorne, 2021). Investment treaties should require multi-tiered dispute resolution mechanisms where negotiation, mediation, or independent expert determination constitutes a mandatory precondition to investor-state arbitration. This approach aligns with the 2019 ICSID Mediation Rules and reflects the policy objective of early dispute

settlement to preserve cooperative relationships. AI-powered case triage and digital ADR platforms could enhance settlement rates by providing predictive analytics on likely outcomes and clustering disputes based on factual similarities, thereby reducing costs and delays. Such procedural innovations should be framed within due process safeguards, ensuring that automated recommendations remain advisory and non-binding unless expressly accepted by the parties. The creation of co-funded environmental monitoring platforms that integrate satellite imagery, IoT sensors, and AI analytics would enable real-time environmental compliance tracking, promote transparency, and reduce information asymmetries that often complicate investor-state disputes. These platforms could operate under a joint governance framework involving both home and host states, consistent with principles of cooperative federalism embedded in multilateral environmental agreements such as the Paris Agreement (2015). By providing shared evidentiary baselines, such platforms may facilitate amicable settlements and improve evidentiary integrity in arbitral proceedings (Suárez, 2023).

Host states in East Africa frequently face resource and expertise constraints in regulating complex technological systems, including AI. Consequently, treaties should include obligations for capacity-building, financed jointly by China, host states, and international financial institutions, to train regulators in interpreting AI-generated outputs and enforcing compliance. In parallel, independent auditing mechanisms should be mandated for high-stakes AI systems used in monitoring, adjudication, or enforcement. Accredited third-party experts should conduct such audits, akin to the external auditing standards referenced in the OECD Due Diligence Guidance for Responsible Business Conduct (2018). These measures ensure that reliance on AI does not compromise accountability or lead to opaque decision-making processes in investor-state disputes. Finally, procedural rules governing investor-state arbitration should incorporate specific safeguards for the admission and evaluation of AI-assisted evidence. Institutional rulebooks (e.g., ICC, LCIA, ICSID) or model guidelines could require disclosing the methods, datasets, and algorithms underlying any AI-generated expert evidence presented in arbitral proceedings. Parties should retain the right to cross-examine AI outputs through human experts, and tribunals should be empowered to appoint neutral technical experts to assist in assessing such evidence. These safeguards resonate with due process principles under Paper 18 of the UNCITRAL Model Law on International Commercial Arbitration and uphold the evidentiary integrity of proceedings in a technologically evolving landscape (Chojecki & Nappert, 2021).

8. POTENTIAL IMPLEMENTATION PATHWAYS: PILOT PROJECTS

One potential implementation pathway involves the establishment of the Sino–East African Environmental Monitoring Consortium, a tripartite initiative comprising Chinese investors, East African host states, and independent scientific experts. This consortium would deploy a pilot artificial intelligence (AI)-driven satellite and sensor monitoring platform to oversee select infrastructure projects, such as hydroelectric cascades along major river basins. The primary purpose of this

mechanism is to ensure real-time environmental compliance by integrating remote sensing technologies with predictive analytics. Such systems could generate shared dashboards providing early-warning alerts to relevant stakeholders and standardized environmental performance reports. These reports would have significant evidentiary value in alternative dispute resolution (ADR) mechanisms, particularly in investor–state disputes where environmental obligations under bilateral investment treaties (BITs) and domestic environmental regulations are contested. The legal foundation for such an initiative can draw from Paper 12 of the Paris Agreement, which promotes transparency in climate-related measures, and Principle 10 of the Rio Declaration on Environment and Development, which underscores access to environmental information. Similar monitoring systems have been endorsed by the International Law Commission (ILC) in its work on protecting the atmosphere and transboundary harm, supporting the idea that technology-driven transparency strengthens compliance and reduces disputes (Bagna et al., 2021).

Furthermore, the consortium could operate under public–private partnership (PPP) arrangements, ensuring that the obligations of both investors and host states under international investment law—including fair and equitable treatment (FET) standards—are complemented by scientifically verified data. This would mitigate litigation risks under instruments such as the ICSID Convention and UNCITRAL Arbitration Rules, which often grapple with evidentiary challenges in environmental impact disputes. Data governance frameworks must also address confidentiality and sovereignty concerns, drawing on the OECD Guidelines on Data Governance for Growth and Well-being and the African Union Convention on Cyber Security and Personal Data Protection (Malabo Convention). Another innovative pathway entails the creation of an AI-assisted Alternative Dispute Resolution (ADR) portal specifically tailored to infrastructure disputes involving Chinese investors and East African states. This online platform would enable stakeholders to submit complaints, which the system would process through a confidential AI-powered triage mechanism. The algorithm would assess jurisdictional issues, classify disputes according to their nature—such as construction delays, environmental compliance, or contractual interpretation—and recommend ADR methods (e.g., mediation, conciliation) or complete arbitration proceedings. The platform would facilitate transparent and efficient resolution processes by integrating blockchain-based document authentication and secure streaming of documentary evidence and environmental data. Appointed mediators or experts could access real-time environmental compliance data, reducing the evidentiary uncertainty that often prolongs infrastructure disputes (Komakech & Ombati, 2023).

Legally, such a portal would align with global trends towards digital dispute resolution as recognized in instruments such as the UNCITRAL Technical Notes on Online Dispute Resolution (2016). In international investment law, the system could serve as an early intervention tool to prevent escalation to investor–state arbitration, which is often criticized for being costly and adversarial. By embedding confidentiality protocols, the portal would adhere to standards outlined in Paper 9 of the

UNCITRAL Rules on Transparency in Treaty-based Investor–State Arbitration, which balances openness with legitimate confidentiality interests. Moreover, the portal could be structured to comply with regional frameworks, including the East African Community (EAC) Treaty provisions on dispute settlement and the China–Africa Cooperation Forum (FOCAC) policy frameworks encouraging dispute prevention and amicable settlement in Belt and Road projects. A third pilot project could focus on a Treaty Modernization Program, providing a renegotiation toolkit leveraging AI-based modeling techniques (Van Staden et al., 2018). This toolkit would simulate different drafting options for clauses in bilateral investment treaties (BITs) or infrastructure-related treaties between China and East African states. By running predictive analytics on historic dispute frequencies, outcomes, and compliance trends, the system could model how specific legal formulations—such as umbrella clauses, stabilization clauses, or environmental carve-outs—affect the likelihood and nature of future disputes. This would empower negotiators to make evidence-based, forward-looking choices when drafting or amending treaties. Such a program addresses the pressing need for treaty reform, which has been highlighted in ongoing debates within UNCITRAL Working Group III on ISDS reform and the OECD's Multilateral Investment Treaty Reform discussions. It aligns with recommendations in the UNCTAD Investment Policy Framework for Sustainable Development, which calls for a balance between investor protection and regulatory space for host states. The program would also incorporate comparative legal analysis of recent treaty innovations, including environmental and human rights obligations in the 2019 Netherlands Model BIT and the Morocco–Nigeria BIT (2016), which pioneered sustainability clauses. This AI-assisted tool could promote harmonization with sustainable development goals (SDGs), particularly SDG 16 on peace, justice, and strong institutions by allowing negotiators to visualize risk profiles under alternative treaty designs (Onyejegbu, 2023).

9. CONCLUSION

Artificial intelligence (AI) presents a measurable and transformative potential to reduce transaction costs, enhance environmental monitoring, and facilitate more efficient and informed dispute resolution in investor–state arbitration, particularly in relation to technically complex environmental projects in East Africa involving Chinese investors under the framework of bilateral investment treaties (BITs) and regional economic agreements. This promise aligns with the growing demand for predictive analytics and advanced data processing in disputes involving natural resources, environmental degradation, and climate change mitigation obligations. For instance, AI-driven remote sensing tools can provide verifiable evidence regarding compliance with environmental impact assessments (EIAs), a recurrent point of contention in disputes concerning large-scale infrastructure projects such as those financed under the Belt and Road Initiative (BRI). Moreover, the integration of machine learning models in document review and legal analytics has the potential to expedite arbitral proceedings while reducing costs, thereby addressing concerns about the accessibility and affordability of investor–state dispute

settlement (ISDS), which have long been critiqued in scholarly literature for their protracted duration and high costs (Katterbauer & Moschetta, 2022).

However, technological promise must be accompanied by robust governance mechanisms to ensure that the deployment of AI tools respects fundamental principles of international investment law and public international law, particularly those pertaining to due process, transparency, and regulatory autonomy. This necessitates precise treaty drafting that preserves the regulatory space of host states in accordance with Paper 12 of the African Continental Free Trade Area (AfCFTA) Protocol on Investment, and ensures consistency with general principles reflected in Paper 31 of the Vienna Convention on the Law of Treaties (VCLT). Procedural safeguards, such as those outlined in the UNCITRAL Rules on Transparency in Treaty-based Investor-State Arbitration, must be integrated to guarantee that AI-assisted evidence gathering does not compromise the right to be heard or equality of arms between disputing parties. Furthermore, introducing AI systems into adjudicatory processes raises questions under principles such as nemo judex in causa sua and the requirement of an independent and impartial tribunal under Paper 18 of the UNCITRAL Arbitration Rules (Katterbauer, Genc, et al., 2024).

A critical component of such governance is capacity building to mitigate asymmetries between resource-constrained host states and foreign investors with superior technological capabilities. Without institutional strengthening and access to technical expertise, introducing AI tools could exacerbate rather than reduce existing inequalities in ISDS proceedings. This concern resonates with the normative objectives of the United Nations Guiding Principles on Business and Human Rights (UNGPs), which emphasize access to remedy and non-discrimination. Independent auditing of algorithmic systems should also be mandated to prevent systemic bias, as required under emerging soft law instruments such as the OECD AI Principles (2019) and the UNESCO Recommendation on the Ethics of Artificial Intelligence (2021). Algorithmic accountability and periodic transparency reports can serve as essential safeguards against opacity and error in automated decision-support systems used in environmental compliance monitoring and arbitral case management. Policymakers and practitioners must conceptualize AI not as a substitute for legal reasoning or normative interpretation but as a suite of instruments capable of rendering treaty implementation and dispute resolution more evidence-based, transparent, and environmentally sustainable. Such an approach aligns with contemporary trends in international investment governance, which increasingly seek to integrate sustainable development considerations into treaty frameworks, as exemplified by recent model BITs from countries such as India (2016) and the Netherlands (2019). By embedding AI deployment within a governance architecture that prioritizes legality, accountability, and environmental stewardship, states and arbitral institutions can harness technological innovation while safeguarding the legitimacy and fairness of the ISDS regime in East Africa and beyond.

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NAVIGATING THE LABYRINTH: THE IMPACT OF PATENT LAW AND AI REGULATIONS ON HEALTHCARE INNOVATION IN CHINA AND AFRICA

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ABSTRACT

The convergence of artificial intelligence (AI) and healthcare promises a paradigm shift in diagnostics, treatment personalization, and drug discovery. However, this convergence occurs within a complex legal and ethical framework, where patent law and nascent AI-specific regulations intersect. This article conducts a comparative analysis of the impact of this regulatory nexus on healthcare innovation in two distinct contexts: China, a state-directed technological superpower, and Africa, a continent of 54 diverse nations pursuing collective technological sovereignty. It argues that while China employs a strategic, top-down model that leverages its patent system to fuel a national AI-healthcare industrial policy, African nations navigate a polycentric and fragmented landscape. The continent's primary challenge lies in balancing the imperative for robust patent protection to incentivize innovation, both foreign and domestic, against the urgent need for equitable access to healthcare. This balancing act occurs within a complex, multi-level governance structure, where nascent continental strategies from the African Union must be reconciled with diverse national priorities and limited institutional capacity, all while avoiding a new wave of technological dependency. The article concludes that the evolving regulatory frameworks in both regions will not only shape their domestic health outcomes but also critically influence the global governance of AI in medicine.

Keywords: *AI Regulation, Healthcare Innovation, Patent Law, China, Africa.*

Jel Codes: *K39, O34, I18.*

YAPAY ZEKA DÜZENLEMELERİ VE PATENT HUKUKUNUN ÇİN VE AFRİKA'DA SAĞLIK İNOVASYONU ÜZERİNDEKİ ETKİSİ: LABİRENTTE YÖN BULMAK

ÖZET

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Yapay zekâ (YZ) ile sağlık sektörünün kesişimi; teşhis, tedavinin kişiselleştirilmesi ve ilaç keşfi alanlarında paradigmatik bir dönüşüm vaat etmektedir. Ancak bu dönüşüm, patent hukuku ile henüz gelişmekte olan yapay zekâya özgü düzenlemelerin iç içe geçtiği karmaşık bir hukuki ve etik çerçeve içerisinde gerçekleşmektedir. Bu çalışma, söz konusu düzenleyici kesişimin sağlık inovasyonu üzerindeki etkisini iki farklı bağlam üzerinden karşılaştırmalı olarak incelemektedir: devlet yönlendirmeli teknolojik bir süper güç olan Çin ve kolektif teknolojik egemenlik arayışındaki 54 farklı ülkeden oluşan Afrika kıtası. Çalışma, Çin'in patent sistemini ulusal YZ-sağlık sanayi politikasını desteklemek amacıyla kullanan stratejik ve yukarıdan aşağıya işleyen bir model benimsediğini ileri sürmektedir. Buna karşılık Afrika ülkeleri ise çok merkezli ve parçalı bir düzenleyici yapı içerisinde hareket etmektedir. Kıtanın temel sorunu; hem yabancı hem de yerel inovasyonu teşvik etmek için güçlü patent koruması sağlama gerekliliği ile sağlık hizmetlerine adil erişim ihtiyacı arasında denge kurmaktır. Bu denge arayışı, Afrika Birliği'nin yeni ortaya çıkan kıtasal stratejilerinin, farklı ulusal öncelikler ve sınırlı kurumsal kapasite ile uyumlaştırılmasını gerektiren çok katmanlı bir yönetişim yapısı içinde gerçekleşmekte; aynı zamanda yeni bir teknolojik bağımlılık dalgasından kaçınma çabasıyla şekillenmektedir. Çalışma, her iki bölgede gelişmekte olan düzenleyici çerçevelerin yalnızca kendi iç sağlık sonuçlarını değil, aynı zamanda tıpta yapay zekânın küresel yönetişimini de kritik biçimde etkileyeceği sonucuna varmaktadır.

Anahtar Kelimeler: *Yapay Zekâ Düzenlemeleri, Sağlık İnovasyonu, Patent Hukuku, Çin, Afrika.*

JEL Kodları: *K39, O34, I18.*

1. INTRODUCTION: THE TRIPLE HELIX OF AI, PATENTS, AND HEALTHCARE

The integration of sophisticated artificial intelligence into healthcare is producing a paradigmatic shift in medicine. From algorithm-driven radiology and genomic pattern recognition to optimizing clinical trials, AI is redefining therapeutic development. This technological transformation, however, is fundamentally mediated by intellectual property law. This technological transformation is mediated radically by the framework of intellectual property law, wherein the patent system functions as the primary mechanism for incentivizing capital-intensive research and development by conferring time-limited exclusivity. Historically, this regime has proven adept at protecting discrete, human-originated inventions such as novel pharmaceutical compounds and tangible medical devices (Bostyn, 2003). However, the emergence of AI-generated and AI-assisted inventions presents a series of profound juridical and philosophical challenges that strain the foundations of existing patent law. Core tenets of inventorship are being questioned, as legal systems globally grapple with whether a non-human, autonomous AI can be recognized as an "inventor," a status traditionally reserved for natural persons (Dolan et al., 2023). Furthermore, the criterion of "non-obviousness," which is predicated on a hypothetical person having ordinary skill in the art, becomes nebulous when the discovery is made by a machine learning model capable of identifying multifactorial correlations invisible to human experts.

Perhaps the most significant hurdle lies in the patent eligibility of the AI algorithms themselves, which must navigate the thorny distinction between a patentable "application" of an abstract idea and the unpatentable abstract idea itself. A diagnostic algorithm, for instance, must demonstrate a sufficiently "inventive concept" that transforms it from a mere mathematical abstraction into a specific, practical tool with a concrete, real-world outcome—such as saving lives. Consequently, the evolving jurisprudence in this domain will not only determine the commercial viability of AI in medicine. Still, it will also fundamentally redefine the legal and conceptual boundaries of human ingenuity and invention in the age of algorithms (Dutfield, 2017).

The profound patent law questions surrounding AI in healthcare—about inventorship, non-obviousness, and the patent-eligibility of algorithms—are further complicated by the concurrent emergence of a dense thicket of AI-specific regulations aimed at ensuring safety, efficacy, and equity. This creates a dual-hurdle "regulatory labyrinth" where innovators must navigate not only the incentive structures of intellectual property law but also the compliance mandates of data privacy regimes like the EU's GDPR and China's PIPL, alongside stringent requirements for algorithmic transparency and rigorous clinical validation. This article examines the construction and navigation of this labyrinth within two critical and strategically divergent geographies: the People's Republic of China and the continent of Africa. China's approach is characterized by a state-directed, centralized model, leveraging its Digital Silk Road initiative and strategic ambition to achieve global AI leadership by 2030; this top-down framework prioritizes national security and economic dominance, creating a structured, if tightly controlled, environment for AI development and deployment (Vladyslav et al., 2024). In stark contrast, Africa's regulatory landscape is emergent, polycentric, and inherently fragmented, being shaped by a complex interplay of national policies, regional coalitions, and significant external influence from global powers and non-governmental organizations. This approach is heavily informed by a historical legacy of healthcare inequity and a pressing, pragmatic need for technological leapfrogging to address gaps in infrastructure and clinical capacity. Consequently, the interplay between China's orchestrated governance and Africa's adaptive, multi-stakeholder model presents a vital comparative lens through which to analyze how divergent regulatory philosophies are shaping the global future of AI-driven healthcare, determining not only the pace of innovation but also the distribution of its benefits and the governance of its risks (Gold, 2003).

2. RESEARCH METHODOLOGY

The article employs a qualitative, comparative case study design to investigate the complex interplay between patent law, AI regulation, and healthcare innovation. The methodological approach is structured to facilitate a deep, contextualized analysis of two strategically significant yet fundamentally different cases: the People's Republic of China and the continent of Africa. This section

delineates the research methodology, detailing case selection, data collection, and analytical procedures, before outlining the multi-disciplinary theoretical framework that underpins the analysis.

The core of this research is a structured, comparative case study. This methodology is particularly apt for investigating contemporary phenomena within their real-life contexts, especially when the boundaries between the phenomenon and its context are not clearly evident. By comparing China and Africa, the study leverages a "most different systems" design. China represents a centralized, state-capitalist model with a unified legal system and a top-down industrial policy. Africa, in contrast, constitutes a polycentric, multi-state continent with diverse legal traditions and an emergent, consensus-driven approach to governance. This stark contrast allows for the isolation of how different governance structures, state capacities, and historical legacies shape the regulatory nexus of AI and patents in healthcare. The comparison is not intended to rank one model as superior but to elucidate the distinct trade-offs, strategic choices, and convergent challenges inherent in each pathway (Tambo et al., 2016).

This research is grounded in a systematic qualitative methodology, employing a comparative policy analysis that triangulates a wide array of primary and secondary sources to ensure analytical robustness and validity. The primary research involved a meticulous examination of foundational legal and regulatory texts, including China's Patent Law, Cybersecurity Law, Personal Information Protection Law (PIPL), and the Interim Measures for Generative AI Services, contrasted with the constitutive agreements of African bodies like the African Regional Intellectual Property Organization (ARIPO) and the Organisation Africaine de la Propriété Intellectuelle (OAPI), alongside national laws from key jurisdictions such as Kenya, Nigeria, South Africa, and Rwanda. This legal analysis was supplemented by a close reading of strategic policy documents, including China's "New Generation AI Development Plan" and the African Union's "Digital Transformation Strategy for Africa," and operational guidelines from agencies like China's National Intellectual Property Administration (CNIPA) and the Africa Medical Devices Forum (AMDF). To situate this primary data within the scholarly discourse, the study integrates a comprehensive review of secondary sources, including peer-reviewed literature from fields such as law, science and technology studies, and public health, analytical reports from international organizations like WIPO and the WHO, and documented case studies of real-world AI deployments, such as Zipline's drone logistics in Rwanda and Ghana, thereby ensuring the findings are both theoretically informed and empirically grounded (Lin et al., 2016).

This research employed a structured, two-stage analytical procedure to dissect the complex interplay of policy, law, and innovation in AI and healthcare. The process commenced with a dedicated within-case analysis, where the Chinese and African contexts were examined as independent, holistic ecosystems. For China, this involved meticulously tracing the causal and reinforcing links between its top-down national strategies, the permissive implementation of patent law by the China National Intellectual Property Administration (CNIPA), and the resultant ascent of state-favored corporate champions in the AI-healthcare sector. Simultaneously, the African case was analyzed by assessing the

dynamic interplay between supranational harmonization efforts led by bodies like the African Union, the persistent reality of national-level regulatory fragmentation, and the overarching developmental imperative for technological leapfrogging. Following this deep contextual understanding, the study proceeded to a systematic cross-case comparison along pre-defined analytical axes derived from the core research questions. This comparative framework explicitly evaluated the contrasting philosophy of governance (state-directed industrial policy versus polycentric, needs-based consensus), the divergent function of IP law (a strategic weapon for global market capture versus a delicate instrument for managing technology transfer and access), the opposing regulatory approaches (comprehensive top-down control versus emergent bottom-up harmonization), and the distinct data governance paradigms (state-controlled sovereignty versus the pursuit of equitable pan-African data spaces). It was this rigorous, structured comparison that not only illuminated the starkly divergent developmental paths of the two models but also, and perhaps more significantly, enabled the identification of their critical, converging challenges—namely, the universal imperatives to mitigate algorithmic bias and to navigate the contentious arena of global AI standard-setting (Pan, 2015). For the theoretical framework, this article is situated at the intersection of several theoretical traditions, constructing a multi-disciplinary lens to analyze its core problem.

The analysis is fundamentally informed by theories of technological sovereignty and national innovation systems (NIS). The concept of technological sovereignty posits that states seek to assert control over critical technological domains to ensure economic competitiveness, national security, and policy autonomy. China's model is a textbook case of a state actively constructing a sovereign technological ecosystem through its NIS, where public policy, industry, and academia are aligned to achieve strategic goals. Conversely, Africa's pursuit of collective technological sovereignty, as articulated in its continental strategies, represents a novel, supranational application of this concept, aiming to reduce dependency and assert agency in the global digital order. The research draws heavily on law and political economy (LPE) scholarship, which critiques the notion of law as a neutral arbiter and instead examines how legal structures are shaped by, and in turn shape, political and economic power relations. The article treats patent law not as a static, technical field but as a malleable instrument of political economy. In China, patent law is strategically deployed to serve a state-capitalist industrial policy. In Africa, the debates around IP and TRIPS flexibilities are viewed through the LPE lens, highlighting the enduring power imbalances in the global political economy and the use of law as a site of resistance and re-negotiation.

To critically assess the societal implications, the framework incorporates theories of data colonialism and biopolitics. Data colonialism theory suggests that new forms of capital accumulation are emerging through the extraction and control of data, potentially creating new dependencies between technologically advanced and developing regions. This informs the analysis of risks in Africa, where a lack of local data sovereignty could lead to a new form of technological subjugation. Simultaneously, a

biopolitical analysis, inspired by Foucault, is used to interpret the Chinese model. The potential fusion of AI-generated health data with the social credit system exemplifies a form of biopower where the state's power extends to the management and control of the biological lives of its population, optimizing health for economic productivity and social stability at the expense of individual autonomy (Ventose, 2011).

Given Africa's fragmented landscape, the theory of polycentric governance is essential. This framework explains how order can emerge from multiple, overlapping centers of decision-making (nation-states, regional organizations like the AU, ARIPO, OAPI) rather than a single, central authority. The African model is analyzed not as a failure of centralization but as an experiment in polycentric governance, where coordination, harmonization, and coalition-building are the primary mechanisms for managing complex, transnational technological challenges (Naidoo et al., 2022). By integrating methodological rigor and theoretical perspectives, this article provides a nuanced, critical, and comprehensive analysis of how the regulatory labyrinth of patents and AI is being constructed and navigated in two pivotal regions, with profound implications for the future of global health (Singh, 2023).

3. THE CHINESE MODEL: STRATEGIC PATENTING AND STATE-DIRECTED INNOVATION

China has decisively positioned itself as a global leader in the application of artificial intelligence to healthcare, a status not achieved by happenstance but meticulously engineered through a sophisticated and strategic interplay of national policy, patent law, and regulatory design. This orchestrated ecosystem is most evident in the nation's patent landscape, which has undergone a remarkable transformation from one of adherence to intellectual property (IP) to one of prolific and strategic generation. China now leads the world in the volume of AI-related patent filings, a quantitative dominance that reflects a qualitative shift in national ambition (Ye et al., 2019). Within healthcare, this surge is strategically channeled into government-prioritized domains such as medical imaging diagnostics, AI-accelerated drug discovery—often termed "AI-drug conjugates"—and the data-rich field of wearable health monitors. This focus is directly orchestrated by central initiatives, such as "Made in China 2025" and the "New Generation AI Development Plan," which translate high-level strategy into tangible action through substantial R&D subsidies, tax incentives, and targeted support for state-backed enterprises. The Chinese patent office, the CNIPA, acts as a crucial enabler within this framework, having issued guidelines that are notably permissive toward AI inventions (Durojaye, 2013). While maintaining the mainstream global position of not recognizing the AI itself as an inventor, the CNIPA adopts a pragmatic, utility-focused stance, permitting the patenting of AI-based methods and systems when they are convincingly integrated into a specific technical process, such as a concrete medical diagnostic application (Pesapane et al., 2021). This approach effectively sidesteps protracted philosophical debates in favor of a principle of tangible

industrial application, thereby creating a streamlined pathway from laboratory innovation to market commercialization. This synergistic system—where national strategy dictates priority areas, fiscal policy funds the research, and a pragmatic patent office facilitates legal protection—has catalyzed the rapid maturation of technologies from corporate and institutional giants like BGI Group in genomics and Alibaba Health in telemedicine, solidifying China's integrated and state-directed model of technological ascendancy (Teremetskyi et al., 2024).

China's regulatory framework for artificial intelligence in healthcare functions as a strategically calibrated instrument, deliberately balancing assertive state control with targeted facilitation to accelerate commercial and technological dominance. This dualistic nature is evident in the coexistence of restrictive data governance and permissive market-access pathways. On the one hand, a formidable architecture of control, comprising the Cybersecurity Law, the Personal Information Protection Law (PIPL), and the 2023 Interim Measures for Generative AI Services, establishes a tightly bound operational ecosystem. These regulations mandate stringent security assessments, enforce rigid data sovereignty, and compel algorithmic adherence to state-defined sociopolitical principles, creating significant compliance burdens, particularly concerning the cross-border transfer of patient data, which can impede international research collaboration (Katterbauer & Cleenewerck, 2024). Conversely, and strategically, the National Medical Products Administration (NMPA) has implemented a "green channel" approval process designed to fast-track innovative AI medical devices, effectively counterbalancing the restrictive data environment by drastically reducing time-to-market for domestic innovators (Pan, 2015). This regulatory dichotomy is not paradoxical but synergistic; it creates a protected and preferential domestic market. The state's unique capacity to orchestrate access to massive, centralized health datasets—deploying them in sanctioned partnerships with national tech champions like Tencent and Ping An—provides a formidable, non-tariff barrier to foreign competition and an unparalleled testbed for training and refining complex AI models (Yueh, 2009). Thus, the Chinese regulatory model is not merely a set of constraints but a sophisticated industrial policy tool. By creating a walled garden—where data is protected as a national asset and market access is streamlined for compliant domestic entities—China cultivates a generation of AI healthcare solutions that are simultaneously advanced by the scale of available data and inherently aligned with the state's sovereign priorities, ensuring that control and commercialization proceed in lockstep toward the objective of global leadership (McMahon & Richardson, 2022).

The domestic impact of China's integrated AI-healthcare strategy is profound and dualistic, simultaneously demonstrating the immense potential for public health advancement while raising fundamental questions about its societal costs. On one hand, the deployment of AI-assisted diagnostic tools, particularly in medical imaging, is occurring at an unprecedented scale within urban hospital networks, serving a critical function in alleviating the diagnostic burden on a perennially stretched healthcare system (Wu, 2010). Furthermore, the integration of these AI tools with telemedicine

platforms presents a potent strategy for mitigating stark regional inequities in healthcare access, potentially delivering specialist-level diagnostic capabilities to remote and rural populations (Xie, 2024). However, this technologically enabled progress is intrinsically tethered to a model of governance that invites significant ethical and political critique. The potential fusion of sensitive health data, generated by these AI systems, with the architecture of the state's social credit system creates a paradigm of bio-surveillance that extends far beyond therapeutic intent, repurposing patient information for broader social scoring and behavioral monitoring. Consequently, while the top-down, state-capitalist model has proven remarkably efficient at marshaling resources and accelerating technological innovation, it does so within a framework of pervasive state control (Russo, 2015). This framework prioritizes collective health outcomes and social stability, often at the deliberate expense of individual data privacy and autonomy, thereby illustrating a distinct trade-off where gains in public health efficiency and access are counterbalanced by an unprecedented deepening of state power into the biopolitical lives of its citizens (Chen & Liu, 2023).

4. THE AFRICAN CONTEXT: FRAGMENTATION, LEAPFROGGING, AND SOVEREIGNTY

The African narrative regarding intellectual property and artificial intelligence in healthcare is inherently complex, defying characterization as a monolithic bloc due to the continent's 54 sovereign states with their divergent legal traditions, infrastructural capacities, and public health priorities. While the regulatory landscape is consequently fragmented, a nascent continent-wide strategy is beginning to cohere, primarily through the dual frameworks of the African Regional Intellectual Property Organization (ARIPO) and the Organization Africaine de la Propriété Intellectuelle (OAPI). Despite these regional structures, the patent landscape for AI-healthcare remains characterized by a significant imbalance, with a low volume of locally generated patents and a market often dominated by foreign-protected technologies. This dominance perpetuates long-standing concerns regarding cost-prohibitive access, a lack of local adaptation to endemic diseases and diverse patient populations, and the reinforcement of a cycle of technological dependency. At the heart of the African context lies a fundamental and unresolved tension: the imperative to incentivize innovation, both foreign and domestic, through robust IP protection, set against the urgent, often immediate, public health need for equitable and affordable access to medical technologies (Townsend et al., 2023). This dichotomy is vividly reflected in the historical and continued use of Trade-Related Aspects of Intellectual Property Rights (TRIPS) flexibilities, such as compulsory licensing, by several African nations to ensure access to essential medicines. As AI-based diagnostic and prognostic tools evolve from novel conveniences to critical components of healthcare delivery, a similar dynamic is poised to emerge, forcing a re-evaluation of foundational IP concepts. This raises profound, forward-looking questions: could a diagnostic algorithm for a disease like malaria or tuberculosis be deemed an "essential medicine," thereby justifying the invocation of public health flexibilities to override patent exclusivity? Furthermore, the central

challenge for African nations will be to architect IP and innovation policies that successfully foster a nascent local AI ecosystem without simultaneously erecting the very legal barriers that could limit the widespread dissemination of these potentially life-saving tools, thus navigating a precarious path between fostering invention and ensuring implementation (Alsamara & Farouk, 2024).

In stark contrast to China's established and centralized model, the regulatory framework for AI in healthcare across much of Africa is characterized by its emergent and often fragmented nature, with most nations currently lacking comprehensive, AI-specific legislation. While data protection laws are gradually evolving, frequently inspired by frameworks like the GDPR, a pervasive gap exists in institutional capacity and consistent enforcement (le Roux-Kemp, 2010). This regulatory ambiguity, particularly the absence of clear pathways for approving AI as a medical device, generates a climate of uncertainty that can deter both foreign investment and the legitimate, large-scale deployment of clinically validated technologies. This regulatory ambiguity, however, presents a strategic opportunity for 'regulatory leapfrogging.' Unencumbered by legacy systems, countries like Rwanda and Ghana have pioneered agile approval pathways for innovative services like Zipline's drone delivery. The African Union's 'Digital Transformation Strategy' provides a visionary framework for this. Yet, the leapfrogging thesis faces significant hurdles: a lack of specialized regulatory personnel, persistent digital infrastructure gaps, and the political challenge of harmonizing disparate national interests. The success of this approach hinges not on simply adopting foreign best practices, but on adapting them into context-specific, risk-proportionate frameworks that can be consistently enforced across the continent. Foundational continental initiatives, such as the African Union's "Digital Transformation Strategy for Africa (2020-2030)" and its nascent "Continental AI Strategy," represent critical steps in this direction, articulating a collective vision for harmonized digital health policies, robust data governance, and the systematic building of regulatory capacity. Practical efforts to realize this vision are underway through mechanisms like the Africa Medical Devices Forum (AMDF), which aims to harmonize the assessment and approval of medical devices—a category that increasingly encompasses AI-based software. This proactive, polycentric approach seeks to circumvent the pitfalls of earlier regulatory models, aiming to create an ecosystem that is simultaneously conducive to innovation, firmly anchored in public health priorities, and capable of fostering cross-border collaboration in a rapidly evolving technological landscape (Mensah et al., 2024).

The potential impact of artificial intelligence on African healthcare systems is undeniably transformative, offering a pragmatic pathway to technological leapfrogging that could circumvent traditional infrastructural and human resource constraints. AI-powered mobile health (mHealth) platforms and tele-diagnostic systems offer viable solutions to the critical shortage of healthcare professionals, enabling the extension of quality care to previously underserved populations through digital means. Pioneering projects, such as Zipline's AI-optimized drone logistics for delivering blood products and essential medicines in Rwanda and Ghana, or the deployment of machine learning

algorithms for the rapid interpretation of chest X-rays to combat tuberculosis in South Africa, serve as compelling proof of concept for this paradigm. However, the realization of this promise is critically contingent upon mitigating the primary attendant risk: the profound exacerbation of the existing digital divide. Without deliberate, equity-focused policy interventions, there is a significant danger that the benefits of AI-healthcare will become the exclusive purview of urban, affluent elites, thereby inadvertently deepening existing health inequities and leaving rural and impoverished communities further marginalized (Mahomed, 2018). Consequently, the ultimate success of the AI revolution in African healthcare hinges not merely on technological adoption, but on the parallel and foundational development of three critical pillars: first, the widespread construction of robust digital infrastructure to ensure connectivity; second, a dedicated focus on developing and validating algorithms on diverse African genomic and clinical datasets to ensure fairness and mitigate embedded biases that could harm local populations; and third, the cultivation of innovative, sustainable business models that are explicitly designed to prioritize broad accessibility and public health impact over the narrow pursuit of profit maximization (Ngwena, 2000).

5. COMPARATIVE ANALYSIS: DIVERGENT PATHS, CONVERGING CHALLENGES

A comparative analysis of the Chinese and African models for governing AI in healthcare reveals a stark dichotomy in underlying philosophies, strategic objectives, and state capacities. The driving force behind China's model is unequivocally state-directed and industrial, fueled by a geopolitical ambition to achieve technological sovereignty and global leadership. In contrast, the African approach is—aspirationally—polycentric and needs-based, prioritizing the resolution of foundational public health challenges through consensus and coalition-building. This fundamental divergence is mirrored in their intellectual property strategies: China deliberately wields its patent system as a strategic instrument to cultivate domestic corporate champions and capture future global market share, whereas African nations and regional bodies are primarily concerned with leveraging the IP framework as a mechanism for managing technology transfer and, crucially, safeguarding equitable access to the medical innovations that result. Ultimately, the regulatory approaches embody this core contrast: China has established a comprehensive, top-down framework that effectively balances control with commercialization, while Africa is pioneering a harmonized, bottom-up strategy that seeks to build regulatory capacity and consensus among its diverse nations, aiming for agile and context-sensitive governance. Ultimately, these models represent two distinct answers to the question of how to govern transformative technology: one demonstrates the formidable efficiency of a centralized, state-capitalist system in driving rapid technological adoption, while the other explores the more complex, yet potentially more resilient, path of building a regulatory ecosystem that is inclusive, equitable, and tailored to locally defined human needs.

Despite the profound divergence in their developmental philosophies and governance structures, the Chinese and African models for AI in healthcare confront a set of critical, converging challenges that underscore the universal complexities of technological integration. A paramount concern for both is mitigating algorithmic bias and promoting health equity. Each must ensure their AI models are trained on demographically and clinically representative data; for China, this necessitates addressing the significant regional and ethnic diversity within its Han-majority population to avoid suboptimal outcomes for minority groups, while Africa must contend with ensuring diagnostic and predictive accuracy across the continent's vast genetic and phenotypic diversity to prevent the entrenchment of new, data-driven health disparities. Similarly, both grapple with the fundamental tension in data governance between fostering open data access to fuel innovation and upholding robust privacy and protection standards. Their resolutions, however, reflect their core philosophies: China prioritizes state control and national security as a mechanism to resolve this tension, whereas Africa seeks a more nuanced path that attempts to balance individual rights with the strategic creation of a pan-African data space to catalyze continental research. Ultimately, both are active and strategic participants in the emerging field of global standard-setting for AI. Their objectives, however, reveal their differing positions in the global order: China is assertively aiming to export its techno-governance standards as a component of its soft power and digital sovereignty agenda, while Africa, coalescing through the African Union, is cultivating a unified voice to ensure that emerging global rules are equitable and do not perpetuate existing patterns of technological dependency, thereby advocating for a multilateralism that acknowledges its specific developmental needs and right to technological self-determination (Fadare & Jemilohun, 2012).

Ultimately, the Chinese and African models present two distinct risk profiles. China's top-down efficiency carries the inherent risk of creating a biopolitical surveillance state, where health innovation serves as a handmaiden to social control and individual rights are secondary to national ambition. Africa's polycentric, consensus-driven model, while aspiring to equity and inclusivity, risks policy paralysis, regulatory capture by foreign interests, and a failure to build the critical mass needed to foster a self-sustaining local innovation ecosystem. The converging challenge for both, therefore, is not only technical but profoundly political: to build governance structures that can harness AI's benefits while constructing robust safeguards against their respective, and severe, systemic risks (Chirwa, 2016).

6. CONCLUSION AND FUTURE TRAJECTORIES

In conclusion, the intricate interplay of patent law and artificial intelligence regulation transcends mere technical jurisprudence, emerging as a fundamental determinant of future global health sovereignty. The Chinese paradigm demonstrates the formidable efficacy of a cohesive, state-directed strategy that synergistically leverages intellectual property and regulatory frameworks to accelerate technological advancement, albeit within a structure that subordinates individual privacy to state control

and industrial policy. Conversely, Africa's trajectory is inherently more complex, necessitating a delicate and continuous balancing of innovation incentives, equitable access, and ethical governance across a mosaic of sovereign nations. Looking forward, China's trajectory will involve navigating the international repercussions of its data sovereignty and AI governance models while striving to maintain its momentum at the frontiers of AI-driven medicine. For Africa, the imperative lies in accelerating the finalization, harmonization, and implementation of its Continental AI Strategy, concurrently building robust regulatory capacity and investing critically in the digital infrastructure and human capital required to transition from a consumer to a co-creator and owner of context-specific AI solutions. Ultimately, the "regulatory labyrinth" is not a static maze to be solved but a dynamic architecture perpetually under construction. The 'regulatory labyrinth' is not a static maze but a dynamic architecture whose blueprint is being drawn now. The choices made in Beijing, Addis Ababa, and national capitals will define the next century of global health. The central question is whether this AI-driven future will be characterized by hegemonic techno-governance or by a distributed, equitable sovereignty. The answer depends on whether global frameworks can emerge that acknowledge both the power of state-directed strategy and the imperative of polycentric, human needs-based innovation.

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PETROL FİYATLARI VE BİST100 İLİŞKİSİ: PANDEMİ VE SONRASI DÖNEM İÇİN ASİMETRİK BİR İNCELEME

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ÖZET

Petrol fiyatları; üretim, tedarik zinciri ve tüketim kanalları üzerinden ekonomik yapının tamamını etkileyen stratejik bir dışsal şok niteliğindedir. Makroekonomik ve finansal istikrarın temel belirleyicilerinden biri olan petrol fiyatlarındaki değişimler, bu yönüyle kritik bir inceleme alanı sunmaktadır. Petrol fiyatlarındaki artışlar bir yandan üretim maliyetlerini ve enflasyonu tetikleyerek toplam çıktıyı azaltırken, diğer yandan faiz oranlarının yükselmesine neden olmakta ve şirket değerlemelerini düşürerek borsa üzerinde bir baskı yaratmaktadır. Dolayısıyla, bu çalışmanın amacı, petrol fiyatlarının Türkiye hisse senedi piyasası üzerindeki nedensel etkilerini ampirik olarak incelemektir. Çalışmada değişken olarak WTI petrol fiyatı ile BİST100 endeksi kullanılmış olup, analiz dönemi ise küresel ölçekte ekonomik çalkantıların yaşandığı COVID-19 pandemisi ve sonrasını kapsayacak şekilde 2019M1-2025M9 olarak belirlenmiştir. Metodolojik olarak, Hacker ve Hatemi-J (2006) tarafından geliştirilen simetrik nedensellik analizinin yanı sıra, çalkantılı dönemlerdeki saklı nedensellikleri tespit etmek amacıyla Hatemi-J (2012) asimetrik nedensellik analizi ve Hatemi-J (2014) çalışmasına dayanan asimetrik etki-tepki fonksiyonları uygulanmıştır. Hatemi-J (2012) analizi bulguları, petrol fiyatlarından BİST100 endeksine doğru herhangi bir nedensellik ilişkisi olmadığını göstermektedir. Buna karşın asimetrik nedensellik analizi sonuçları, petrol fiyatının pozitif ve negatif bileşenlerinden, sırasıyla BİST100 endeksinin pozitif ve negatif bileşenlerine doğru anlamlı bir nedenselliğin varlığını ortaya koymaktadır. Ayrıca asimetrik etki-tepki fonksiyonu tespitleri, petrol fiyatlarındaki düşüşlerin BİST100'deki düşüş eğilimini hafifletme potansiyeline sahip olduğunu göstermektedir. Çalışmanın bulguları, özellikle küresel petrol arzının kesintiye uğradığı dönemlerde politika yapıcıların alacağı tedbirlere ve yatırımcıların risk yönetimi stratejilerine yönelik bir yol gösterici niteliği göstermektedir.

Anahtar Kelimeler: *Petrol fiyatları, BİST100, Asimetrik nedensellik, Asimetrik Etki-Tepki.*

Jel KODLARI: *C32, G14, Q43.*

THE RELATIONSHIP BETWEEN OIL PRICES AND THE BIST100: AN ASYMMETRIC ANALYSIS FOR THE PANDEMIC AND POST-PANDEMIC PERIOD

ABSTRACT

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Oil prices constitute a strategic external shock that affects the entire economic structure through production, the supply chain, and consumption channels. As one of the key determinants of macroeconomic and financial stability, fluctuations in oil prices present a critical area of analysis. While increases in oil prices reduce total output by triggering production costs and inflation, they also cause interest rates to rise and generate pressure on the stock market by lowering corporate valuations. Therefore, this study aims to empirically examine the causal effects of oil prices on the Turkish stock market. In this study we use the BIST100 index and WTI oil price as variables, with the analysis period defined as 2019Q1-2025Q3 to encompass the COVID-19 pandemic and its aftermath, a period marked by global economic turmoil. Methodologically, in addition to the symmetric causality analysis developed by Hacker and Hatemi-J (2006), Hatemi-J's (2012) asymmetric causality analysis and asymmetric impulse-response functions based on Hatemi-J's (2014) work were applied to identify latent causal relationships during turbulent periods. The findings of the symmetric causality analysis indicate that there is no causal relationship from oil prices to the BIST100 index. In contrast, the results of the asymmetric causality analysis reveal the existence of significant causality from the positive and negative components of oil prices to the positive and negative components of the BIST100 index, respectively. Furthermore, the findings from the asymmetric impulse-response function analysis suggest that declines in oil prices have the potential to mitigate downward trends in the BIST100. The study's findings provide as a guide for the measures to be taken by policymakers and the risk management strategies to be adopted by investors, particularly during periods when global oil supplies are disrupted.

Keywords: *Oil Prices, BIST100, Asymmetric Causality, Asymmetric Impulse-Response.*

JEL Codes: *C32, G14, Q43.*

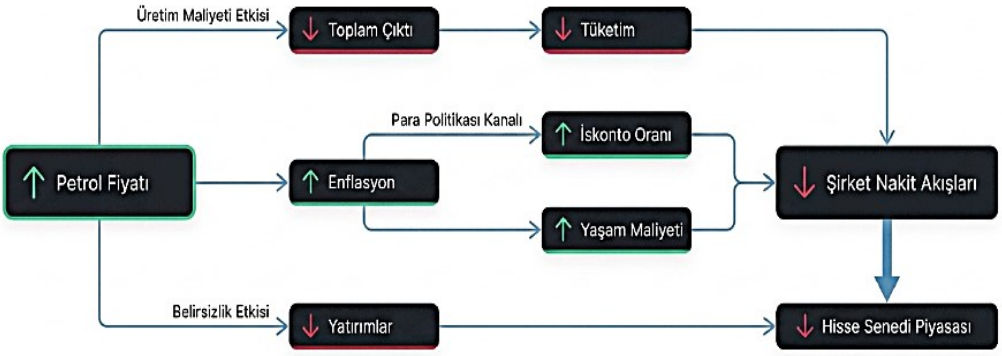
1. GİRİŞ

Petrol, önemli bir üretim faktörü olmasının yanı sıra finansal piyasalarda da likiditesi yüksek stratejik bir emtia olarak karşımıza çıkmaktadır. Bu nedenle, petrol fiyatlarındaki dalgalanmalar enflasyon ve büyüme gibi birçok makroekonomik faktörün yanı sıra hisse senedi piyasaları üzerinde de belirleyici bir role sahiptir (Bjornland, 2009; Jimenez-Rodriguez ve Sanchez, 2005). Nitekim yaşanan çok sayıda ekonomik ve jeopolitik olay da petrol fiyatları ve hisse senedi piyasası ilişkisini şekillendirmiştir. 1970'lerde yaşanan petrol krizleri ve 1979 İran Devrimi sırasında yaşanan petrol fiyat artışları hisse senedi fiyatlarında düşüşe neden olmuştur (Bashirov, 2023). 1980'lerde yaşanan petrol fiyatlarındaki düşüş ise üretimde girdi maliyetlerini azaltarak ekonomik büyümeye ve hisse senedi piyasası üzerinde olumlu bir etki yaratmıştır (Patidar vd., 2024). 2000'li yıllarda yaşanan petrol talep artışıyla enerji hisselerinin değeri artmıştır (Das vd., 2023). 2008 Küresel finans kriz ve 2020 yılında yaşanan COVID-19 salgının yarattığı talep düşüşü ile hem petrol fiyatları hem de enerji hisse senedi fiyatları olumsuz etkilenmiştir (Duppati vd., 2023). 2022 yılında başlayan Rusya-Ukrayna Çatışması (RUÇ) da petrol fiyatlarında ciddi bir artışa yol açmıştır (Bagchi ve Paul, 2023). Petrol fiyatlarının hisse

senedi piyasalarına olan etkisini anlamak, yatırımcılar ve portföy yöneticileri için varlık fiyatlamalarında bu ilişkileri erken uyarı sinyali olarak kabul ederek risk yönetimi stratejilerinin geliştirilmesi açsından önem taşımaktadır.

Literatürde petrol fiyatlarının hisse senedi piyasası üzerindeki etkisi beş aktarım mekanizması üzerinden açıklanmaktadır: Bunlar; Şekil 1'de de gösterildiği gibi üretim, belirsizlik, değerleme, mali ve parasal aktarım mekenizmalarıdır.

Şekil 1. Petro Fiyatları ve Hisse Senedi Piyasası Arasındaki Aktarım Mekanizması



Kaynak: Tang vd., (2010).

Üretim kanalı, petrol fiyat artışlarının arz tarafında girdi maliyetleri aracılığıyla firma karlılığını, talep tarafında ise ürün satış fiyatlarına etkisiyle hanehalkı gelirini olumsuz etkilediğini açıklamaktadır (Hamilton, 2003). İkinci aktarım mekanizması olan değerleme kanalında ise, petrol fiyatlarındaki artışların hisse senedi piyasasına etkisi üzerinden şirket değerlemelerine etkisine odaklanılmaktadır. Bu etkinin petrol ihraççı ekonomilerde pozitif, ithalatçı ekonomilerde ise negatif olduğuna dair bulgular mevcuttur (Filis ve Chatziantoniou, 2014). Üçüncü aktarım mekanizması mali aktarım kanalı da petrol fiyatlarındaki artışların petrol ihraç eden ülkelerinde artışa ithal eden ülke gelirlerinde azalışa neden olduğuna dair bulgular sunmaktadır (Farzanegan, 2011; Emami ve Adibpour, 2012). Bir diğer aktarım mekanizması para kanalında ise, petrol fiyat artışlarının, beklenen enflasyonu artırararak merkez bankalarının faiz oranlarını yükseltmesine neden olduğu ifade edilmektedir. Faiz oranlarındaki artışın iskonto oranını artırdığı ve hisse senedi fiyatlarını düşürdüğü dolayısıyla gelecekteki nakit akışlarını olumsuz etkilediği ileri sürülmektedir (Basher ve Sadorsky, 2006; Mohanty ve Nandha, 2011). Son aktarım mekanizması belirsizlik kanalına göre, petrol fiyat artışlarının belirsizliğe neden olarak büyüme beklentilerini düşürmekte ve dolayısıyla hisse senedi fiyatlarını olumsuz etkilemektedir (Brown ve Yücel, 2002).

Ampirik yazında petrol fiyatlarının hisse senedi piyasalarına etkilerini inceleyen çalışmaların sonuçları büyük bir çeşitlilik ve farklılık göstermektedir. Chen (2010) ve Filis (2010) petrol fiyatları ve hisse senedi piyasası arasında negatif ilişki olduğunu desteklemektedirler. Benzer şekilde, Jones ve Kaul (1996), Sadorsky (1999), Papapetrou (2001) ve Asteriou ve Bashmakova (2013) çalışmaları da bu

argümanı desteklemekte ve özellikle petrol ithalatçısı ülkelerde petrol fiyatındaki şokların üretim maliyetlerini etkileyerek hisse senedi getirilerini düşürdüğünü savunmaktadırlar. Diğer taraftan, Cong vd. (2008) ve Al Janabi, Hatemi-J ve Irandoust (2010) iki piyasa arasında istatistiksel olarak anlamlı bir ilişkinin olmadığını ileri sürerken, Huang vd. (1996), Jammazi ve Aloui (2010) ve Apergis ve Miller (2009), petrol şoklarının hisse senedi performansını tahmin etmede yeterli ya da geçerli bir bilgi sunmadığını tespit etmişlerdir. Pozitif ilişkiye dair kanıtlar sunan çalışmalar ise genellikle bulgularını ülkelerin petrol ihracatçısı olmasına ve sektörel farklılıklara dayandırmaktadır. Wang vd. (2013), Bjornland (2009) ve Lescaroux ve Mignon (2008), net petrol ihracatçısı ülkelerde artan petrol fiyatlarının milli geliri artırması nedeniyle (gelir etkisi) hisse senedi piyasalarının pozitif tepki verdiğini ortaya koymuşlardır. Bununla birlikte, sektörel ve firma bazında yapılan çalışmalardan Nandha ve Faff (2008), Elyasiani vd. (2011) ve Scholtens ve Yurtsever (2012), petrol, doğalgaz ve madencilik gibi petrole dayalı üretici sektörlerin artan petrol fiyatlarından kâr marjlarını yükselterek olumlu yönde etkilendiğini kanıtlamışlardır.

Yukarıdaki kapsamlı literatürden hareketle bu çalışmanın temel amacı, özellikle COVID-19 pandemisi ve sonrasındaki ekonomik ve jeopolitik olayları kapsayan 2019M1-2025M9 dönemi verilerini kullanarak petrol fiyatlarındaki dalgalanmaların, net petrol ithalatçı konumundaki Türkiye'nin hisse senedi piyasasını temsil eden BIST100 endeksi üzerindeki olası asimetrik etkilerini ampirik bir çerçevede analiz etmektir. Çalışmada, Hacker ve Hatemi-J (2006) simetrik nedensellik testi (bundan sonra HHJ (2006)), Hatemi-J (2012) asimetrik nedensellik testi (bundan sonra HJ (2012)) ve Hatemi-J (2014) asimetrik etki-tepki fonksiyonları (bundan sonra HJ (2014)) aracılığıyla, negatif ve pozitif petrol fiyatı şokları ile borsa arasındaki saklı nedensel yönleri ayrıştırmayı ve literatürdeki doğrusal olmayan ilişki tartışmalarına güncel bir katkı sunmayı amaçlamaktadır.

Çalışma şu şekilde devam etmektedir: İkinci bölümde, ulusal ve uluslararası yazındaki araştırmaların sunduğu teorik ve ampirik bulguları incelenmektedir. Üçüncü bölümde, çalışmada kullanılan veri seti, uygulanan HHJ (2006), HJ (2012) ve HJ (2014) metodolojileri, dördüncü bölümde uygulanan yöntemlerden hareketle tespit edilen sonuçlar açıklanmaktadır. Çalışmanın son bölümünde ise, sonuç ve tartışmalar ifade edilmiştir.

2. LİTERATÜR

Petrolün küresel ekonomi üzerindeki makro düzeydeki belirleyici rolü, fiyat hareketlerinin finansal piyasalar üzerindeki yansımalarının derinlemesine incelenmesini zorunlu kılmıştır. İlgili literatür incelendiğinde; söz konusu etkileşimin doğrusal ve doğrusal olmayan yaklaşımlar, coğrafi farklılıklar, petrol fiyat şokları, volatilite aktarım mekanizmaları ve küresel kriz dönemleri gibi oldukça geniş bir perspektifte ele alındığı görülmektedir. Bu bağlamda, petrol fiyatlarındaki değişimlerin hisse senedi piyasalarına etkisi, ülkelerin yapısal ekonomik dinamiklerine bağlı olarak heterojen bir görünüm sergilemektedir.

Genel kabul gören teorik yaklaşıma göre, petrol fiyatlarındaki artışlar petrol ihracatçısı ülkelerin finansal piyasalarında pozitif bir şok yaratırken (Filis vd., 2011; Mohanty vd., 2011; Wang vd., 2013), petrol ithalatçısı ülkelerin aleyhine bir konjonktür oluşturmaktadır. Buna karşın Guesmi ve Fattoum (2014), petrol fiyat şoklarının hisse senedi piyasaları üzerindeki etkisinin ithalatçı ve ihracatçı ülkeler arasında radikal bir farklılık göstermediğini savunarak bu genel kabule alternatif bir perspektif sunmaktadır. Öte yandan, bu etkileşimin coğrafi bölgelere göre varyasyonlar içerdiğini ileri süren çalışmalar da mevcuttur (Alamgir ve Amin, 2021; Mensi vd., 2023; Dai ve Tang, 2024). Nitekim Demirer vd. (2020) söz konusu etkinin ülkelerin gelişmişlik düzeylerine göre farklılaştığını ortaya koyarken, Arouri vd. (2012) petrol fiyat dalgalanmalarının Avrupa hisse senedi piyasaları arasında kayda değer bir volatilite yayılımına yol açtığını vurgulamıştır. Benzer bir yaklaşımla Bagchi ve Paul (2023), G7 ülkelerini inceledikleri çalışmada, brent ham petrol fiyatının SX, NASDAQ ve USD hariç olmak üzere, test edilen tüm hisse senedi getiri oranları üzerinde uzun vadeli ve kalıcı etkiler bıraktığını tespit etmiştir.

Hisse senedi piyasalarının petrol fiyat şoklarına verdiği tepkiler, makroekonomik toplam arz ve talep dinamikleri ile uyumludur ve bu tepkilerin yönü ile şiddeti her ülkenin kendine özgü ekonomik yapısına göre değişkenlik arz etmektedir (Nandha ve Faff, 2008; Miller ve Ratti, 2009; Wang vd., 2013; Sadorsky, 2014; Diaz vd., 2016; Ready, 2018; Ji vd., 2020; Sarwar vd., 2020; Hwang ve Kim, 2021; Sadeghi ve Roudari, 2022; Wei vd., 2023). Finansal literatür, küresel krizlerin enerji piyasaları üzerinde kırılganlıkları artıran majör etkiler yarattığını ve bu dönemlerde risk yayılım mekanizmalarının genişlediğini doğrulamaktadır (Niu vd., 2022; Faisal vd., 2024). Örneğin, COVID-19 pandemisi sürecinde küresel enerji talebinde meydana gelen sert daralma, petrol fiyatlarının tarihsel açıdan en düşük seviyelere gerilemesine neden olmuştur (Antriyandarti vd., 2024). Benzer şekilde 2022 yılında yaşanan RUÇ da özellikle Avrupa kıtasını derinden etkilemiş; Avrupa'nın Rus enerji kaynaklarına olan yapısal bağımlılığı, enerji arz güvenliği ekseninde ciddi endişeleri beraberinde getirerek piyasalardaki türbülansı tetiklemiştir (Umar vd., 2022). Çalkantılı dönemlerde finansal piyasa belirsizlikleri ile hisse senedi piyasası performansı arasındaki ilişkileri anlamak ve risk yönetimini iyileştirmek için hayati önem taşımaktadır.

Mevcut ampirik çalışmaların önemli bir kısmı doğrusal metodolojilere dayanmaktadır. Bu durum, söz konusu etkileşimin doğrusal olmayan, asimetrik ve zamana göre değişken doğasının tam anlamıyla yansıtılmasını engellemektedir. Buna ek olarak, COVID-19 pandemisi ve RUÇ gibi yakın dönemde meydana gelen küresel ekonomik ve jeopolitik sarsıntıların ardından, petrol fiyatları ile hisse senedi piyasaları arasında evrilen yeni nesil dinamikler ve yapısal kırılmalar literatürde hâlâ yeterince araştırılmamış akademik bir boşluk olarak varlığını sürdürmektedir.

3. VERİ ve YÖNTEM

3.1. Veri

Bu çalışmada, 2019M1:2025M9 dönemi arasındaki aylık veriler kullanılarak, BİST100 endeski ve petrol fiyatları arasındaki nedensellik ilişkisi incelenmektedir. Çalışmada kullanılan değişkenlerine ait bilgiler Tablo 1'de ifade edilmektedir.

Tablo 1. Değişkenlere Ait Bilgiler

Değişken	Sembol	Kaynak
West Texas Petrol Fiyatları	WTI	Dünya Bankası Pink Sheet
BİST100 Endeksi	BIST	Investing.com

Bu çalışmada verilerin pozitif ve negatif bileşenlerinin heterojenliği ve nedensellik ilişkisinin farklılışabileceği düşüncesinden hareketle, petrol fiyatları ve BIST100 endeksi nedensellik ilişkisi HHJ (2006) simetrik ve HJ (2012) asimetrik nedensellik analizleri ile incelemektedir. Ayrıca, çalışmada HJ (2014) tarafından geliştirilen etki-tepki fonskiyonları da kullanılmaktadır.

3.2. Yöntem

3.2.1. HHJ (2006) Analizi

Toda ve Yamamoto (1995) (bundan sonra TY (1995)) nedensellik yaklaşımının devamı niteliğinde olan HHJ (2006) simetrik nedensellik analizi, farklı eş bütünleşme derecelerine sahip serilerde nedensellik analizine imkân tanımakta ve kaldıraçlı bootstrap yöntemi kullanmaktadır. Analizde, kaldıraçlı bootstrap yönteminin kullanılmasının nedeni olarak TY (1995) analizinin küçük veri setlerinde asimptotik dağılıma sahip χ^2 kullanılmasının görece daha kötü performans sergilediğinin tespit edilmesidir (Hacker ve Hatemi-J, 2006). Söz konusu yaklaşımda öncelikle VAR ($p+d_{max}$) modeli (1) numaralı denklemdeki gibi tahmin edilmektedir (Hacker ve Hatemi-J, 2006):

$$y_t = v + A_1\ y_{t-1} + A_p\ y_{p-1} + \cdots + A_{p+d}\ y_{t-(p+d)} + \varepsilon_t \qquad (1)$$

(1) numaralı denklem incelendiğinde y_t; z adet bağımsız değişken vektörünü, A; parametreyi, v; sabiti ve ε_t; hata terimini, d; bütünleşme derecesini, p; gecikme uzunluğunu temsil etmektedir.

HHJ (2006) analizinde kullanılan bootstrap (yeniden örnekleme) yöntemi; hem sınırlı varsayımların olduğu durumlarda oldukça güvenilir sonuçlar elde edilmesine hem de daha büyük örneklemlerle yeniden örnekleme yapılmasına imkân tanımaktadır (Simon ve Bruce, 1991). $T \times 1$ boyutundaki kaldıraç vektörleri (2) numaralı denklemdeki gibi tanımlanmaktadır (Hacker ve Hatemi-J, 2006):

$$h_1 = \mathrm{diag}(X_1(X_1'X_1)^{-1}X_1') \qquad (2)$$

$$h_2 = \mathrm{diag}(X(X'X)^{-1}X') \qquad t = 1, \ldots, T$$

Bu hipotezlerden hareketle analizde MWALD istatistik değeri, bootstrap yönteminin 800 kez tekrar edilmesiyle elde edilmektedir. Bootstrap kritik değeri < MWALD istatistik değeri ise, nedenselliğin olmadığı yönündeki sıfır hipotezi (H_0) reddedilmektedir.

3.2.2. HJ (2012) Analizi

HJ (2012) analizinde, simetrik nedensellik testlerinin aksine pozitif ve negatif şoklarının etkisinin heterojen olduğu kabul edilmektedir. Simetrik nedensellik testlerinde şokların etkilerinin homojen kabul edilmesi özellikle finansal piyasalarda gerçekleşen asimetrik bilgi varlığının göz ardı edilmesine neden olmaktadır. Nitekim finansal piyasa katılımcılarının negatif bir şoka pozitif bir şoktan daha sert tepki verdiği diğer bir ifadeyle gerçek hayatta asimetrik yapının varlığı bulunduğu kabul edilmektedir. Öncüsü Akerlof (1970) olan asimetrik bilgi olgusu sonrasında Spence (1973) ve Stiglitz (1974) çalışmaları tarafından desteklenmiştir.

İlk kez Granger ve Yoon (2002) çalışmasında serilerin negatif ve pozitif bileşenlerinin heterojen olduğu ileri sürülmüş ve serilerin homojen kabul edilmesinin gizli eş bütünleşme sorununa neden olabileceği savunulmuştur. Gerçekleştirdikleri çalışmalarında veriler negatif ve pozitif bileşenlerine ayrıştırılarak uzun dönem eş bütünleşme analizi uygulanmıştır (Granger ve Yoon, 2002). HJ (2012) çalışmasında, bu çalışmadan hareketle serilerin nedensellik etkilerinin de farklılaşıp farklılaşmayacağına yanıt aramak için serileri pozitif ve negatif şoklarını ayrıştırarak asimetrik nedensellik analizi gerçekleştirmiştir (Hatemi-J, 2012).

HJ (2012) yaklaşımında negatif ve pozitif bileşenlerin ayrıştırıldığı y_{1t} ve y_{2t} sırasıyla denklem (3) ve (4)'teki gibi gösterilmektedir (Hatemi-J, 2012):

$$y_{1t} = y_{1t-1} + \varepsilon_{1t} = y_{1,0} + \sum_{i=1}^{t} \varepsilon_{1i} \tag{3}$$

$$y_{2t} = y_{2t-1} + \varepsilon_{2t} = y_{2,0} + \sum_{i=1}^{t} \varepsilon_{2i} \tag{4}$$

$$t = 1,2,..,T$$

(3) ve (4) numaralı denklemlerde yer alan $y_{1,0}$ ve $y_{2,0}$ sabitleri başlangıç değerlerini ve ε_{1i} ve ε_{2i} değişkenleri beyaz gürültü bozucu terimlerini temsil etmektedir. (5) ve (6) numaralı denklemlerde pozitif ve negatif şokların ayrıştırılması yer almaktadır:

$$\varepsilon_{1i}^{+} = \max(\varepsilon_{1i}, 0), \qquad \varepsilon_{2i}^{+} = \max(\varepsilon_{2i}, 0) \tag{5}$$

$$\varepsilon_{1i}^{-} = \max(\varepsilon_{1i}, 0), \qquad \varepsilon_{2i}^{-} = \max(\varepsilon_{2i}, 0) \tag{6}$$

$$\varepsilon_{1i} = \varepsilon_{1i}^{+} + \varepsilon_{1i}^{-}, \qquad \varepsilon_{2i} = \varepsilon_{2i}^{+} + \varepsilon_{2i}^{-} \tag{7}$$

y_{1t} *ve* y_{2t} değişkenlerine ait şoklar (8) ve (9) numaralı denklemlerde yer almaktadır:

$$y_{1t}^{+} = \sum_{i=1}^{t} \varepsilon_{1i}^{+} \ , \qquad y_{1t}^{-} = \sum_{i=1}^{t} \varepsilon_{1i}^{-} \tag{8}$$

$$y_{2t}^{+} = \sum_{i=1}^{t} \varepsilon_{2i}^{+} \ , \qquad y_{2t}^{-} = \sum_{i=1}^{t} \varepsilon_{2i}^{-} \tag{9}$$

Analiz, $y_t^+ = (y_{1t}^+, y_{2t}^+)$ varsayımı çerçevesinde, denklem (10)'da yer alan (p) gecikmeye sahip VAR modeli oluşturularak uygulanmaktadır.

$$y_t^+ = v + A_1 y_{t-1}^+ + \cdots + A_p y_{t-1}^+ + \mu_t^+ \tag{10}$$

(10) numaralı denklemde, değişken vektörü y_t^+; sabit vektörü v; hata terimi vektörü μ_t^+ ve bilgi kriterleri ile r mertebesinde gecikme uzunluğu A_r ile temsil edilmektedir. Asimetrik analizi sonrasında şokların etki-tepki fonksiyonlarını belirlemek amacıyla HJ (2014) asimetrik etki-tepki fonksiyonları kullanılmaktadır. Metodolojilerin detaylı arka planı için Akgül (2022) çalışması incelenebilir.

4. AMPİRİK BULGULAR

Çalışmada, öncelikle serilerin durağanlaşma düzeylerini araştırmak amacıyla, Augmented Dickey Fuller (ADF), Phillips-Perron (PP) ve Ziwot-Andrews (ZA) birim kök testleri uygulanmıştır. Birim kök testlerine ilişkin sonuçlar Tablo 2' de yer almaktadır.

Tablo 2. Birim Kök Testi Sonuçları

Değişkenler	ADF	PP	ZA
lnWTI	-1.561	-2.207	-3.583 (2020m12)
lnBIST	-1.480	-2.283	-3.445 (2022m8)
ΔlnWTI	**-4.336*** **	**-6.898*** **	**-10.781*** (2020m5)**
ΔlnBIST	**-4.181*** **	**-7.401*** **	**-8.235*** (2023m1)**

Not: ''***'' simgesi %1 anlamlılık düzeyini temsil etmektedir.

Üç birim kök testinden elde edilen bulgular *lnWTI* ve *lnBIST* değişkenlerinin %1 anlam düzeyinde birinci dereceden durağan I(1) olduklarını göstermektedir. HHJ (2006) ve HJ (2012) analizlerine ait bulgular Tablo 3'te sunulmaktadır.

Tablo 3. HHJ (2006) ve HJ (2012) Analizlerine ait Sonuçlar

Sıfır Hipotezi	MWALD Test İstatistiği	Bootstrap Kritik Değeri			Bütünleşme Derecesi ($p+d_{max}$)
		%1	%5	%10	
***lnWTI*→lnBIST**	4.307	9.117	6.049	4.416	2+1
***lnWTI*⁺ → *lnBIST*⁺**	**11.957*** **	11.336	6.635	5.174	2+1
***lnWTI*⁻ → *lnBIST*⁻**	**10.337** **	11.539	6.673	4.876	2+1
***lnWTI*⁺ → *lnBIST*⁻**	1.464	12.258	6.561	5.029	2+1

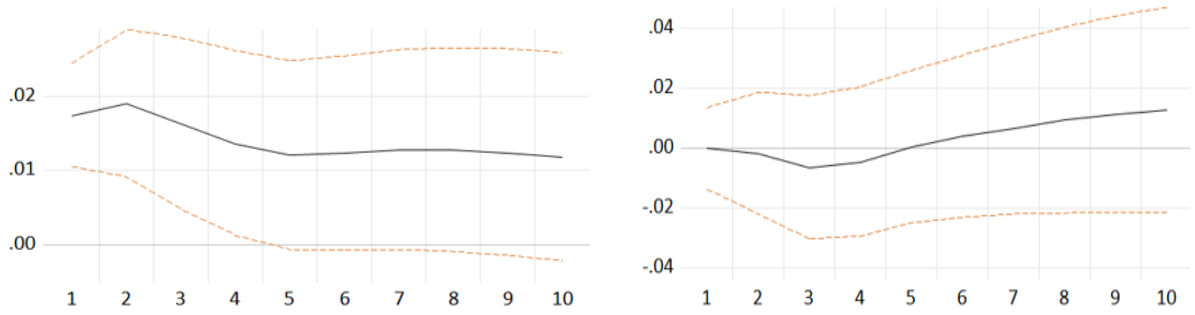
$lnWTI^- \rightarrow lnBIST^+$	1.664	10.179	6.888	5.178	2+1

Not: "**" ve ''***'' simgeleri sırasıyla %5 ve %1 anlamlılık düzeyini temsil etmektedir. Akaike bilgi kriteri dikkate alınarak modeldeki gecikme uzunluğu 2 olarak uygulanmıştır. Bootstrap sayısı ise, 1000 olarak uygulanmıştır.

Tablo 3'teki simetrik nedensellik sonucuna göre ($lnWTI$→lnBIST), petrol fiyatlarının BIST100 endeksinin nedeni olmadığı tespit edilmiştir. Buna karşılık, asimetrik nedensellik testi sonuçlarında %5 ve %1 anlamlılık düzeyinde asimetrik nedensellik ilişkileri gözlemlenmektedir. Buna göre, %1 anlam düzeyinde petrol fiyatları pozitif şoklarının ($lnWTI^+$) BIST100 endeksi pozitif şoklarının ($lnBIST^+$) ve %5 anlam düzeyinde petrol fiyatları negatif şoklarının ($lnWTI^-$) BIST100 endeksi negatif şoklarının ($lnBIST^-$) nedeni olduğu görülmektedir. Simetrik ve asimetrik nedensellik testlerinde karşımıza çıkan bu iki farklı sonuç değişkenler arasındaki şokların homojen kabul edildiğinde gizli eş bütünleşmenin ortaya çıkabileceği ihtimalini göstermektedir.

Şekil 2'de asimetrik nedensellik testi sonuçlarına ilişkin HJ (2014) etki-tepki analizlerine ait bulgular açıklanmaktadır.

Şekil 2. Asimetrik Etki-Tepki Analizleri



Panel A: $lnWTI^-$ Şokundan $lnBIST^-$ Şokuna Asimetrik Etki-Tepki Analizi

Panel B: $lnWTI^+$ Şokundan $lnBIST^+$ Şokuna Asimetrik Etki-Tepki Analizi

Şekil 2'de yer alan asimetrik etki tepki fonksiyonu sonuçlarına göre, A panelinde petrol fiyatları negatif şokları BIST100 endeksinde meydan gelen gelen negatif şokları azaltmaktadır. B panelinde ise petrol fiyatları pozitif şokları BIST100 endeksinde meydan gelen gelen pozitif şokları artırmaktadır.

5. SONUÇ

Bu çalışmada, petrol fiyatları ile BIST100 endeksi arasındaki ilişki 2019M1-2025M9 dönemi kapsamında simetrik ve asimetrik nedensellik yöntemleriyle incelenmiştir. Özellikle Türkiye gibi petrole bağımlı bir ekonomide petrol fiyatlarındaki dalgalanmalar, finansal piyasalar açısından kritik sonuçlar doğurabilmektedir. COVID-19 pandemisi ve RUÇ gibi küresel gelişmeler ise enerji piyasalarındaki oynaklığı artırarak petrol fiyatları ile hisse senedi piyasaları arasındaki ilişkinin daha karmaşık bir yapı kazanmasına neden olmuştur. Çalışmada kullanılan asimetrik nedensellik yaklaşımı, pozitif ve negatif şokların etkilerini ayrı ayrı inceleyerek doğrusal analizlerin ortaya koyamadığı saklı

ilişkilerin tespit edilmesine imkân sağlamaktadır. Ayrıca asimetrik etki-tepki fonksiyonları sayesinde şokların yönü ve etkisi daha ayrıntılı biçimde değerlendirilebilmektedir. Bu yöntemsel yaklaşım, özellikle kriz ve belirsizlik dönemlerinde finansal piyasaların petrol fiyat hareketlerine verdiği farklı tepkilerin daha kapsamlı analiz edilmesine katkı sunmaktadır.

Analiz sonuçları, simetrik nedensellik testine göre petrol fiyatlarından BIST100 endeksine doğru anlamlı bir nedensellik ilişkisi bulunmadığını ortaya koymuştur. Ancak asimetrik nedensellik analizi, petrol fiyat şoklarının yönüne bağlı olarak BIST100 endeksi üzerinde farklı etkiler yarattığını göstermiştir. Elde edilen bulgulara göre, petrol fiyatlarındaki pozitif şokların BIST100 endeksinin pozitif bileşenlerinin; petrol fiyatlarındaki negatif şokların ise BIST100 endeksinin negatif bileşenlerinin nedeni olduğunu göstermektedir. Böylece, seriler arasında doğrusal olmayan ve asimetrik bir yapı olduğu, simetrik analizlerin ise söz konusu saklı ilişkileri tam olarak ortaya koymakta yetersiz kaldığı tespit edilmiştir. Asimetrik etki-tepki fonksiyonlarına ait bulgular da petrol fiyatlarındaki negatif şokların BIST100 endeksindeki negatif şokları azaltıcı yönde etkide bulunduğunu göstermektedir. Buna karşılık petrol fiyatlarındaki pozitif şokların, BIST100 endeksindeki pozitif hareketleri artırdığı belirlenmiştir. Bu durum, petrol fiyat hareketlerinin hisse senedi piyasası üzerindeki etkisinin yalnızca büyüklük açısından değil, aynı zamanda yön bakımından da farklılaştığını ortaya koymaktadır.

Çalışmanın bulguları, özellikle RUÇ ve COVID-19 pandemisi gibi küresel ekonomik ve jeopolitik kırılmaların yaşandığı dönemlerde, petrol piyasası ve finansal piyasalar arasındaki etkileşimin karmaşık ve kırılgan bir yapıya dönüştüğünü doğrulamaktadır. Ayrıca elde edilen sonuçlar, petrol fiyat şoklarının Türkiye gibi enerji ithalatçısı ülkelerde finansal piyasa dinamikleri açısından önemli bir risk unsuru olduğunu göstermektedir. Bu kapsamda çalışma, politika yapıcılar açısından enerji fiyatlarındaki dalgalanmaların finansal piyasalar üzerindeki etkilerini dikkate alan makroekonomik politika çerçevelerinin geliştirilmesinin önemine işaret etmektedir. Yatırımcılar açısından ise petrol fiyatlarındaki yönsel değişimlerin hisse senedi piyasası üzerindeki olası etkilerinin göz önünde bulundurulması, portföy çeşitlendirmesi ve risk yönetimi stratejileri bakımından kritik bir gereklilik oluşturmaktadır.

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THE RELATIONSHIP BETWEEN HAPPINESS, WELL-BEING, AND URBAN LIFE SATISFACTION: A CROSS-SECTIONAL PRELIMINARY STUDY IN TURKEY

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ABSTRACT

In the field of psychology, focusing solely on pathology leads to the neglect of phenomena such as optimism, hope, future orientation, creativity, and responsibility, resulting in psychology becoming a model devoid of positive attributes. On the other hand, positive psychology, examines emotions and positive behaviors with the aim of promoting human happiness. Thus, approaches aimed at understanding happiness and discovering ways to achieve it constitute one of the fundamental topics of positive psychology. This study aims to examine well-being and urban life satisfaction as predictors of happiness within this context. The study included 744 participants from 15 different urban of Turkey, reached through web-based online application between March 2025 and March 2026. Participants completed the Oxford Happiness Scale short form, the Warwick-Edinburgh Mental Well-being Scale, and the Urban Life Satisfaction Scale A, along with a short socio-demographic questionnaire. According to the results, no statistically significant difference was found in the average level of happiness among participants living in the 15 different cities. However, statistically significant differences were observed in the average levels of well-being and urban life satisfaction among participants living in different cities. While happiness and well-being shared 47.4% of the variance between themselves, urban life satisfaction explained 4.8% of the variance in happiness and 3.9% of the variance in well-being. The age variable, along with urban life satisfaction, contributed to explaining the variance in well-being. Length of time spent in the urban had no effect. Similarly, when considered together with urban life satisfaction, neither the age variable nor the length of time spent in the urban had an effect on explaining the variance in happiness. Under these conditions, an increase of approximately 1% was achieved in explaining the variance in both well-being and happiness. When the results are evaluated as a whole, it is observed that urban life satisfaction is a significant component of both well-being and happiness.

Keywords: *Happiness, Well-Being, Satisfaction with Urban Life.*

JEL Codes: *I31, N9, I3.*

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1. INTRODUCTION

In the field of psychology, focusing solely on pathology leads to the neglect of phenomena such as optimism, hope, future orientation, creativity, and responsibility, resulting in psychology becoming a model devoid of positive attributes (Seligman ve Csikszentmihalyi, 2000). On the other hand, positive psychology, examines emotions and positive behaviors with the aim of promoting human happiness (Scorsolini-Comin ve ark. 2013). Thus, approaches aimed at understanding happiness and discovering ways to achieve it constitute one of the fundamental topics of positive psychology (Pelechano, González-Leandro, Garcia ve Morán, 2012). This study aims to examine well-being and urban life satisfaction as predictors of happiness within this context.

2. METHOD

2.1. Participants

The study included 744 participants, 467 women (62.80%) and 277 men (37.20%), aged between 18 and 76 years (mean = 24.54; s = 9.08). It was found that 18 of the participants were primary school graduates (2.40%), 17 were middle school graduates (2.30%), 89 were high school graduates (12.00%), and 619 were university graduates (83.20%) (1 person did not specify their educational status (0.1%)). Regarding income level, 62 participants (8.30%) described it as low, 490 as medium (65.90%), and 192 as high (25.80%).

2.2. Materials

In the study, participants were given a socio-demographic questionnaire consisting of several questions, along with the Oxford Happiness Scale short form, the Warwick-Edinburgh Mental Well-being Scale, and the A Urban Life Satisfaction Scale.

Oxford Happiness Scale: The scale, which consists of seven items in its short form and two items that are reverse, is composed of five-point Likert-type response options ranging from Strongly Disagree (1) to Strongly Agree (5). In the study where the scale was adapted into Turkish, the Cronbach alpha internal consistency coefficient was stated as 0.74, and the test-retest reliability coefficient was 0.85 (Doğan and Çötok, 2011).

Warwick-Edinburgh Mental Well-being Scale: This scale, which does not have any reversed items and where high scores indicate high mental (psychological) well-being, consists of 14 items. The items are administered with five-point Likert-type response options ranging from strongly disagree (1) to strongly agree (5). In the study where the scale was adapted into Turkish, the Cronbach alpha internal consistency reliability coefficient was stated as 0.92 (Keldal, 2015).

A Urban Life Satisfaction Scale: The A Urban Life Satisfaction Scale, where a high score indicates satisfaction with urban life, consists of 50 items with a five-point rating scale from Not Satisfied (1) to Very Satisfied (5). There are no reverse-pointing items in the scale. In the study in which the scale was developed, the Cronbach alpha internal consistency reliability coefficient was stated as 0.95 (Tatar et al., 2017).

2.3. Procedure

The study was implemented between March 2025 and March 2026 using a web-based form. The form link was shared on social media, and 744 people living in 15 different urban in Turkey, reached through this method, voluntarily participated in the study. The form first explained the purpose of the study and requested "consent form" followed by the questions and items.

2.4. Data Analysis

First, the Cronbach's Alpha internal consistency reliability coefficients of the scales used in the study were calculated, and then Pearson correlation analysis was performed between the total scores. Then, a comparison of the total scores of the three scales in the 15 different urban was performed using one-way analysis of variance (ANOVA). Inter group comparisons were conducted using the Tukey test. Finally, happiness and well-being level were predicted using linear regression analyses.

3. FINDINGS

First, the Cronbach's Alpha internal consistency reliability coefficients of the scales used in the study were calculated. According to the results, the Cronbach's Alpha coefficients of the scales were determined as 0.71 for The Oxford Happiness Questionnaire, 0.91 for the Warwick-Edinburgh Mental Well-Being Scale, and 0.95 for the A Urban Life Satisfaction Scale. Then, correlations were calculated between the total scores of the scales, and coefficients of 0.69 ($p < 0.001$) were determined between the happiness scale and the well-being scale, 0.22 ($p < 0.001$) between the happiness scale and the urban life satisfaction scale, and 0.20 ($p < 0.001$) between the well-being scale and the urban life satisfaction scale (Table 1).

Table 1. Cronbach's Alpha Internal Consistency Reliability Coefficients and Correlation Coefficients between Total Scores of the Scales

Scales	n	n of Items	1	2	3
1. The Oxford Happiness Questionnaire	744	7	(0.71)		
2. Warwick-Edinburgh Mental Well-Being Scale	744	14	0.69***	(0.91)	
3. A Urban Life Satisfaction Scale	744	50	0.22***	0.20***	(0.95)

Notes: Cronbach's Alpha internal consistency reliability coefficients are given in the diagonal. ***$p < 0.001$

Table 1 shows the 15 urban included in the study and the number of participants from each urban. Participants were first compared in terms of satisfaction with urban life, well-being, and happiness levels

according to their urban of residence. The comparison was made using one-way analysis of variance. According to the results, there is a statistically significant difference in the average satisfaction levels of participants from 15 different cities; $F(14, 729) = 2.76$; $p < 0.001$. According to this result, there is no difference only between Antalya, Manisa, and İzmir. Apart from these, all other cities show differences from each other. The lowest average value was observed for Antalya, and the highest average value for Konya. When the cities are ranked from lowest to highest satisfaction level, they are as follows: Antalya, Manisa, İzmir, Adana, Aydın, Muğla, Kocaeli, Balıkesir, Bursa, İstanbul, Denizli, Ankara, Mersin, Eskişehir, and Konya (Table 2, Table 3).

Table 2. Comparison of Urbans in Terms of Life Satisfaction, Well-Being, and Happiness Levels

Urban	n	Urban Life Satisfaction				Mental Well-Being				Happiness			
		Mean	Std. Dev.	F(14, 729)	Sig.	Mean	Std. Dev.	F(14, 729)	Sig.	Mean	Std. Dev.	F(14, 729)	Sig.
Adana	32	57.46	11.03	2.76	0.001	52.84	8.71	1.87	0.026	24.59	4.84	0.93	0.526
Ankara	48	62.90	14.48			52.54	8.60			23.15	4.25		
Antalya	24	55.00	11.23			49.58	8.59			21.96	4.24		
Aydın	55	58.45	10.71			52.15	9.35			23.73	4.04		
Balıkesir	60	59.91	13.00			47.35	8.43			22.25	4.45		
Bursa	93	60.49	14.76			51.66	9.57			23.35	5.16		
Denizli	43	62.13	9.64			48.28	9.16			22.02	4.65		
Eskişehir	23	63.43	10.76			50.04	11.76			23.35	3.82		
İstanbul	88	61.51	11.90			50.16	9.53			23.15	5.01		
İzmir	77	56.38	12.53			51.83	11.39			22.81	5.26		
Kocaeli	21	59.70	14.48			53.38	8.35			22.81	3.80		
Konya	25	67.18	14.99			49.60	9.73			23.68	4.54		
Manisa	77	55.20	13.43			52.49	12.14			23.86	5.02		
Mersin	29	63.03	14.90			50.83	10.70			23.59	5.03		
Muğla	49	58.64	12.41			47.16	11.43			23.18	4.09		
Total	744	59.65	13.06			50.72	10.13			23.17	4.71		

Table 3. Ranking from Lowest to Highest Level of Satisfaction with Urban Life

1. Antalya / Manisa / İzmir
2. Adana
3. Aydın
4. Muğla
5. Kocaeli
6. Balıkesir
7. Bursa
8. İstanbul
9. Denizli
10. Ankara
11. Mersin

12. Eskişehir
13. Konya

There is a statistically significant difference between the average well-being levels of participants from different urban; $F(14, 729) = 1.87$; $p < 0.05$. According to this result, the average well-being levels of Balıkesir and Muğla are lower than those of Adana, Ankara, Aydın, Bursa, İzmir, Kocaeli, and Manisa. Also, the average well-being level of Denizli is lower than those of Ankara and Manisa. According to another comparison, there is no statistically significant difference between the average happiness levels of participants from 15 different urban; $F(14, 729) = 0.93$; $p > 0.05$ (Table 2).

In the study, happiness score was then predicted using simple linear regression analysis with the satisfaction with urban life score, and 4.8% of the variance in happiness was explained (Model 1). When happiness score was predicted using simple linear regression analysis with well-being score, it was found that well-being explained 47.4% of the variance in happiness (Model 2). When happiness score was predicted using multiple linear regression analysis with well-being score and satisfaction with urban life score, 48.1% of the variance in happiness was explained (Model 3). When age and length of urban life variables, which did not have a statistically significant effect, were added (Models 4 and 5), it was observed that there was no significant change in the amount of variance explained in happiness, and it remained at 48.2% (Table 4).

Table 4. Prediction of Happiness Using Simple and Multiple Linear Regression Analysis

Model		B	Std. Error	Beta	t	Sig.	R	R Square	Adjusted R Square	F	Sig.
1	Constant	18.460	.789		23.397	.000	.219	.048	.047	37.409	.000
	Urban Life Satisfaction	1.581	.258	.219	6.116	.000					
2	Constant	6.922	.640		10.807	.000	.689	.474	.474	669.56	.000
	Mental Well-Being	.320	.012	.689	25.876	.000					
3	Constant	5.470	.782		6.992	.000	.694	.481	.480	344.023	.000
	Mental Well-Being	.313	.013	.672	24.889	.000					
	Urban Life Satisfaction	.622	.195	.086	3.193	.001					
4	Constant	5.322	.834		6.384	.000	.694	.482	.480	228.928	.000
	Mental Well-Being	.312	.013	.671	24.738	.000					
	Urban Life Satisfaction	.625	.195	.086	3.199	.001					
	Age	.007	.014	.013	.488	.625					
5	Constant	5.285	.833		6.342	.000	.695	.482	.480	171.738	.000
	Mental Well-Being	.313	.013	.671	24.681	.000					
	Urban Life Satisfaction	.598	.197	.083	3.040	.002					
	Age	-.006	.015	-.011	-.366	.715					
	Time Spent In The Urban (year)	.025	.014	.053	1.785	.075					

Similarly, well-being was predicted using simple linear regression analysis with satisfaction with urban life score, and 3.9% of the variance in well-being was explained (Model 6). When age was included in the model (Model 7), the explained variance increased to 4.5%, and when the length of time spent in the urban was added (Model 8), the explained variance increased to 4.9%.

Table 5. Prediction of Well-Being Using Simple and Multiple Linear Regression Analysis

Model		B	Std. Error	Beta	t	Sig.	R	R Square	Adjusted R Square	F	Sig.
6	Constant	41.568	1.704		24.400	.000	.198	.039	.038	30.242	.000
	Urban Life Satisfaction	3.068	.558	.198	5.499	.000					
7	Constant	39.502	1.949		20.273	.000	.213	.045	.043	17.546	.000
	Urban Life Satisfaction	3.056	.558	.197	5.475	.000					
	Age	.086	.040	.077	2.133	.033					
8	Constant	39.320	1.943		20.237	.000	.222	.049	.046	12.793	.000
	Urban Life Satisfaction	3.207	.559	.207	5.732	.000					
	Age	.108	.045	.097	2.424	.016					
	Time Spent In The Urban (year)	-.050	.040	-.050	-1.238	.216					

4. DISCUSSION

Although the study compares 15 different cities in terms of satisfaction with life, well-being, and happiness levels, and is indicated with a statistical significance level, the sample-population representativeness appears weak due to the small number of participants taken from each urban for such studies. In other words, a larger number of people taken from each urban is expected for such a comparison. Because the participation of the participants in the study was based on voluntariness via online means, the possibility of bias is high. The selection of participants, i.e., their participation in the study, was not entirely random when done online. Technology use and age may have played an important role in this selection. On the other hand, this study design allowed for the examination of the effect of satisfaction with urban life on both well-being and happiness of individuals. Thus, although this study design is simple, the importance of satisfaction with urban life in terms of well-being and happiness has been observed.

5. CONCLUSION

Summarize the main findings, practical implications, limitations, and possible avenues for future research. Keep the style concise and consistent with the journal’s publication standards.

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ENTROPİ TEMELLİ SÜRDÜRÜLEBİLİR EKONOMİ:

EKONOMİK BÜYÜMEYE TERMODİNAMİK BİR YAKLAŞIM

Sefer Faruk ÖZKURT*

ÖZET

Bu çalışmanın amacı, ekonomik büyümenin sürdürülebilirliğini termodinamiğin ikinci yasası ve entropi kavramı çerçevesinde yeniden değerlendirmektir. Ana akım büyüme iktisadı, ekonomiyi büyük ölçüde para, piyasa ve dairesel gelir akımı üzerinden tanımlamakta; üretimin dayandığı enerji dönüşümünü, düşük entropili doğal kaynak kullanımını ve yüksek entropili atık üretimini çoğu zaman analizin dışında bırakmaktadır. Bu nedenle çalışma, ekonomiyi kapalı ve döngüsel bir parasal sistem olarak değil; doğadan düşük entropili enerji ve madde alan, üretim ve tüketim süreçleri sonunda bunları yüksek entropili atık ve ısıya dönüştüren açık bir sistem olarak ele almaktadır. Çalışmada kavramsal-analitik yöntem kullanılmış, yeni bir ampirik model kurulmamış ve mevcut literatür kuramsal bir çerçevede yeniden yorumlanmıştır. Georgescu-Roegen (1971) ve Daly (1991) çalışmanın teorik omurgasını oluşturmakta; Kümmel ve Lindenberger (2014) enerji-büyüme ilişkisine destekleyici ampirik kanıt sağlamaktadır. Çalışmanın temel sonucu, büyümenin kendiliğinden sorunlu olmadığı; ancak biyofiziksel sınırlar, kaynak akışı ve entropi maliyeti dikkate alınmadan sürdürülebilir kabul edilemeyeceğidir.

Anahtar Kelimeler: *Entropi, Termodinamiğin İkinci Yasası, Sürdürülebilir Ekonomi, Ekolojik İktisat, Ekonomik Büyüme, Enerji Dönüşümü.*

Jel Kodları: *Q01, Q57, O44, B41.*

ENTROPY-BASED SUSTAINABLE ECONOMY:

A THERMODYNAMIC APPROACH TO ECONOMIC GROWTH

ABSTRACT

This study aims to reassess the sustainability of economic growth within the framework of the second law of thermodynamics and the concept of entropy. Mainstream growth economics largely defines the economy through money, markets and the circular flow of income; consequently, the energy conversion on which production depends, the use of low-entropy natural resources and the generation of high-entropy waste generally remain outside the core analysis. For this reason, the study treats the economy not as a closed and circular monetary system but as an open system that receives low-entropy

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energy and matter from nature and transforms them into high-entropy waste and heat through production and consumption processes. The study adopts a conceptual-analytical method; it does not construct a new empirical model, but reinterprets the existing literature within a coherent theoretical framework. Georgescu-Roegen (1971) and Daly (1991) constitute the theoretical backbone of the paper, while Kümmel and Lindenberger (2014) provide supporting empirical evidence for the energy-growth relationship. The main conclusion is that growth is not inherently problematic; nevertheless, it cannot be considered sustainable unless biophysical limits, resource throughput and entropy costs are taken into account.

Keywords: *Entropy, Second Law of Thermodynamics, Sustainable Economy, Ecological Economics, Economic Growth, Energy Conversion.*

Jel Codes: *Q01, Q57, O44, B41.*

1. INTRODUCTION

Sustainability is directly related to the tension between economic growth and environmental limits. In mainstream growth economics, success is usually measured by growth rates, market expansion and monetary indicators, while the economy is commonly represented as a circular flow between firms and households. This representation is useful for explaining monetary exchange; however, it leaves out the physical foundation on which economic activity rests. The energy and matter obtained from nature, the transformation required by production and the waste and heat generated at the end of the process remain largely invisible in the standard picture.

From the perspective of the second law of thermodynamics, the economic process cannot be understood as a fully reversible and circular exchange. It is a one-directional process in which low-entropy resources are transformed into high-entropy waste and heat. In this sense, the economy is not an isolated mechanism operating independently from nature. It is an open subsystem that continuously draws usable energy and matter from the environment and releases degraded matter and dissipated heat back into it (Georgescu-Roegen, 1971; Daly, 1991; Avery, 2012).

This physical dimension is not a minor theoretical detail. Empirical studies on the relationship between energy and growth show that the productive weight of energy can be much greater than its small share in total cost suggests (Kümmel and Lindenberger, 2014). This finding challenges approaches that regard energy as economically secondary merely because it is relatively cheap in monetary terms. If production is interpreted as the transformation of energy and matter, the importance of energy cannot be reduced to its market price alone.

The central research question of this paper is therefore as follows: under what conditions can economic growth be considered sustainable when it is evaluated in the light of the second law of thermodynamics and the concept of entropy? This question has two dimensions. First, it asks whether

mainstream growth economics and common sustainability discourse sufficiently account for the irreversible transformation of low-entropy resources into high-entropy waste. Second, it asks what an entropy-based framework adds to the evaluation of growth by reading it not only as an increase in output but also as a process of resource and energy transformation.

The basic argument of the study is not that growth is inherently bad. The argument is more precise: growth cannot be regarded as sustainable unless biophysical limits and entropy costs are explicitly considered. Economic success should therefore be evaluated not only by the increase in production, but also by resource use, energy quality, ecological carrying capacity and social welfare. In methodological terms, this paper is conceptual and analytical. It does not develop a new empirical model. Instead, it brings together the theoretical line of Georgescu-Roegen and Daly with contemporary empirical findings on energy and growth and with the broader literature on ecological economics and sustainability.

The rest of the paper is organized as follows. The second section reviews the relevant literature and conceptual background. The third section explains the conceptual-analytical method used in the study. The fourth section develops the theoretical framework through the entropy-based interpretation of the economic process. The fifth section discusses energy, growth and entropy cost. The sixth section presents policy implications. The final section concludes the study.

2. LITERATURE REVIEW

The relationship between sustainability and economic growth has occupied an important place in economic thought since environmental limits became visible in the 1970s. Sustainability is a multidimensional concept that includes environmental, economic and social components and functions as a general vision for solving long-term development problems (Tutulmaz, 2012). This multidimensional nature implies that sustainability cannot be fully understood through the tools of a single discipline. It also suggests that economic analysis should be reframed in a way that incorporates the physical conditions of production and consumption.

The problem of nature and natural resources is not entirely new in economics. However, the treatment of these issues as a challenge to the core assumptions of mainstream economics is relatively recent. Environmental economics and natural resource economics largely developed within a neoclassical framework, whereas ecological economics emerged as a more radical field that places the economy inside the ecosystem rather than outside it (Ulucak, 2018). The central criticism is that neoclassical growth models often treat ecological constraints as external or secondary, while attributing a strong adaptive capacity to technological progress. Ecological economics, by contrast, regards nature as an internal boundary of economic activity.

The thermodynamic interpretation of the economy is most strongly associated with Georgescu-Roegen (1971). He criticized the neoclassical representation of the economy as a reversible mechanical system and argued that the economic process is subject to the second law of thermodynamics. Economic

activity transforms low-entropy resources into high-entropy waste and heat. Natural resources are therefore not external additions to the economic model; they are internal and limiting conditions of value creation. Daly (1991) extended this line of thought through the concept of steady-state economics. He defined the economy as an open subsystem of a finite ecosystem and placed throughput, the one-directional flow of matter and energy, at the center of the analysis.

This theoretical line also raises the question of how economic value and cost are measured. Market prices and gross domestic product may capture the monetary volume of economic activity, yet they do not directly reveal the entropy cost of production and consumption. Eroğlu and Canan (2019) emphasize that the price mechanism can make natural resources appear less valuable than they are from an ecological point of view. Similarly, Jakimowicz (2020) argues that monetary reductionism obscures irreversibility and complexity, while Røpke (2020) stresses that the circular flow model hides the economy's dependence on high-quality energy and its generation of waste.

The need for a new economic framework is therefore not only environmental but also epistemological. Røpke (2020) argues that a new economics should go beyond market exchange and define the economy as a provisioning process grounded in thermodynamics, ecology, energy history and social metabolism. Jakimowicz (2020) shows that the second law of thermodynamics has contributed to the historical development of entropy economics and ecological economics. Avery (2012) summarizes this idea in simple terms: the economy can be read as a system that takes usable energy and resources from its environment, produces order within itself, and returns waste and heat to the environment.

Empirical evidence on the energy-growth relationship supports this conceptual argument. Kümmel and Lindenberger (2014) show that energy conversion can play a role in production that is substantially larger than its cost share implies. This finding is important because it indicates that energy is not merely another input priced in the market; it is a physical condition of production. Taken together, the literature reveals separate but connected streams: sustainability studies, ecological economics, entropy economics, thermodynamic approaches to the economy and empirical work on energy and growth. The contribution of this paper is to bring these streams together in a single conceptual-analytical framework for evaluating the sustainability of economic growth.

3. METHODOLOGY

This study adopts a conceptual-analytical method. Its aim is not to produce a new measurement or econometric estimation, but to reinterpret the relationships among economic growth, production, energy, natural resources, entropy and sustainability through the existing academic literature. For this reason, the paper should be read as a theoretical synthesis rather than an empirical analysis.

The choice of method is determined by the nature of the research question. The question of whether economic growth can be considered sustainable in the light of the second law of thermodynamics is not, in the first instance, a numerical question. It is a conceptual question concerning how the economy is defined, which assumptions guide its modelling and how value and cost are understood. Such a question requires the identification and comparison of competing theoretical assumptions rather than the construction of a new econometric model.

Accordingly, the study does not create a new data set, conduct a cross-country comparison or estimate a statistical model. Empirical findings are not excluded; however, they are used in a supporting role. In particular, Kümmel and Lindenberger's (2014) findings on the productive weight of energy are treated as secondary evidence that strengthens the theoretical argument. The purpose is not to test a new empirical hypothesis but to show how existing empirical results can be interpreted within an entropy-based framework.

The sources used in the study have been selected according to their analytical function. Georgescu-Roegen (1971) and Daly (1991) provide the theoretical backbone. Kümmel and Lindenberger (2014) provide empirical support for the role of energy in growth. Røpke (2020), Jakimowicz (2020) and Avery (2012) serve as connecting and explanatory sources that clarify the interdisciplinary character of entropy-based economics. Tutulmaz (2012), Ulucak (2018), Çamdalı (2024), and Eroğlu and Canan (2019) are used to connect the discussion with the Turkish academic literature on sustainability, ecological economics and thermodynamics-economy relations.

The analysis proceeds through four conceptual comparisons. The first comparison concerns whether the economy should be defined as a closed monetary circuit or as an open system that receives low-entropy matter and energy from nature and releases high-entropy waste and heat. The second comparison concerns whether the economic process should be viewed as a reversible equilibrium mechanism or as an irreversible process subject to the second law of thermodynamics. The third comparison concerns whether value and cost should be measured only by market prices or also by energy quality, resource scarcity and entropy cost. The fourth comparison concerns whether growth should be evaluated only as quantitative output expansion or as a process constrained by biophysical limits.

The method has clear limitations. Since the study is conceptual and analytical, its claims are not tested at the country, sector or firm level. The conclusions are therefore theoretical reframings rather than empirical generalizations. Expressions such as labor as organized biological energy or capital as stored energy and labor should also be understood as conceptual propositions, not as strict physical laws. These limitations do not weaken the argument; they define its scope and prepare the ground for later empirical research.

4. THEORETICAL FRAMEWORK

4.1. The Entropic and Irreversible Character of the Economic Process

Georgescu-Roegen (1971) argues that mainstream economics overlooks the physical character of the economic process by representing it as reversible, circular and mechanical. In his view, economic activity is not a movement that can be run forward and backward like a mechanical oscillation. It is a process with a direction. This direction arises from the second law of thermodynamics: production and consumption transform usable energy and matter into less usable forms, and this transformation cannot be fully reversed along the same path.

This point determines the central argument of the paper. The economy is not an abstract monetary system operating outside the physical world. It is a transformation process governed by physical constraints. Every act of production organizes matter and energy for human purposes, but it also leaves behind heat, waste and dispersed materials. The economic process therefore has an entropic character.

4.2. Low-Entropy Resources, Economic Value and Natural Limits

The irreversible character of the process determines the position of natural resources within economic analysis. Natural resources are not external data added to a model after the fact. They are internal conditions of production and value creation. In an entropy-based reading, production means using low-entropy resources and converting them into useful forms. The problem is not that matter or energy disappears; the problem is that usable energy degrades into heat and concentrated resources become dispersed (Avery, 2012).

A simple analogy may clarify this point. The molecules of a dispersed perfume do not disappear, but they cannot be gathered again into their original concentrated form without additional energy and loss. Similarly, economic activity does not destroy matter in an absolute sense; rather, it changes the quality and availability of matter and energy. This means that economic value is related not only to price but also to the physical condition of resources.

4.3. Critique of the Circular Flow and the Linear Throughput of Matter and Energy

Daly (1991) translates Georgescu-Roegen's entropy argument into a critique of the circular flow model. The standard model presents the economy as a continuous circulation of goods, services and money between households and firms. While this model is useful for representing exchange, it obscures the physical basis of the economy. It makes the economy appear self-contained, as if it were not embedded in nature.

Daly argues that the actual physical foundation of the economy is not circular but linear. The economy takes low-entropy matter and energy from the ecosystem and returns high-entropy waste and heat to it. He calls this one-directional flow throughput and places it at the center of economic analysis.

Røpke (2020) develops a similar criticism by arguing that the circular flow model hides the dependence of the economy on high-quality energy and the generation of waste. This distinction between circular monetary flow and linear matter-energy throughput is essential for an entropy-based sustainable economy.

4.4. Reinterpreting Production Factors: Labor, Capital and Energy

If the economic process is a physical transformation, the standard production factors must also be reinterpreted. Production is not merely an abstract combination of labor and capital. It is a process that transforms energy and matter over time. Within this framework, labor may be interpreted as the organized and purposeful use of biological energy, while capital may be interpreted as accumulated past labor and energy embodied in tools, machines and infrastructure.

These expressions are not intended as strict physical laws. They are conceptual propositions that make the physical dimension of production visible. Their importance is supported by empirical findings showing that the role of energy in production can be far greater than its cost share suggests (Kümmel and Lindenberger, 2014). Energy is therefore not a marginal input simply because it is cheap. It is one of the conditions that makes production possible.

4.5. The Distinction Between Growth and Development and the Steady-State Economy

The theoretical line reaches a clear policy-relevant distinction in Daly's (1991) separation of growth and development. Growth refers to quantitative expansion, especially the increase in the physical scale of the economy and its throughput. Development refers to qualitative improvement in welfare, knowledge, efficiency and institutional capacity. A finite and non-growing ecosystem cannot support an endlessly expanding physical economy, but qualitative development can continue within physical limits.

The steady-state economy should not be understood as stagnation or crisis. It refers to an economy that maintains a sustainable physical scale, limits resource throughput and emphasizes qualitative development. This distinction leads to the main theoretical proposition of this paper: growth is not rejected in itself, but it cannot be considered sustainable unless its biophysical scale and entropy cost are evaluated.

5. DISCUSSION: ENERGY, GROWTH AND ENTROPY COST

The theoretical framework developed above suggests that growth should not be evaluated only as an increase in output or monetary volume. It should also be understood as a transformation of resources and energy. When growth is read in this way, the sustainability debate changes its ground. The question is not simply how much an economy produces, but what kind of resource flow and entropy cost make that production possible.

Mainstream economics tends to evaluate production factors through their cost shares. Labor and capital appear important because their shares in total cost are large, while energy appears less important because its monetary share is relatively small. However, energy is not only a cost item. It is a physical enabling condition of production. Kümmel and Lindenberger (2014) show that the production elasticity of energy may be significantly higher than its cost share. This means that small changes in energy input can have larger effects on output than standard cost-share reasoning would predict.

This distinction is crucial for understanding why energy shocks may produce output losses greater than expected. The energy crises of the 1970s revealed that the role of energy in the production system cannot be reduced to its market price. In addition, part of the growth that is commonly attributed to exogenous technological progress may be reinterpreted as the result of the productive role of energy conversion. The point is not to deny technological progress, but to insist that technology itself operates through matter and energy.

The same problem appears in the measurement of growth. Gross domestic product measures the monetary volume of economic activity, but it does not reveal how much energy, material flow and waste are associated with that activity. A country may increase GDP while also increasing its dependence on low-entropy resources and its production of high-entropy waste. Such growth may look successful in monetary terms while remaining fragile or unsustainable in biophysical terms.

Entropy cost is also related to consumption patterns. If production converts low-entropy resources into high-entropy waste, then consumption that adds little to social welfare also carries an entropy cost. Status-oriented or display-based consumption may generate production and resource use without proportional welfare gains. This observation is not a moral judgement against consumer preferences. It is an analytical point: resource use that does not significantly improve welfare still consumes energy, materials and ecological capacity.

The conclusion of this discussion is a careful reframing of growth. Economic growth may support welfare, productivity and qualitative development. However, it cannot be evaluated only through the increase in output. It must be evaluated together with energy quality, resource throughput, waste generation, entropy cost and ecological carrying capacity. The analytical contribution of an entropy-based approach is therefore to move the debate from quantity alone to biophysical sustainability.

6. POLICY IMPLICATIONS

An entropy-based sustainable economy does not automatically produce a detailed policy program. However, by reading economic activity as a physical transformation process, it provides important implications for policy design. These implications should be understood as an analytical framework that can complement existing sustainability policies rather than replace them.

The first implication is that GDP should not be treated as a sufficient indicator of sustainability. Monetary indicators should be complemented by biophysical indicators such as energy intensity, material throughput, waste generation, greenhouse gas emissions, ecological footprint and resource efficiency. This does not mean abandoning GDP. It means interpreting GDP together with indicators that reveal the physical basis and ecological cost of economic activity.

The second implication concerns energy efficiency. Improving energy efficiency is necessary because it can reduce the resource and entropy cost of a given level of output. Yet efficiency alone may not be sufficient. If lower unit costs encourage higher total consumption and production, part of the efficiency gain can be offset by a rebound effect. For this reason, efficiency policies should be designed together with targets that limit absolute resource and energy throughput.

The third implication is that production and consumption patterns should be evaluated according to entropy cost as well as monetary value. Durability, repairability and reusability should be treated as important design principles because they can reduce material flow and waste. At the same time, resource use that contributes little to social welfare should be examined more carefully. The aim is not to restrict preferences in a moralistic way, but to make the relationship between welfare, resource flow and waste visible.

The fourth implication concerns the circular economy. Recycling, reuse and closed material cycles are valuable tools for reducing resource flows and waste. Nevertheless, the second law of thermodynamics means that perfect and lossless circularity is not possible. Every recycling process requires energy and involves some degradation or dispersion. Therefore, the circular economy should be understood as an approach that reduces entropy cost, not one that eliminates it.

These implications can be summarized around four concepts: scale, sufficiency, efficiency and qualitative development. Scale refers to keeping the physical size of the economy within ecological carrying capacity. Sufficiency refers to aligning resource use with welfare needs. Efficiency refers to producing a given output with lower resource input. Qualitative development refers to improving welfare, knowledge and quality without relying solely on quantitative expansion. This framework is not a simple anti-growth position; it is a proposal to measure economic success by the capacity to create welfare with lower resource throughput.

7. CONCLUSION

This study started from the question of under what conditions economic growth can be considered sustainable when evaluated through the second law of thermodynamics and the concept of entropy. The answer developed throughout the paper is conceptual rather than econometric: the economy should be understood not as a closed monetary circuit, but as an open system that receives low-entropy energy and matter from nature and transforms them into high-entropy waste and heat.

The study adopted a conceptual-analytical method. It did not create a new data set, estimate an econometric model or conduct a country comparison. Instead, it brought together theoretical and empirical literature on economic growth, energy, natural resources, entropy and sustainability in order to propose a coherent framework. Empirical findings on the energy-growth relationship were used only as supporting evidence for the theoretical argument.

The main result is that economic growth should not be evaluated only as monetary expansion or output increase. Growth is also a physical process based on the transformation of low-entropy resources into high-entropy waste and heat. Monetary indicators can measure the volume of activity, but they do not directly show the energy conversion, resource throughput and waste generation behind that activity. Therefore, an economy may grow in monetary terms without being sustainable in biophysical terms.

The theoretical backbone of this result is provided by Georgescu-Roegen (1971) and Daly (1991). Georgescu-Roegen showed that the economic process is irreversible and subject to the second law of thermodynamics. Daly carried this insight into the sustainability debate by defining the economy as an open subsystem of a finite ecosystem and by placing throughput at the center of analysis. His distinction between quantitative growth and qualitative development is particularly important because it turns sustainability into a question of scale and resource flow.

The contribution of this paper is to combine this theoretical line with contemporary empirical findings on energy and growth and with the broader literature on ecological economics and sustainability. It argues that growth is not inherently negative, but it cannot be considered sustainable unless biophysical limits, entropy cost and social welfare are considered together. In this sense, an entropy-based reading does not invite economics to abandon growth discussions; it invites economics to ask what kind of growth, with which resource base, at what entropy cost and for what social benefit.

The limitations of the study are clear. Because it is conceptual and analytical, it does not empirically test its propositions. Future research can extend this framework by examining countries, sectors or firms through indicators such as energy intensity, material throughput, resource productivity, waste generation and ecological footprint. Such empirical work would make it possible to evaluate more concretely whether economic growth is moving toward or away from biophysical sustainability.

In conclusion, economic growth remains important for welfare and qualitative development, but it cannot be evaluated meaningfully without its physical foundation. The entropy-based approach proposed in this paper provides a conceptual ground for thinking about economic success not only in terms of how much is produced, but also in terms of which resources and energy transformations make that production possible.

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EKONOMİ POLİTİKA BELİRSİZLİĞİ VE BIST BANKA ENDEKSİ ARASINDAKİ ZAMANA GÖRE DEĞİŞEN NEDENSELLİK İLİŞKİSİ

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ÖZET

Küresel ölçekte yaşanan ekonomik belirsizlikler, yatırımcı kararları ve finansal piyasa istikrarı üzerinde belirleyici bir risk unsuru haline gelmiştir. Belirsizlikler piyasa mekanizmalarının işleyişinde aksaklıklara neden olmakta ve yatırımcı güvenini zedelemektedir. Söz konusu riskleri ölçmek amacıyla literatürde piyasa oynaklığının temel bir göstergesi olarak Baker vd., (2016) tarafından geliştirilen Ekonomik Politika Belirsizliği (EPU) endeksi karşımıza çıkmaktadır. Özellikle finansal sistemde risk ve likidite yönetiminin merkezinde yer alan bankacılık sektörü, politika belirsizliklere karşı en hassas sektörlerden biridir. Dolayısıyla, belirsizliklerin bankacılık sektörü ile ilişkisini anlamak, hem sektörel hem de sistemik riskin yönetilmesi açısından da önem taşımaktadır. Bu çalışmanın temel amacı, belirsizlik ve bankacılık sektörü arasındaki nedensellik ilişkisinin ampirik olarak analiz etmektir. Çalışmada değişken olarak EPU ile BİST Banka Endeksi kullanılmış olup, analiz dönemi ise küresel ölçekte ekonomik çalkantıların yaşandığı dönemleri kapsayacak şekilde 1997:M1-2025:M11 olarak belirlenmiştir. Politika şoklarının gelişmekte olan piyasalarda heterojen ve zamana göre değişkenlik gösteren etkiler yarattığı gerçeğinden hareketle, çalışmada Shi vd. (2020) tarafından geliştirilen zamana göre değişen Granger nedensellik analizi tercih edilmiştir. Analizden elde edilen bulgular, EPU'dan BİST Banka Endeksine doğru istatistiksel olarak anlamlı bir nedenselliğin varlığını ve bu nedenselliklerin farklı zaman dilimlerinde dinamik yapı sergilediğini ortaya koymaktadır. Özellikle nedensellik ilişkisinin COVID-19 Salgını, Rusya-Ukrayna Çatışması (RUC) gibi önemli belirsizlikler dönemlerinde daha belirgin olduğu gözlemlenmiştir. Çalışmanın bulguları, portföy yöneticileri için EPU'daki değişimlerin bankacılık sektörü açısından erken uyarı sinyali taşıdığını, politika belirleyiciler için ise küresel politika şoklarını merkeze alan dinamik bir risk yönetiminin zorunlu olduğu göstermektedir.

Anahtar Kelimeler: *BIST Banka Endeksi, Ekonomik Politika Belirsizliği (EPU), Zamanla Değişen Granger Nedensellik.*

Jel KODLARI: *E44, G10, C20.*

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THE TIME-VARYING CAUSAL RELATIONSHIP BETWEEN ECONOMIC POLICY UNCERTAINTY AND THE BIST BANKING INDEX

ABSTRACT

Economic uncertainties on a global scale have become a key risk factor affecting investor decisions and financial market stability. Uncertainties are causing disruptions in the functioning of market mechanisms and undermining investor confidence. To measure these risks, the Economic Policy Uncertainty (EPU) index developed by Baker et al. (2016) and recognized in the literature as a key indicator of market volatility is used. The banking sector, which plays a central role in risk and liquidity management within the financial system, is one of the sectors most sensitive to policy uncertainties. Therefore, understanding the relationship between uncertainties and the banking sector is also important for managing both sectoral and systemic risks. The primary objective of this study is to empirically analyze the causal relationship between uncertainty and the banking sector. The study uses the EPU and the BIST Banking Index as variables, and the analysis period is defined as 1997:M1–2025:M11 to cover periods of global economic turmoil. Given that policy shocks have heterogeneous and time-varying effects in emerging markets, this study employs the time-varying Granger causality analysis developed by Shi et al. (2020). The analysis results reveal a statistically significant causal relationship between the EPU and the BIST Banking Index and show that these causal relationships exhibit a dynamic structure across different time periods. Notably, the causal relationship was observed to be more pronounced during periods of significant uncertainty, such as the COVID-19 pandemic and the Russia-Ukraine Conflict (RUC). The study's findings suggest that changes in the EPU serve as an early warning signal for the banking sector for portfolio managers, while for policymakers, they highlight the necessity of a dynamic risk management approach centered on global policy shocks.

Keywords: *BIST Banking Index, Economic Policy Uncertainty (EPU), Time-Varying Granger Causality.*

JEL Codes: *E44, G10, C20.*

1. GİRİŞ

Küreselleşmenin etkisiyle birlikte, dünyada meydana gelen kriz, savaş ve politik olayların neden olduğu ekonomik belirsizlik faktörleri ülkelerin finansal piyasalarını etkileyen önemli bir makroekonomik unsur haline gelmiştir. Yaşanan ekonomik belirsizlikler karşısında özellikle gelişmekte olan piyasa ekonomileri daha kırılgan bir yapı sergilemektedir. Belirsizliğin arttığı dönemlerde yatırıcımların piyasaya olan güvenini zedelenmekte ve bu durum piyasa işleyişinde aksaklıklara neden olmaktadır (Özcelebi ve İzgi, 2023).

Belirsizliklerin hisse senedi piyasası üzerindeki etkileri de son yıllarda birçok araştırma tarafından analiz edilen konular arasında yer almaktadır. Belirsizliklerin hisse senedi piyasaları üzerindeki etkisi,

"bekle ve gör" teorisi ile açıklanmaktadır. Baker ve Bloom (2016) tarafından önerilen teroiye göre, belirsizlikler yatırımcıları yatırımlarından uzaklaştırarak borsa getirilerini olumsuz etkilemektedir. Nitekim, literatürdeki belirsizliklerin hisse senedi piyasasınında oynaklığı artırdığı ve getirileri düşürüdüğünü (Christou vd., 2017; Kundu ve Paul, 2022; Das vd., 2019; Guo vd., 2018) yönünde bulgular bu teoriyi doğrular niteliktedir. Ancak, belirsizliklerin etkileri ve bu etkilerin zamana bağlı olarak değişip değişmediği halen tartışma konusudur. Örneğin Çin piyayasında yapılan iki çalışmada, Xiong vd. (2018) çalışmasında, EPU'nun hisse senedi getirileri üzerindeki etkisinin zamana bağlı olarak değiştiğini ileri sürmekte iken Yang ve Jiang (2016) çalışmasında EPU ile borsa arasındaki ilişkinin gecikmeli ve çift yönlü olduğuna dair kanıtlar sunmaktadır. Arouri vd. (2016) ise ABD piyayası için yaptığı çalışmada, EPU ile hisse senedi piyasası arasındaki asimetrik ilişkiyi ortaya koymaktadır. Literatürde yer alan çalışmaların çoğu zamansal ve sektörel dinamikleri gelişmiş ülke piyasalarına için sınırlı bir biçimde yansıtmaktadır. Oysa, Türkiye'nin de içerisnde yer aldığı gelişmekte olan ekonomileri finansal piyasaları, belirsizliklere karşı oldukça duyarlıdır. Bu kapsamda finansal sistemin yapı taşlarından biri olan bankacılık sektörü, politika belirsizliklerinden en fazla etkilenmesi beklenen sektörlerden biridir. Bu nedenle, Türkiye' de bankacılık sektörünün belirsizliklere olan tepkisinin zaman içerisinde değişip değişmediğinin anlaşılması yatırımcı davranışlarının belirlebilmesi açısından önem taşımaktadır.

Bu çalışma, 1997:M1-2025:M11 dönemi son yıllarda belirsizliklerin ölçümünde en çok başvurulan Baker vd. (2016) tarafından önerilen EPU Endeksi ile Türkiye bankacılık sektöründe faaliyet gösteren bankaların piyasa performansını yansıtması bakımından önemli bir gösterge olan BIST Banka endeksi arasındaki nedensellik ilişkisini analiz etmeyi amaçlamaktadır. Çalışmada yöntem olarak Shi vd. (2020) tarafından geliştirilen zamana göre değişen Granger nedensellik analizi tercih edilmiştir. Literatürde ekonomik politika belirsizliği ve hisse senedi piyasaları arasındaki ilişkiyi ele alan çok sayıda çalışma bulunmasına rağmen, Türkiye özelinde bankacılık sektörüne odaklanan ve söz konusu ilişkinin zaman içerisindeki değişimini analiz eden çalışmalar sınırlı sayıdadır. Ayrıca mevcut çalışmaların önemli bir kısmı doğrusal ve sabit parametreli yöntemlere dayanmakta olup, ilişkinin farklı ekonomik ve finansal koşullar altında değişebilecek yapısını yeterince yansıtamamaktadır. Bu çalışma, Shi vd. (2020) tarafından geliştirilen zamanla değişen Granger nedensellik yöntemi kullanılarak ekonomik politika belirsizliğinin BIST Banka Endeksi üzerindeki etkisinin hangi dönemlerde güçlendiğini veya zayıfladığını ortaya koymaktadır.

Çalışma üç bölümden oluşmaktadır. Birinci bölümde belirsizliklerin finansal piyasalar üzerindeki etkileri tartışılmakta, ikinci bölümde ulusal ve uluslararası literatürde hisse senedi piyasası ve ekonomi belirsizlik endeksi arasındaki çalışmalar ele alınmaktadır. Üçüncü bölümde ise, çalışmada kullanılan yöntem ve ampirik bulgular değerlendirilmektedir.

2. LİTERATÜR

Son yıllarda literatürde artarak devam eden hisse senedi piyasası ve ekonomi politika belirsizliği arasındaki ilişkiyi inceleyen çalışmalar analiz ettikleri ülke, sektör, dönem ve kullandıkları yönteme göre farklı sonuçlar elde etmektedir.

Literatürdeki yaygın görüş, EPU endeksindeki artışların hisse senedi getirilerini düşürdüğü ve piyasa oynaklığını artırdığı yönündedir (Boutchkova vd., 2012; Liu ve Zhang, 2015; Arouri vd., 2016; Yu vd., 2018; Su vd., 2019) Ancak, bu etki piyasa koşullarına (Ko ve Lee, 2015) ve zamana (Antonakakis vd., 2013; Pastor ve Veronesi, 2012; Erdoğan vd., 2022; Zhao ve Wang, 2022; Hong vd. 2024) göre doğrusal olmayan (Pala, 2024), bir gelişim göstermektedir. Söz konusu çalışmalarda DCC-GARCH, DCC-MGARCH, SVAR, VAR, NARDL, Markov rejim geçişli modeler gibi dinamik modeler kullanılmıştır. Literatürde, belirsizliğin her sektörü aynı şiddette etkilemediğine dair bulgular da yer almaktadır (Korkmaz ve Güngör, 2018; Hoque ve Zaidi, 2019; Hu vd., 2018; Kocaarslan, 2020; Seçme, 2024; Meriç ve Kamışlı, 2024). Küresel ölçekte finans, sağlık ve imalat sektörleri EPU şoklarına karşı yüksek duyarlılık sergilerken, tarım ve teknoloji gibi sektörlerin daha dirençli olabildiği saptanmıştır (Rehman vd., 2019). Türkiye bankacılık sektörü üzerine yapılan analizler, EPU'nun sadece bir getiri kaybı unsuru değil, aynı zamanda bir sistemik kırılganlık tetikleyicisi olduğunu ortaya koymaktadır ABD kaynaklı belirsizliklerin Türkiye'deki bankacılık sektörü kırılganlık olasılığını artırması, finansal istikrarın korunması noktasında dış şokların ne kadar belirleyici olduğunu göstermektedir (Aytaç Emin, 2025). EPU ve Banka Endeksi (XBANK) arasındaki ilişkinin yönü konusunda kısıtlı çalışma (Ceyhan, 2025; Topcu, 2025; Gürçay, Akbalık & Turgut, 2026) yer almakta ve söz konusu çalışmalarda yöntem olarak sabit parametreli TY, Granger vb. nedensellik analizleri tercih edilmiştir.

Literatürdeki çalışmalar incelendiğinde, hisse senedi piyasaları ile ekonomik politika belirsizliği arasındaki ilişkinin dinamik ve koşullara bağlı bir yapı sergilediğini ortaya koymaktadır. Bulgular, çoğunlukla belirsizlik artışlarının getiriler üzerinde baskı oluşturduğunu ve piyasa oynaklığını artırdığını göstermekte; ancak ilişkinin doğrusal ve sabit parametreli modellerle tam olarak açıklanamadığı, etkilerin zaman ve ekonomik koşullara göre değişebildiği vurgulanmaktadır. Ayrıca sektör bazlı çalışmalar, bu etkinin homojen olmadığını ve özellikle bankacılık sektörünün belirsizlik şoklarına daha duyarlı olabildiğini göstermektedir. Türkiye özelinde ise bankacılık sektörü ile ekonomik politika belirsizliği arasındaki ilişkinin yönü ve niteliğine dair bulguların tutarlı olmadığı, sonuçların kullanılan yöntem ve örnekleme dönemine göre farklılaştığı görülmektedir. Bu bulgular, ilişkinin zaman içinde değişen yapısını dikkate alan daha esnek ve dinamik yöntemlere duyulan ihtiyacı açık biçimde ortaya koymaktadır. Bu doğrultuda çalışma, zamana göre değişen nedensellik yaklaşımı kullanarak Türkiye bankacılık sektörü özelinde ekonomik politika belirsizliği ile hisse senedi piyasası arasındaki ilişkiyi daha kapsamlı ve güncel bir çerçevede yeniden değerlendirmeyi amaçlamaktadır.

3. VERİ SETİ, METODOLOJİ VE BULGULAR

3.1. Veri Seti ve Metedoloji

Bu çalışma, ekonomi politika belirsizlik endeksi ve BIST banka endeksi arasındaki nedensellik ilişkisini analiz etmek amacıyla 1997M1- 2025M11 dönemini kapsayan aylık zaman serisi verileri kullanılmıştır. Çalışmada kullanılan değişkenlerine ait tanımlamalar Tablo 1' de sunulmaktadır.

Tablo 1. Değişkenlere Ait Tanımlamaları

Değişken	Sembol	Kaynak
Ekonomi Politika Belirsizlik Endeksi	EPU	Economic Policy Uncertainty
Bist Banka Endeksi	XBANKA	Investing

Bu çalışmada politika şoklarının özellikle gelişmekte olan piyasalarda heterojen ve zamana göre değişkenlik gösteren etkiler yarattığı gerçeğinden hareketle, Shi vd. (2020) tarafından önerilen Zamana Göre Değişen Granger Nedensellik yaklaşımı tercih edilmiştir. Bu dinamik yaklaşım, üç farklı zamana göre değişen nedensellik algoritması sonuçlarını özyinelemeli genişleyen (Recursive expanding, RE), ileriye doğru genişleyen (Forward expanding, FE) ve hareketli (Rolling, RO) pencere yaklaşımı kullanarak ortaya koymaktadır. Bu yaklaşım, diğer nedensellik yaklaşımlarına kıyasla bazı avantajlar sağlamaktadır. Bunlardan ilki serilerdeki heterojen yapının tespiti yakalaması, ikincisi bootstrap yaklaşımının kullanılması ile çoklu test süreçlerinde ortaya çıkabilecek boyut sapmalarını kontrol altına alması ve son olarak farklı dereceden eş bütünleşme derecesine sahip serilerde nedenselliğin araştırılmasına imkan tanımasıdır.

Zamana göre değişen Granger nedensellik testi için ilk aşamada gecikmeli VAR (LA-VAR) modeli Denklem (1)'de gösterildiği gibi tahmin edilmektedir:

$$y_t = \alpha_0 + \alpha_1 t + \sum_{i=1}^{k} \beta_i y_{t-i} + \sum_{j=k+1}^{k+G} \beta_j y_{t-j} + \varepsilon_t \qquad (1)$$

(1) numaralı denklemde yer alan n boyutlu vektör olan y_t, bağımlı değişkeni, G ise EPU ve XBANK değişkenlerini içeren bağımlı değişken y_t'nin maksimum gecikme uzunluğunu temsil etmektedir. Denklem (2)'de regresyon modeli aşağıdaki gibi gösterilmektedir:

$$y_t = \Gamma\tau_t + \Phi x_t + \Psi z_t + \varepsilon_t \qquad (2)$$

(2) numaralı denklemde $\Gamma = (\alpha_0, \alpha_1)_{nx(q+1)}$, $\tau_t = (1, t)'_{2x1}, \Phi = (\beta_1, \dots, \beta_k)_{nxnk}$, $\Psi = (\beta_{k+1}, \dots, \beta_{k+G})_{nxnk}$, $x_t = (y'_{t-1}, \dots, y'_{t-k})'_{nkx1}$ ve $z_t = (y'_{t-k-1}, \dots, y'_{t-k-1})'_{nGx1}$ vektörleri olarak tanımlanmaktadır. Modelde değişkenler arasında nedensellik ilişkisinin olmadığını ifade etmek için kullanılan $H_0 = R\varphi = 0$ şeklinde ifade edilmektedir. Sıfır hipotezinin reddedilip reddedilmeyeceğine ilişkin karar ise φ = vec(Φ) matrisi üzerine getirilen bazı kısıtlar aracılığıyla tanımlanmaktadır. Denklemde bileşenlerinin sıfıra eşit olduğu varsayıldığından R matrisi $m \times n^2k$ boyutuna ve G

gecikmeli vektörlere ait Ψ katsayılar matrisi analize dahil edilmemektedir. Buna göre, (1) numaralı denklem tekrar düzenlendiğinde (3) numaralı denklemine dönüşmektedir:

$$Y = \tau\Gamma' + X\Phi' + Z\Psi' + \varepsilon_t \tag{3}$$

Denklem (3)'te $Y = (y_1, \dots, y_T)'_{Txn}$, $\tau = (\tau_1, \dots, \tau_T)'_{Tx2}, X = (x_1, \dots, x_T)'_{Txnk}$, $Z = (z_1, \dots, z_T)'_{TxnG}$, $\varepsilon = (\varepsilon_1, \dots, \varepsilon_T)'_{Txn}$ ve $Q_\tau = I_T - \tau(\tau'\tau)^{-1}\tau'$,Q= $Q_\tau - Q_\tau Z(Z'^{Q_\tau}Z)^{-1}Z'^{Q_\tau}$ olarak tanımlanmaktadır. (4) numaralı denklemde Sıfır hipotezini (H_0) test etmek için hesaplanan Wald istatistiği (W) sunulmaktadır.

$$W = (R\hat{\varphi})'\left[R\left\{\hat{\Sigma}_\varepsilon \otimes (X'QX)^{-1}\right\}R'\right]^{-1}R\hat{\varphi} \tag{4}$$

Zamanla değişen Granger nedensellik testinde serilerin alt örneklemlerden elde edilen Wald istatistikleri hesaplanmaktadır. Buna göre, gözlemlerin başlangıç noktası f_{r1} ve bitiş noktası f_{r2} ile ifade edilmektedir ve $f_{rw} = f_{r2} - f_{r1}$ şeklinde tanımlanmaktadır. Bu alt örneklemden elde edilen Wald istatistiği $W_{f_{r2},f_{r1}}$ olarak gösterilmektedir. Bu doğrultuda, $\tau_{r1} = [f_{r1}T], \tau_{r2} = [f_{r2}T], \tau_w = [f_{rw}T]$ ve T örneklem büyüklüğünü ve τ_{r0} VAR tahmini için gereken minimum örneklem sayısını göstermektedir ($\tau_{r0} = [f_{r0}T]$).

FE pencere algoritmasına göre, ilk gözlemde başlangıç noktası τ_{r1} sabitlenir ve süreç τ_{r2}'nin τ_{r1}'den T'ye doğru hareket etmesine eşdeğerdir. RO pencere algoritmasında, başlangıç noktası τ_{r1} ve bitiş noktası $\tau_{r2} = \tau_{r1} + \tau_{r0} - 1$ şeklinde tanımlanmaktadır. RE pencere algoritmasında ise, RO pencere algoritmasında olduğu gibi τ_{r2} ile sabit bir mesafeyi korumak yerine, regresyonun başlangıç noktası τ_{r1}'den $\tau_{r2} - \tau_{r0} + 1$'e kadar değişmektedir. İlgilenilen her bir f_r örneklemi için Wald test istatistiği (5) numaralı denklemdeki gibi gösterilmektedir:

$$SW_{f_r}(f_{r0}) = \frac{sup}{f_{r2} = f_r, f_{r1}\epsilon[0, f_{r2} - f_{r0}]}\{W_{f_{r1},f_{r2}}\} \tag{5}$$

(5) numaralı denklemde yer alan, $[f_{rT}]$ gözlemi için nedensellik ilişkisi çıkarımı sup Wald istatistiği $SW_{f_r}(f_{r0})$'a dayanmaktadır. Son olarak, optimal gecikme uzunluğu bilgi kriterlerine göre tahmin edilen VAR modeli ve test istatistiği hesaplanmaktadır.

3.2. Bulgular

Çalışmada, öncelikle serilerin durağanlaşma düzeylerinin belirlenmesine yönelik amacıyla, Augmented Dickey Fuller (ADF), Phillips-Perron (PP) ve Ziwot-Andrews (ZA) tesleri uygulanmıştır. Tablo (2)' de serilerin durağanlaşma düzeylerine ilişkin sonuçlara yer verilmektedir.

Tablo 2. Durağanlık Testi Sonuçları

	Düzey			Birinci Fark			Sonuç
	ADF	PP	ZA	ADF	PP	ZA	
$lnEPU$	-3.491** (0.0404)	-6.279* (0.0000)	-7.329* (2007M8)	-6.398* (0.0000)	-26.934* (0.0000)	-14.451* (2020M12)	I(0)
$lnXBANKA$	-2.258 (0.4575)	-2.678 (0.2454)	-3.590 (2018M2)	-4.572* (0.0011)	-18.466* (0.0000)	-18.860* (2021M5)	I(1)

Not: %1 ve %5 anlamlılık düzeyi sırasıyla "*" ve "**" simgeleri ile ifade edilmektedir. Durağanlık analizlerinde sabitli ve trendli modeller tercih edilmiştir. Parantez içerisindeki yer alan ifadeler ADF ve PP testlerinde olasılık değerlerini ve ZA testinde ise kırılım tarihlerini belirtmektedir. Optimum gecikme sayısını 12 olarak seçilmiştir.

Serilerin durağanlaşma düzeyleri incelendiğinde, EPU değişkeninin ADF testinde %5, PP ve ZA testlerinde %1 anlam düzeyinde düzeyde I(0) durağanlaştığı; $lnXBANKA$ değişkeninin ise tüm birim kök testlerinde %1 anlam düzeyinde birinci farkta I(1) durağanlaştığı görülmektedir.

Tablo 3. Granger Nedensellikler için Wald Testi Sonuçları

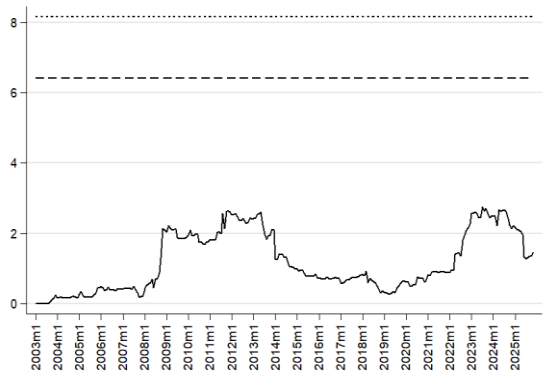
Nedenselliğin Yönü	FE Wald	RE Wald	RO Wald
$lnEPU \quad GC? \rightarrow \ lnBISTBANKA$	2.756	15.763*	15.763*
	(8.322)	(8.414)	(9.061)
	[12.420]	[13.910]	[13.910]

Not: %1 ve %5 anlamlılık düzeyi sırasıyla "*" ve "**" simgeleri ile ifade edilmektedir. FE Wald, RE Wald ve RO Wald ifadeleri sırasıyla ileriye doğru genişleyen (Forward expanding, FE), öz yinelemeli genişleyen (Recursive expanding, RE) ve hareketli (Rolling, RO) yaklaşımlarına ait Wald test istatistikleridir. Parantez ve köşeli parantez içinde yer alan değerler sırasıyla %95 ve %99 kritik değerleri ifade etmektedir. Gecikme uzunluğu Akaike bilgi kriterine göre p(2) olarak belirlenmiştir. Baum vd. (2022) takip edilerek tüm modeller d(1), p(2), minimum pencere boyutu 72 ve boostrapt 499 entegrasyonuna trend eklenerek heteroskedastisiteye karşı dirençli (robust) olarak tahmin edilmiştir.

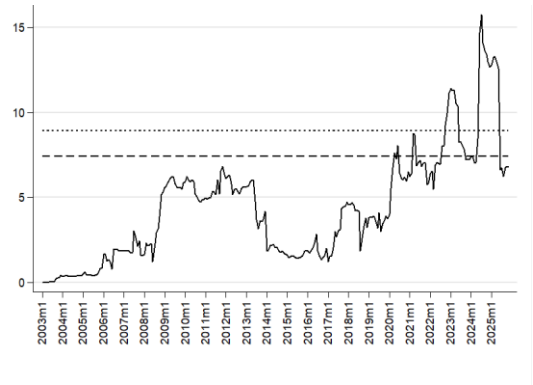
Tablo 3'te yer alan analiz sonuçları incelendiğinde, sabit bir başlangıç noktasına dayanan FE Wald test istatistiklerinin BIST Banka Endeksi için anlamlılık düzeyine ulaşamadığı, yani Granger nedenselliğin olmadığına dair sıfır hipotezini reddedemediğimizi göstermektedir. Ancak, RE ve RO Wald testi bulguları, FE sonuçlarından önemli ölçüde farklılaşmaktadır. RE ve RO yaklaşımlarında hesaplanan Wald değerleri, %95 ve %99 bootstrap test istatistiklerini aşmaktadır. Dolayısıyla Granger nedenselliğin olmadığına dair H_0 hipotezi %5 ve %1 anlam düzeyinde reddedilmektedir. Buna göre, ekonomi politika belirsizlik endeksinin BIST Banka Endeksine doğru Granger nedenselliğin varlığı söz konusudur.

Şekil 1. EPU ile BIST Banka Endeksi Arasındaki Zamana Göre Değişen Granger Nedensellik Testleri

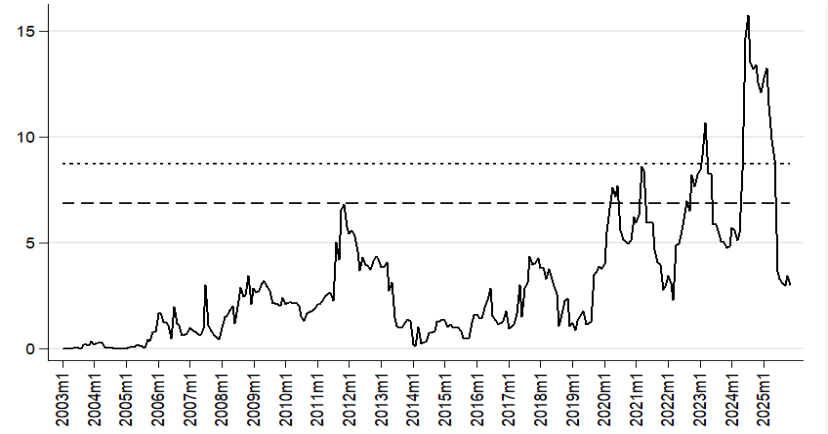
$lnEPU \rightarrow lnBISTBANKA$ FE Wald



$lnEPU \rightarrow lnBISTBANKA$ RE Wald



$lnEPU \rightarrow lnBISTBANKA$ RO Wald



Elde edilen bulgular, $lnEPU$ endeksinin değiştiği dönemlerde $lnEPU$ ve $lnXBANKA$ değişkenleri arasında belirgin bir nedensellik ilişkisi oluştuğunu göstermektedir. Şekil 1 incelendiğinde, ekonomik politika belirsizliğinin Türkiye bankacılık sektörü üzerindeki etkisinin zaman içerisinde değişkenlik gösterdiğini ortaya koymaktadır. Özellikle küresel kriz dönemleri ile Türkiye ekonomisinde finansal kırılganlıkların arttığı süreçlerde, EPU endeksinden BIST Banka Endeksine doğru nedensellik ilişkisinin güçlendiği gözlenmektedir. FE Wald testi sonuçları genel olarak kritik değerlerin altında kalsa da, 2010 sonrası dönemde belirsizlik şoklarının bankacılık sektörü üzerindeki etkisinin arttığı görülmektedir. Buna karşılık RE ve RO Wald testleri, özellikle 2021 sonrası dönemde istatistiksel olarak anlamlı nedensellik ilişkilerinin ortaya çıktığını göstermektedir. Bu dönemde küresel enflasyonist baskılar, Türkiye'deki kur oynaklığı, yüksek enflasyon süreci ve para politikası belirsizlikleri bankacılık sektörü üzerindeki kırılganlığı artırmıştır. Özellikle 2022-2024 döneminde Wald istatistiklerinin kritik değerleri aşması, ekonomik politika belirsizliğinin BIST Banka Endeksi üzerinde güçlü etkiler yarattığını ortaya koymaktadır.

Sabit katsayılı Granger nedensellik testleri, Türkiye ekonomisindeki yapısal kırılmaları ve dinamik değişimleri tam olarak yansıtmadığı için bu nedensel ilişkiyi reddetme eğilimindedir. Nitekim FE sonuçlarının aksine, RO ve RE yaklaşımlar kullanılarak zamanla değişen dinamikler analize dahil edildiğinde, nedensel bağlantıların özellikle kriz ve belirsizlik dönemlerinde %99 güven düzeyinde çok daha güçlü ve istatistiksel olarak anlamlı hale geldiği görülmüştür. Bu bulgu, gelişmekte olan piyasalarda finansal nedensellik analiz edilirken, zamanla değişen parametrelerin ve belirsizliğin modellenmesinin metodolojik önemini açıkça ortaya koymaktadır.

4. SONUÇ

Bu çalışmada, ekonomi politika belirsizliği ile Bist Banka Endeksi arasındaki ilişki, 1997:M1–2025:M11 dönemini kapsayan aylık veri seti kullanılarak zamana göre değişen Granger nedensellik yaklaşımı çerçevesinde analiz edilmiştir. Çalışma, ekonomi politika belirsizliğinin BİST Banka Endeksi üzerindeki etkisini ve bu etkinin zaman içerisindeki değişimini ortaya koymaktır.

Analiz sonuçları, ekonomi politika belirsizliğinin Bist Banka Endeksi üzerindeki etkisinin sabit olmadığını, aksine ekonomik ve finansal koşullara bağlı olarak güçlenip zayıflayan dinamik bir yapı sergilediğini ortaya koymuştur. Özellikle COVID-19 salgını, Rusya-Ukrayna Çatışması, küresel enflasyonist baskılar, döviz kuru oynaklığı ve para politikası belirsizliklerinin arttığı dönemlerde ekonomi politika belirsizliğinin bankacılık sektörü üzerindeki etkisinin önemli ölçüde güçlendiği görülmüştür. Bu sonuç, bankacılık sektörünün küresel şoklara karşı yüksek duyarlılık gösterdiğini ve belirsizliklerin sektör performansı üzerinde belirleyici rol oynadığını ortaya koymaktadır. Çalışmanın bir diğer önemli bulgusu, zamanla değişen parametreleri dikkate alan yöntemler kullanıldığında, özellikle kriz ve yüksek belirsizlik dönemlerinde nedensellik ilişkilerinin daha güçlü ve istatistiksel olarak anlamlı hale geldiği belirlenmiştir.

Elde edilen sonuçlar, yatırımcılar ve portföy yöneticileri açısından ekonomi politika belirsizliği göstergelerinin bankacılık sektörü performansını öngörmede önemli bir erken uyarı mekanizması olarak kullanılabileceğine işaret etmektedir. Politika yapıcılar açısından ise, küresel belirsizliklerin finansal sistem üzerindeki etkilerini azaltabilmek için öngörülebilir, şeffaf ve güven artırıcı politika çerçevelerinin geliştirilmesi önem taşımaktadır. Bu bağlamda, ekonomi politika belirsizliğinin yakından izlenmesi ve risk yönetimi süreçlerine entegre edilmesi, finansal istikrarın korunmasına katkı sağlayacaktır.

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THE MACROECONOMIC IMPACTS OF CLIMATE CHANGE ON ASIA-PACIFIC ECONOMIES: SECTORAL VULNERABILITIES

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ABSTRACT

Climate change has become a source of structural vulnerability threatening macroeconomic stability in the Asia-Pacific region, characterised as the "mother of externalities." According to United Nations ESCAP data, the region, which accounts for 60% of global economic growth, is warming at nearly twice the global average, and climate-related disasters cause an average annual economic loss of 924 billion dollars. This figure corresponds to 2.9% of the region's GDP, and it is projected to rise to 953-980 billion dollars in a scenario of a 1.5-2°C temperature increase. The agricultural sector is one of the most vulnerable areas to climate change. According to the Agricultural Heat Stress Score (AHSS) methodology developed by ESCAP, Afghanistan, Pakistan, India, Nepal, and Bangladesh fall into the high-risk category. In the region, agriculture accounts for more than a quarter of GDP and employs a large portion of the rural workforce. In August 2024, floods triggered by the Remal cyclone in Bangladesh submerged approximately 2 million hectares of rice fields. ESCAP's macroeconomic analysis covering 30 countries identifies Afghanistan, Cambodia, Iran, Kazakhstan, Laos, Mongolia, Myanmar, Nepal, Tajikistan, Uzbekistan, and Vietnam as the economies most vulnerable to climate risks. These countries share common characteristics, including low adaptation capacity, limited financial resources, and high dependence on climate-sensitive sectors. In conclusion, the impacts of climate change on Asian economies are no longer future scenarios but real costs reflected in today's financial statements. Regional countries must make a strategic choice between the cost of adaptation investments and the heavy economic losses brought by inaction. The financing cost of the green transition, according to IEA data, ranges between 8-9.4% in Southeast Asia, which is significantly higher than the 5-6.5% range in developed countries. This situation constitutes one of the most significant structural barriers to the region's low-carbon transition.

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JEL Codes: *C68, Q51, Q54.*

1. INTRODUCTION

For years, economists have asked whether climate change is best described as a market failure, a battle over who pays the price, or a deep-rooted structural problem in the global economy. In the Asia-Pacific region, according to ESCAP (2023), climate-related disasters cost the region about USD 924 billion every year. That's not an abstract figure—that's nearly 3 percent of the region's entire GDP, and forecasts say those losses are only going up, likely reaching between USD 953 and 980 billion if global temperatures climb by 1.5 to 2°C.

The scope of the issue is evident when you consider that this area generates 60% of global economic activity, warms up almost twice as quickly as the rest of the world, and sustains most of the rain-fed agriculture and the people who depend on it. This is aptly referred to as the "mother of externalities" by the UN. Here, climate change is more than a far-off menace. It is a vulnerability that necessitates thorough, comprehensive research because it is intertwined in society's physical and economic fabric. Counting single events is no longer sufficient. However, not every industry or community is equally affected by the effects of climate change. For instance, agriculture continues to be the foundation of rural livelihoods and accounts for more than 25% of GDP in many lower-income nations. Harvests in these areas fall off virtually instantly when the temperature rises or the rain stops. What took place in August 2024 in Bangladesh? In a couple of days, Cyclone Remal inundated around two million hectares of rice crops, demonstrating in one catastrophic moment how vulnerable rain-dependent agricultural systems are to climate shocks. Southeast Asia's transition to sustainable energy is costly in addition to being a technological and policy challenge. The financing cost ranges from 8 to 9.4 percent, which is significantly more than what OECD economies spend by 2.5 to 3 percentage points. That gap is more than just a figure for many nations. The investments required to deal with a warming planet are hindered by this wall that divides ambitious plans for climate adaptation from reality.

This work aims to make three important advances in light of this complex setting. First, it analyses the overall and sectoral economic effects of climate change using data from 30 Asia-Pacific economies, extending beyond mere numbers. The technique does not merely create a single index by combining all of the data. Instead, it distinguishes between the four primary physical aspects of climate stress: variations in rainfall, temperature anomalies, rising sea levels, and the frequency of extreme weather events. This gives us a clearer, more insightful picture than relying solely on general indicators. Second, the study explores the differences hidden in the headline numbers. The research divides the data by socioeconomic group and structural sensitivity to climate change because ESCAP's country-level risk rankings suggest unequal vulnerability. This makes it easy to observe where the economic harm is

focused and for whom. Are there areas of tremendous risk even in wealthy nations, or do richer economies do better? These questions are directly addressed in the research.

Finally, this effort bridges the gap in green finance. Using the cost differential for low-carbon investments as an explanatory variable, the study links factual data on physical climate risk to the financial realities that affect each country's ability to respond. In other words, it examines how much of the harm we might be able to stop or manage depending on who can and cannot afford it. Policymakers must understand the link between risk and fiscal architecture if they are to develop lasting remedies. As a result, to understand climate change in the Asia-Pacific area, we also need to consider structural, financial, social, and economic aspects. This study aims to connect those threads by offering research that is precise, nuanced, and rooted in the lived experience of a location on the front lines of global change.

Dell et al. (2012) marked a turning point in the way economists connect macroeconomic outcomes to the environment. They created a within-country panel estimator that tracks annual temperature fluctuations from national baselines and then shows a clear relationship between those changes and economic expansion. According to their main findings, a single one degree Celsius increase in the annual average temperature in poorer countries virtually surely results in a full percentage point drop in GDP growth. Rich countries, however, have little or no influence. The simplicity of that asymmetry—higher vulnerability in low-income economies—generated intense interest, particularly since it seemed to reflect underlying problems, such as weak institutions, a greater reliance on climate-sensitive industries like agriculture, and a lower capacity for adaptation. By pushing the data further and finding similar splits, further investigations (Burke et al., 2015; Acevedo and colleagues, 2020) corroborated this conclusion.

Burke et al. (2015) went beyond simple replication. By modifying the original model to include a quadratic term for temperature, they were able to represent the reality that the link between temperature and productivity is not simply a straight line. Instead, circumstances deteriorate after 13°C, when aggregate productivity rises. In places that are already exceedingly hot, every degree makes the pain worse. Such nonlinear destruction should come as no surprise to anyone following Asia's climate story, where lowland farming districts regularly report temperatures over ideal ranges for staples like rice. Every degree that is added during the growing season reduces rice yields in tropical Asia by about 10% (Welch et al., 2010). The latest IPCC Assessment, which projects 3–10% yield decreases for the region with only 1.5°C warming—a benchmark that is dangerously close to reality—supports these warnings.

Researchers from the Asia-Pacific have concurrently developed this empirical basis. Chang et al. (2023) found striking details after going through twenty years' worth of regional data: the impact of rising temperatures on GDP is not consistent. Structural changes, like economies transitioning from agricultural to industrialisation, have a significant impact on the damage profile. For instance, countries

that still rely mostly on agriculture are not as vulnerable as those that rely substantially on manufacturing. Kaushik et al. (2024) reached the same conclusion using panel data from 28 Asian economies: rising temperatures hinder growth, but the poorest individuals suffer the most. To further narrow the focus, ESCAP (2025) created the Agricultural Heat Stress Score. It paints a clear picture: Bangladesh, Afghanistan, Pakistan, India, and Nepal are the countries most affected by climate change's effects on agriculture. ESCAP's panel is currently a crucial empirical standard with macroeconomic projections for thirty countries.

Agriculture stands out among sectors due to the richness and specificity of the data in Asia. Citing Welch et al. (2010) once more, we view rice as a climate barometer since yields rapidly decline when it is not at its ideal temperature. Concerns about food security and rural livelihoods are reinforced by the IPCC's Sixth Assessment (2022), which uses a more comprehensive approach but falls within the same range and predicts non-trivial losses in staple yields. Other industries, such as labour, infrastructure, and tourism, have not been subjected to the same level of regional econometric analysis. However, labour productivity is a significant factor that could account for half of all economic losses in high-emissions scenarios, according to projections from ADB (2024).

Despite being more recent, the financial aspect of climate adaptation is becoming more popular as a field of study. Unwanted clarity on the cost gap is provided by the IEA's 2024 analysis: financing green transitions is over twice as expensive in emerging Asia, with rates ranging from 8 to 9.4 percent, compared to merely 5 to 6.5 percent in wealthier economies. Causes are clear enough—higher sovereign risk, thinner local capital markets, and little track record for green investment vehicles. Recent work by Acheampong and Said (2024), along with Nguyen and Nguyen (2024), digs into what it takes for adaptation spending to pull its weight. They find the answer is not just more money, but better financial markets and institutions. Where those are stronger, adaptation investments deliver bigger reductions in climate risks.

This paper seeks to advance the discussion in a number of ways. First, it divides climate stress into four different physical channels instead of directing all climatic consequences through the blunt variable of temperature. This method allows us to determine which climate changes have the greatest economic impact and where future adaptation expenditures will be most significant. Second, the research does more than just map losses; it directly quantifies the additional financial shot adaptation will require, understanding that high finance costs naturally impact which climate initiatives are possible. Last but not least, the empirical work is based on a remarkably lengthy panel spanning 25 years, which encompasses the disruptive energy price rises that took place between 2021 and 2023 as well as the economic shock brought on by COVID-19. This sweep provides a rare chance to assess whether climate-economy relationships endure the strain of compounding global shocks, as opposed to in a static "normal" year. The study's characteristics go beyond just updating earlier studies on the

relationship between climate change and the economy by analysing where action is most needed and what types of intervention are actually feasible given the local financial realities.

2. METHODOLOGY

This work's empirical model is supported by two related theoretical pillars. First, it makes use of the linear panel damage function developed by Dell et al. (2012). By connecting a country's yearly weather fluctuations to economic growth, their approach enables us to treat annual temperature variances as good quasi-experimental variation. Therefore, we may read the coefficient on temperature anomaly as showing the direct causal impact of a one-degree increase (in comparison to the historical standard) on GDP growth while taking into consideration all of the country's permanent features through fixed effects. The key idea here is that annual weather variations are unrelated to and independent of short-term economic behaviour or policy.

Burke et al. (2015) provide the nonlinear damage function as the second framework to elaborate on this. By adding a squared term to the temperature variable, they allow the model to represent a hypothetical inverted-U shape in the link between heat and productivity. In other words, this suggests that productivity can rise with temperature up to a certain limit, after which more warming becomes harmful and may rapidly get worse. Each degree that the squared and linear factors are both negative has an adverse effect on economic growth. Due to its numerous policy ramifications, this functional form difference is more than just a mathematical curiosity. The Ramsey REST test is used in the empirical technique to assess whether the data justify adding the quadratic element. The test's rejection of the linear specification provides compelling evidence that the relationship in the real world is nonlinear.

But there are other factors as well. Sea level rise, precipitation variability, and the frequency of extreme weather events are the three main channels into which this study divides the effects of climate change. It accomplishes this by utilising data from Monioudi et al.'s latest ESCAP (2023) study (2025). These problems are viewed as distinct issues rather than vague stand-ins for "climate change" in general. This approach makes it possible to analyse sector-specific vulnerabilities in much more detail. For instance, whereas agriculture is most susceptible to changes in temperature and precipitation, tourism and coastal infrastructure are immediately affected by rising sea levels and more frequent storms.

A balanced panel dataset that covers 30 Asia-Pacific economies from 2000 to 2024, yielding 750 country-year observations, serves as the empirical basis for the research. South Asia, Southeast Asia, East Asia, Central Asia, and several Pacific small island states are among the subregions included in the nation selection, which closely corresponds with the macroeconomic vulnerability assessment from ESCAP (2023). For a more thorough comparative analysis, countries are grouped according to their World Bank income: nine high-income, twelve upper-middle-income, and nine lower-middle or low-income economies. Furthermore, over 20% of the population resides within 100 kilometres of the coast

in 17 of the 30 sample countries, which are coastal or island states. This emphasis draws attention to the particular risks that coastal towns face due to increasing sea levels and more powerful storms.

Macroeconomic metrics from the World Bank World Development Indicators (2024), like GDP per capita growth and agriculture value-added growth, are our main dependent variables. Climate data is treated equally: temperature anomalies are provided by NASA GISS (2024), precipitation changes are provided by ECMWF's ERA5 reanalysis, extreme weather events are provided by EM-DAT (2024), and sea level rise figures are provided by the Copernicus Marine Service (2024). The model calculates green transition finance costs using the IMF's sovereign risk-adjusted cost of capital estimates. (IEA, 2024). Control factors that affect our understanding of the economic environment include the (log) level of GDP per capita, trade openness, investment as a percentage of GDP, average government spending, and the development of the financial sector (Rubin, 1987; IMF Financial Development Index, 2024).

Table 1. Sample Structure and Data Coverage

Category	Description	Value
Sample Period	Observation years	2000–2024
Number of Countries	Asia-Pacific economies	30
Total Observations	Balanced panel country-year observations	750
High-Income Economies	World Bank classification	9
Upper-Middle-Income Economies	World Bank classification	12
Lower-Middle & Low-Income Economies	World Bank classification	9
Coastal & Island Economies	Countries with >20% population within 100 km of coastline	17

The following Table 2 summarises the key variables. A few salient points: The mean annual temperature anomaly for the observed years is 0.51°C (SD: 0.43°C), with a tendency towards higher values. This is consistent with the trend of rapid warming, especially in the latter part of the sample. The average annual growth rate of agriculture is 2.76%, although it is highly variable (SD: 4.38%), indicating how much the sector's productivity is impacted by yearly shocks like storms and droughts.

GDPG measures GDP per capita's annual growth rate (in percentage terms). The annual growth in agricultural value added is measured by AGVA (also in percent).

Regarding climate variables, TEMP is each nation's average annual surface temperature anomaly (in °C) in relation to the baseline from 1951 to 1980. For the quadratic (nonlinear) models, $TEMP^2$, the squared variant, is used. PREC calculates the annual precipitation percentage departure from a rolling 30-year average baseline. EWE is a straightforward count of the number of extreme weather events that occur each year; an event only qualifies if it is severe enough (at least 10 fatalities or 100 impacted individuals, according to the EM-DAT criteria). SLR uses satellite data to measure the yearly rise in sea level in millimetres.

According to IEA (2024), the risk-adjusted capital cost of switching to renewable energy at the national level is captured by the GFCOST variable, green transition finance cost. This variable allows

us to investigate whether and how national adaptability and resilience are impacted by the cost of green finance, an issue that is becoming more pertinent as the energy revolution picks up speed. The list of control variables fills out the economic backdrop: LGDP (log GDP per capita at PPP), TRADE (trade as a share of GDP), GCF (gross capital formation as percent of GDP), GOV (general government spending as percent of GDP), and FDI_F (Financial Development Index).

Table 2. Descriptive Statistics of Main Variables

Variable	Mean	Standard Deviation	Interpretation
Temperature Anomaly (TEMP)	0.51°C	0.43°C	Indicates an accelerating warming trend
Agricultural Value Added Growth (AGVA)	2.76%	4.38%	High volatility in agricultural output
Extreme Weather Events (EWE)	3.84 events	—	Frequent climate-related disasters

The basic estimation is based on a two-way fixed effects panel regression model that accounts for both country-specific and year-specific effects in order to separate the impact of climate and structural variables on economic outcomes across the large Asia-Pacific sample. By enabling us to distinguish between persistent national traits and worldwide trends, the model framework guarantees a more accurate analysis of how climate dangers and economic foundations evolve.

$$GDPG_{it} = \alpha + \beta_1 TEMP_{it} + \beta_2 TEMP^2_{it} + \beta_3 PREC_{it} + \beta_4 EWE_{it} + \beta_5 SLR_{it} + \beta_6 GFCOST_{it} + \gamma \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where λ_t captures year fixed effects that absorb common annual shocks like the global financial crisis, COVID-19, and shared commodity price cycles, and μ_i captures country fixed effects that absorb all time-invariant country-specific characteristics, such as geographic endowments, historical institutional legacies, and structural economic composition. The vector of control variables is called X_{it}. It is expected that, depending on the fixed effects, the error term ε_{it} has no correlation with the regressors. For both the entire sample and income-stratified subsamples, equation (1) is estimated independently. The agriculture sector specification maintains the same structure but substitutes AGVA for GDPG as the dependent variable:

$$AGVA_{it} = \alpha + \beta_1 TEMP_{it} + \beta_2 TEMP^2_{it} + \beta_3 PREC_{it} + \beta_4 EWE_{it} + \beta_5 SLR_{it} + \gamma \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

The analysis begins with the Pesaran (2004) cross-sectional dependence test, which looks at whether residuals across panel countries move together. Given the Asia-Pacific region's shared susceptibility to trade shocks and climate change, cross-sectional reliance is nearly a guarantee. This is crucial because if these regional shocks were ignored, the standard errors and, finally, the inference would be distorted. Next, to find differences in error variance between countries, the Modified Wald

test (Greene, 2000) searches for groupwise heteroscedasticity. The robust rejection of homoscedasticity is consistent with the region's diverse economies, which vary from island republics to continental giants and are all susceptible to different macro and sectoral volatilities. The Wooldridge (2002) test then checks for first-order serial autocorrelation, a common feature in macro panels. If present, we expect residuals from one period to influence the next—a product of inertia in both climate shocks and policy responses.

The Hausman (1978) test has historically been used to reconcile disagreements between the fixed and random effects theories. It is not unexpected that the significant test result in this instance significantly favours the fixed effects estimator and rules out random effects brought on by correlation between unobserved heterogeneity and the regressors, given the sample's institutional and developmental variability. The identification of both heteroscedasticity and cross-sectional dependence supports the use of Panel-Corrected Standard Errors (PCSE), in compliance with Beck and Katz's methodology (1995). This robust estimating method ensures reliable inference even in the presence of such complex error patterns.

The analysis then applies system-GMM estimation to dynamic persistence in GDP growth (Arellano & Bond, 1991; Blundell & Bond, 1998). By incorporating a lagged dependent variable that forecasts present growth based on its own historical values, this method explicitly replicates the inertia in economic growth. This results in endogeneity, which System-GMM addresses via lag levels and differences. The instrument set is compacted in line with Roodman (2009) to avoid overfitting, a commonly overlooked but essential step when working with panels that are not very large. The pre-diagnostics had previously indicated a challenging statistical landscape—complex error structure, significant persistence, and a variety of shocks—and the complexity of the data did not disappoint.

Table 3. Pre-Estimation Diagnostic Tests

Test	Statistic	p-value	Result
Pesaran CD Test (GDP Equation)	17.84	<0.01	Cross-sectional dependence exists
Pesaran CD Test (Agriculture Equation)	19.21	<0.01	Cross-sectional dependence exists
Modified Wald Test	241.3	<0.001	Heteroscedasticity detected
Wooldridge Test	34.7	<0.001	Serial autocorrelation detected
Hausman Test	68.4	<0.001	Fixed effects preferred
Ramsey RESET Test	4.84	0.018	Nonlinear specification justified

The region's systemic vulnerability is supported by the extremely high Pesaran CD statistics of 17.84 for GDP growth and 19.21 for agriculture: economic shocks propagate concurrently throughout the Asia-Pacific region. The Modified Wald and Wooldridge statistics, both of which have p-values far below 0.001, highlight the combined issues of heteroscedasticity and serial autocorrelation. The Hausman test unmistakably favours fixed effects ($\chi^2 = 68.4$, $p < 0.001$), demonstrating the necessity of removing unobservable elements that interact with climate shocks, such as historical institutions, geography, or policy frameworks. To put it another way, this is hardly a complimentary lunch with

uncertain consequences. A challenging problem is model specification. The absence of nonlinearities in the Ramsey RESET test justifies the inclusion of quadratic temperature variables. This is not only a statistical formality because the GDP of the area reacts to temperature changes in a nonlinear, accelerating way rather than a straight line. If this curvature were overlooked, the economic costs of greater temperature anomalies would be greatly underestimated.

3. RESULTS

The model results show that temperature (TEMP) and its square ($TEMP^2$) are both negative and significant. This implies that the dependent variable decreases as the temperature increases, and that this decrease occurs more rapidly. Overheating has a negative macroeconomic impact on worker health, agricultural output, and productivity. Precipitation (PREC) is advantageous and significant; enough rainfall encourages economic activities (such as hydroelectric power and agriculture). Extreme weather events (EWE) and sea level rise (SLR) both have negative coefficients for economic losses: supply networks are interrupted, and infrastructure is harmed by storms, floods, and coastal erosion. The cost of green finance (GFCOST) is negative, indicating that the financing necessary for decarbonization is a cost factor that reduces economic production in the short term. The notable and high value of the log GDP (LGDP) coefficient is 1.214. This indicates that economic expansion increases the dependent variable (such as emissions or energy consumption) more than proportionately since the dependent variable's income elasticity is greater than one.

Table 4. Baseline GDP Growth Results (Preferred Nonlinear PCSE Specification)

Variable	Coefficient	Std. Error	Significance
TEMP	−0.912	0.198	***
$TEMP^2$	−0.541	0.214	**
PREC	0.031	0.013	**
EWE	−0.271	0.049	***
SLR	−0.389	0.127	***
GFCOST	−0.184	0.047	***
LGDP	1.214	—	***
Significance Levels			**Meaning**
***			$p < 0.01$
**			$p < 0.05$

While the strong positive effect of LGDP emphasises that economic development is directly linked to energy access, production capacity, and increased welfare, wealthy nations' ability to allocate more resources to climate adaptation and the positive PREC demonstrate how well-managed water resources support agriculture and energy production, presenting favourable climate conditions as an economic opportunity. Nonetheless, the negative coefficients of TEMP, $TEMP^2$, EWE, and SLR demonstrate that climate change poses a serious threat to macroeconomic stability, including GDP losses, migration, and infrastructure destruction, especially in poor countries. Additionally, the negative

value of GFCOST indicates that the green transition puts pressure on short-term growth, that high financing costs can deter investment and slow down the energy transition, and that policymakers must choose between environmental sustainability and short-term growth objectives. Overall, the model shows that although economic expansion can somewhat counteract the detrimental effects of climate factors, the expenses associated with green finance and harsh weather can ultimately lead to unsustainable results. Consequently, it suggests promoting inexpensive investments in climate-resilient infrastructure and renewable energy.

The agricultural industry has the most dramatic story. Here, the consequences of temperature anomalies are exacerbated; a 1.5°C anomaly, with a coefficient on temperature of -1.834 and a quadratic term of -0.991, affects agricultural value-added growth by around five percentage points. Because agriculture still contributes significantly to GDP in the most vulnerable countries, these sectoral shocks have a domino effect on macroeconomic outcomes. Water is far more significant in agriculture; the positive effects of precipitation are more than twice as great as those of overall GDP growth (0.073). Extreme weather events have the most negative impact on agriculture (−0.474), which is akin to the destruction caused by catastrophes like the Remal storm in 2024, which entirely submerged millions of hectares of cropland. In this scenario, physical climate shocks become a lived experience rather than an idea.

Table 5. Agricultural Sector Results

Variable	Coefficient	Std. Error	Significance
TEMP	−1.834	0.318	***
$TEMP^2$	−0.991	0.284	***
PREC	0.073	0.022	***
EWE	−0.474	0.084	***

Agricultural growth is not statistically significantly impacted by green finance costs; rather, the barriers to immediate output seem to be more closely associated with expenditures in technology and adaptability than with within-year credit constraints. These structural problems may still have a big impact on the medium future because agricultural output will ultimately depend on irrigation, seed technology, and infrastructure investment—all of which are sensitive to financing costs yet evolve over years rather than single cycles. The key findings are then confirmed by several robustness tests. Regardless of whether the analysis substitutes, the temperature and quadratic effects continue to be significant in both sign and size. Driscoll-Kraay standard errors for PCSE use a different temperature dataset, eliminate the pandemic years, or compute system-GMM to explicitly characterise persistence. The GMM model also demonstrates significant dynamic persistence in GDP growth. The instrument's validity is not questioned by the Hansen test, and there are no indications of unexplained serial correlation in the residuals. Since eliminating pandemic years has no appreciable impact on the coefficients, worries that the core climate estimations are influenced by recent shocks are eliminated.

Even if the Berkeley Earth series were replaced with NASA GISS temperature data, the key findings would not change.

Table 6. Robustness Check Results

Robustness Specification	Main Finding
Driscoll-Kraay Standard Errors	Results remain statistically significant
System-GMM Estimation	The temperature effect slightly weaker but significant
Excluding Pandemic Years (2020–2022)	Coefficients remain stable
Alternative Temperature Dataset	Similar coefficient magnitudes obtained

Table 6 presents robustness analyses. The fact that the key conclusions hold when other data sets and econometric methods are used shows how reliable the model's results are. When the pandemic years are removed, the coefficients that are largely kept demonstrate that the climate effects are unaffected by the temporary shocks caused by COVID-19. When everything is said and done, our research paints a bleak picture of the true costs that climate shocks impose across the Asia-Pacific region, particularly among the most vulnerable populations. The evidence is not only statistically significant, but it also has significant ramifications, suggesting that unmanaged climate risks could worsen growth disparities and threaten the progress that so many economies have struggled to make.

4. DISCUSSION

The main conclusion, which shows an average GDP growth drop of roughly 0.91 percentage points for every degree increase in temperature anomaly throughout the entire Asia-Pacific sample, is in line with findings from international studies. Burke et al. (2015) even suggest larger effects using nonlinear specifications, whereas Dell et al. (2012) find a coefficient of –1.0 for poorer nations. In contrast, our estimate makes sense in a dataset that includes both high-income and more vulnerable, lower-income economies, although being slightly lower. The regional average is pulled toward zero by high-income nations, which are less vulnerable to temperature shocks. However, the effect, now at –1.74, is consistent with what is found in international literature for nations with comparable levels of development if we restrict the research to low- and lower-middle-income economies.

According to the United Nations ESCAP (2023), the region's yearly economic losses due to climate change are estimated to be USD 924 billion, or 2.9% of GDP. With an average temperature anomaly of 0.51°C and fewer than four extreme weather occurrences annually, the regression model implies an annual GDP growth loss of about 1.82 percentage points. When you multiply that deficit by the GDP of the area, the annual lost output comes to over USD 890 billion. That is remarkably similar to the damage estimate provided by ESCAP. In other words, two distinct approaches—direct damage accounting and statistical panel regression—converge on comparable numbers, giving both strategies additional legitimacy.

The findings show an even more alarming picture when we isolate the agriculture industry. In this instance, the estimated impact per climatic shock, or coefficients, is much higher than the averages for the entire GDP. According to ESCAP's Agricultural Heat Stress Score methodology (the AHSS), Afghanistan, Pakistan, India, Nepal, and Bangladesh are all considered urgently susceptible. The panel results show more than just theoretical risk, even though crops like rice, wheat, and maize in those countries are already regularly exposed to temperatures at or above their stress thresholds. Our empirical estimates confirm that agricultural output in those "high-risk" economies is being severely impacted, to the extent that macroeconomic projections need to account for it. Cyclone Remal, which struck Bangladesh's rice-producing regions in 2024, serves as an example. In a country where rice makes up around 15% of agricultural GDP, we estimate that a single severe event of the observed severity would cause an annual decrease in output of several percentage points. This is not an abstract statistical artefact; rather, it is entirely congruent with field assessments carried out on the ground. This implies that rural people would face a real, immediate economic shock after such catastrophes.

One of the more creative contributions made here is the direct measurement of the cost barrier imposed by green finance. Financial constraints operate irrespective of actual climate consequences, as evidenced by the GDP growth regression's negative, statistically significant coefficient on green finance cost (GFCOST). Compared to OECD economies, borrowing costs for green transition projects are 2.5 to 3 percentage points higher in Southeast Asian economies. The higher costs of adaptation and mitigation sometimes render them unaffordable for governments and private investors in vulnerable states, even in situations where such investments make perfect economic sense.

This financing shortfall has a significant impact on global climate policy talks, especially with regard to the recently created Loss and Damage Fund, Climate Investment Funds, and the well-known but underfunded Green Climate Fund. Since all these institutions mobilise money, vulnerable countries essentially face a different—and significantly harsher—economic arithmetic than their wealthier counterparts, but they are still far from reducing the cost discrepancy. Therefore, reducing the green financing cost difference by 1 percentage point would increase the affected economies' annual GDP growth by roughly 0.18 percentage points. That's a huge boost in the face of slow development and ongoing vulnerability—much higher than what such investments would currently bring in developed markets.

5. CONCLUSION

Asia-Pacific economies can no longer view climate change as a remote, unimportant problem because its effects are already observable, measurable, and a contributing factor to broader economic instability. Over the course of 25 years, the trends—worsening storms, rising oceans, and hotter years—remain striking and constant across 30 economies. These are real issues that undoubtedly reduce yearly GDP and agricultural output, not speculative dangers. Furthermore, the nations that are most vulnerable

to climate change and have lower incomes suffer the most, losing the most and having the hardest time adapting.

Three main conclusions can be drawn. First, the effects seem nonlinear: rising temperatures result in economic losses that are not gradual but rather accelerate, underscoring the necessity of swift, immediate reductions in emissions. The damage caused by temperature is six times more severe in the poorest economies than in the wealthiest. This is not only about anticipated physical effects; it's also about who can afford to act and who requires assistance according to their circumstances. Third, high green finance costs pose a macroeconomic risk as well as a technical challenge for bankers. Adaptation and regional growth will continue to slow unless the 2.5–3 percentage point financial gap between Southeast Asia and the OECD closes.

It is becoming clear that policymakers have a deeper choice: the growing losses of inaction outweigh the relatively small cost of adaptation measures. In the most vulnerable nations, the sample-average yearly growth deficits already significantly outweigh what well-funded adaptation plans would need. At this point, organised, well-funded adaptation is far less expensive and less risky than inaction. The fundamental issue is not whether adaptation "pays," but rather whether the region's institutional and financial structure will eventually allow those investments to reach the nations and industries that most need them.

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THE EVOLUTION OF SOCIAL MEDIA'S IMPACT ON CONSUMER BEHAVIOR: A LITERATURE REVIEW FROM A PSYCHOLOGICAL WELL-BEING PERSPECTIVE

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ABSTRACT

This study aims to examine the evolution of the impact of social media on consumer behavior from a psychological well-being perspective. With the acceleration of digitalization, social media has assumed a central role in individuals' communication, information access, and purchasing decision-making processes. Based on a literature review, the study reveals that the impact of social media on consumer behavior has developed in three main stages. In the first stage, consumer behavior was shaped by information searching and electronic word-of-mouth communication (eWOM), while in the second stage, interaction, experience, and influencer influence came to the forefront. In the current stage, psychological well-being, social comparison, and emotional processes have become the main determinants of consumer behavior. The findings show that social media affects consumer behavior not only through cognitive but also through emotional and psychological mechanisms. Furthermore, the study provides a comprehensive framework for the multidimensional effects of social media by integrating marketing and psychology literature. In this context, the research makes significant contributions from both theoretical and managerial perspectives.

Keywords: *Social Media, Consumer Behavior, Psychological Well-being, Digital Consumption, Impulse Buying.*

Jel Codes: *M31, D91, L86.*

1. INTRODUCTION

The acceleration of digitalization has led to radical transformations in both communication and consumption behaviors. The increase in digital media use, the expansion of social connections, and the spread of e-commerce have reshaped the ways individuals interact and make consumption decisions. Current studies show that digital environments are transforming the ways individuals communicate, the time spent on digital platforms is increasing, and interactions are becoming faster and more personalized. Similarly, consumption behaviors have also changed in line with data-driven personalization, convenience-oriented decision-making, and increasing dependence on digital platforms (Lemon and

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Verhoef, 2016). The emergence of new e-commerce structures and the changing roles of consumers are also among the important indicators of this transformation (Ryynänen and Hyyryläinen, 2018).

Within this transformation, social media has become a fundamental element at the center of both communication and consumption processes. Social media has become one of the main platforms where individuals interact, access information, and shape their purchasing decisions (Mangold and Faulds, 2009). Social media platforms have restructured forms of social interaction by reducing the importance of traditional face-to-face communication while bringing digital interaction to the forefront. In terms of consumption, these platforms play a dominant role in shaping individuals' self-perceptions, preferences, and consumption habits.

Initially emerging as a communication tool, social media has evolved into a powerful marketing ecosystem over time. This transformation has been made possible by shifting from traditional one-way communication to two-way communication based on reciprocal interaction between brands and consumers (Kietzmann et al., 2011). Today, social media platforms are not only spaces for social interaction but also integrated marketing environments that influence brand awareness, trust, and purchasing decisions (Felix et al., 2017; Tuten and Solomon, 2017). Empirical findings also show a positive relationship between social media marketing activities and consumer purchasing behavior (Hajli, 2014; Yadav and Rahman, 2017). However, social media platforms are shaping all stages of the consumer decision-making process. Consumers are increasingly turning to social media when searching for information, evaluating alternatives, and making purchasing decisions. User-generated content, online reviews, and influencer recommendations reduce perceived risk and increase trust (Hajli, 2015). Studies show that these factors significantly influence consumer perceptions and increase purchase intention (Erkan and Evans, 2016).

Social media also offers a dynamic environment where consumers interact with brands and share their experiences in real time. This interactive structure has shifted power from businesses to consumers, allowing consumers to co-create brand narratives (Gensler et al., 2013). Consumers are no longer just passive recipients, but active participants who consume, contribute to, and produce content (Muntinga et al., 2011). This transformation has led to elements such as electronic word-of-mouth, influencer marketing, and consumer engagement becoming key factors in determining consumer behavior (Chu & Kim, 2011; Cheung & Thadani, 2012; Vrontis et al., 2021). In recent years, the literature has increasingly focused on the effects of social media use on psychological well-being. Findings indicate that social media has complex and bidirectional effects on psychological well-being. While some studies highlight positive outcomes such as increased social connection and perceived social support (Verduyn et al., 2017), others emphasize negative effects such as anxiety, depression, loneliness, and social comparison (Valkenburg et al., 2021). Social comparison, the search for approval, and the need for constant interaction emerge as key mechanisms affecting individuals' psychological states (Vogel et al., 2014).

These psychological processes also appear to influence consumer behavior. Social comparison and fear of missing out (FoMO) can trigger negative emotional states, increasing impulsive and compulsive buying behaviors (Przybylski et al., 2013; Dhir et al., 2018). Similarly, social validation mechanisms such as likes, comments, and shares shape individuals' identity formation and consumption preferences (Nadkarni & Hofmann, 2012; Turel et al., 2014). This demonstrates that consumer behavior in digital environments is shaped not only by information and social interactions but also by psychological processes. However, a significant limitation in the literature is noteworthy. Marketing and psychological well-being studies are often treated separately, making it difficult to understand the holistic impact of social media on consumer behavior (Kietzmann et al., 2011; Yadav & Rahman, 2017). Furthermore, most existing studies focus on specific periods or limited variables, failing to adequately address the transformation over time (Verhoef et al., 2015). Therefore, there is a need to address the impact of social media on consumer behavior from an evolutionary perspective. This approach allows for understanding the dynamic nature of digital environments as well as evaluating consumer behavior within a broader theoretical and contextual framework (Lemon & Verhoef, 2016). In this context, the aim of this study is to examine the evolution of the impact of social media on consumer behavior from a psychological well-being perspective. The study aims to provide a holistic perspective on how social media has shaped consumer behavior over time by bringing together marketing and psychology literature.

2. CONCEPTUAL FRAMEWORK

2.1 The Concept and Development of Social Media

Although the concept of social media has been extensively discussed in the literature, there is no single, universally accepted definition. Early definitional studies focus on the common structural elements of social media. For example, Obar et al. (2015) identified four basic characteristics of social media: Web 2.0-based applications, user-generated content, user-specific profiles, and the creation of social networks. Similarly, El Ouirdi et al. (2014) emphasized that despite numerous definitions, there is no definitional consensus in the literature and proposed a more comprehensive framework based on communication theory. A comprehensive review conducted by Aichner et al. (2020) reveals the diversity of definitions and conceptual approaches by analyzing 25 years of literature. McCay-Peet and Quan-Haase (2017) state that the concept of social media only began to be widely used in the academic field from the mid-2000s onwards.

Alternative approaches define social media from a more functional perspective. van Osch and Coursaris (2013) define social media as technological tools that enable users to create content, communicate, and develop social relationships. Kaplan and Haenlein (2010) describe social media as a group of Internet-based applications that build on Web 2.0 and allow users to create and exchange user-generated content. Despite the differences in definitions, there is a general consensus

in the literature that social media enables user-centric, interactive, and participatory communication processes. The most important difference between social media and traditional media lies in the structure of information flow. While traditional media relies on a vertical and one-way communication model where content is transferred from powerful organizations to passive consumers, social media offers a horizontal and two-way communication process among users (Zahoor & Qureshi, 2017). This transformation represents a radical paradigm shift in communication processes. Csordás et al. (2014) emphasize that, in this context, businesses have had to reconsider their traditional one-way marketing communication approach. It is also noted that consumers perceive social media as a more reliable source of information compared to traditional marketing tools (Zahoor & Qureshi, 2017).

Structurally, social media consists of numerous interrelated components. Technologically based on Web 2.0 infrastructure, these platforms enable the participation of large audiences (Kaplan & Haenlein, 2010). In terms of content, user-generated content constitutes a fundamental element (Kaplan & Haenlein, 2010), while social networking features allow users to create profiles and develop relationships (Boyd & Ellison, 2007). Furthermore, social media communication exhibits a participatory and collaborative structure, allowing for continuous interaction and the co-creation of value. The development of social media has led to significant transformations in communication and information-sharing processes. These platforms have reshaped how individuals interact, access information, and use it (Kietzmann et al., 2011). Social media is no longer merely a tool for information transfer; it has become an environment where users actively participate by producing and sharing content (Kaplan & Haenlein, 2010). However, the literature also highlights that comparative analyses remain challenging due to definitional differences and methodological issues (Aichner et al., 2020; McCay-Peet & Quan-Haase, 2017).

2.2 Consumer Behavior

Consumer behavior is defined as a field that examines the decision-making processes of individuals regarding the consumption of goods and services (Solomon, 2018; Schiffman & Wisenblit, 2015). Classical approaches to consumer behavior are based on the assumption that individuals are rational decision-makers and explain consumption decisions through objective criteria such as price, income, and utility (Kotler & Keller, 2016). Traditional models such as Nicosia, Engel-Kollat-Blackwell, and Howard-Sheth address the consumer decision-making process through the stages of need recognition, information search, evaluation of alternatives, purchase, and post-purchase evaluation (Blackwell et al., 2006).

Over time, these models have evolved to acknowledge that consumer behavior is influenced not only by rational factors but also by emotional and psychological factors. This transformation has become more pronounced, especially with digitalization. Digitalization has fundamentally transformed consumer behavior, making it more dynamic, personalized, and shaped by social influences. Digital

environments differ from classical consumer behavior with features such as frictionless transactions, global reach, social integration, and data-driven personalization (Lemon & Verhoef, 2016; Wedel & Kannan, 2016). Empirical studies show that consumers increasingly rely on digital advertisements, online reviews, and platform-based information in their purchasing decisions (Cheung & Thadani, 2012; Erkan & Evans, 2016).

Digital consumer behavior is defined as a process in which individuals interact with brands, access information, and make purchasing decisions through digital platforms. Stephen (2016) examines digital consumer experiences through dimensions such as digital culture, advertising responses, mobile usage, and online word-of-mouth communication. However, the fact that a significant portion of the studies in the literature are based on surveys and conceptual analyses leads to a limited number of large-scale empirical findings.

Digital environments have also significantly changed consumers' information search and evaluation processes. Consumers now heavily rely on digital sources such as websites, blogs, and social media when evaluating products and services (Cheung & Thadani, 2012). At the same time, consumer–brand interaction has become more participatory and interactive, and brand personality and digital interaction have played a significant role in shaping consumer perceptions (Hollebeek et al., 2014; Dessart et al., 2015). User-generated content and social interaction are among the important elements that guide consumer behavior. The reliability of the information source, the similarity among users, and the level of social interaction directly influence consumer decisions (Herrero et al., 2015). In this context, digitalization has transformed consumer behavior into a more interactive, social, and dynamic structure.

2.3 Psychological Well-being

Psychological well-being is defined as a multidimensional concept encompassing an individual's positive functioning, life satisfaction, and emotional health. One of the most influential approaches in this field is the model developed by Ryff (1989). According to this model, psychological well-being consists of six core dimensions: self-acceptance, positive relationships with others, autonomy, environmental mastery, purpose in life, and personal growth. This model has been further validated by subsequent studies and has become a fundamental reference point in the literature (Ryff & Keyes, 1995). However, the concept of psychological well-being has not reached complete consensus in the literature. Researchers commonly distinguish between hedonic well-being, which focuses on happiness and life satisfaction, and eudaimonic well-being, which emphasizes meaning and self-realization (Ryan & Deci, 2001). Furthermore, psychological well-being differs from related constructs such as mental health and subjective well-being in terms of scope, measurement, and temporal dimensions (Diener, 1984; Keyes, 2002; Cooke et al., 2016).

Theoretical approaches explaining psychological well-being can be broadly classified into process-based, judgment-based, and multidimensional approaches. These include goal-based theories, adaptation theories, and top-down/bottom-up perspectives (Diener, 1984; Diener et al., 1999). Ryff's model, however, offers a holistic framework by integrating these different perspectives into a multidimensional structure of psychological functioning (Ryff, 1989; Ryff & Keyes, 1995). Psychological well-being is gaining increasing importance in the consumer behavior literature. However, due to conceptual and measurement differences, a unified and holistic framework remains limited (Diener et al., 1999; Sirgy, 2012). Contemporary studies conceptualize psychological well-being through emotional, cognitive, and social dimensions, linking it to constructs such as identity, social connection, and interpersonal interaction (Ryan & Deci, 2001; Keyes, 2002). In a digital context, the effects of social media use on psychological well-being are complex and multidimensional. Large-scale studies indicate that the overall effects of social media use are generally small but vary depending on how these platforms are used (Orben & Przybylski, 2019; Valkenburg et al., 2021). Moderate use can enhance social connection and well-being, whereas excessive use has been associated with negative outcomes such as anxiety, depression, and social isolation (Twenge & Campbell, 2019; Kross et al., 2013).

Psychological well-being also influences consumer behavior. Research suggests that individuals with higher levels of well-being are more likely to engage in experiential and prosocial consumption behaviors, including sustainable consumption (Van Boven & Gilovich, 2003; Brown & Kasser, 2005). Emotional states directly affect consumer decisions, with positive emotions increasing the tendency to purchase, while negative emotions may lead to avoidance or impulsive consumption behaviors (Rook & Gardner, 1993; Verplanken et al., 2005). In digital environments, psychological well-being influences consumption behaviors both directly and indirectly. In particular, emotional and psychological states have been shown to mediate the relationship between online stimuli (e.g., social media content and advertising) and consumer responses (Yadav & Rahman, 2017; Erkan & Evans, 2016). Furthermore, psychological well-being is recognized as an important determinant in sustainable consumption behaviors and online purchasing processes (White et al., 2019; Hwang & Kim, 2018).

3. LITERATURE REVIEW

The Evolution of Social Media and Consumer Behavior

The impact of social media on consumer behavior has changed significantly over time, evolving from a simple communication tool into a dominant force influencing all stages of the consumer decision-making process. Early social networking platforms such as SixDegrees and Friendster primarily facilitated online interaction, while later platforms like Facebook and Twitter expanded information sharing and increased user engagement (Boyd & Ellison, 2007; Kaplan & Haenlein, 2010). During the same period, the transition from traditional retail to e-commerce accelerated, and consumers

increasingly relied on online information sources—particularly user reviews and experiences—before making purchasing decisions (Dellarocas, 2003; Cheung & Thadani, 2012).

With the development of digital technologies and the widespread adoption of smartphones, social media has become an integral part of consumer behavior. In this process, influencer culture, online communities, and personalized content delivery have emerged, reshaping how consumers interact with brands (Kaplan & Haenlein, 2010; Stephen, 2016). Empirical studies indicate that social media influences consumer behavior through mechanisms such as product awareness, social proof, promotions, and influencer marketing (Hajli, 2014; De Veirman et al., 2017; Yadav & Rahman, 2017). However, the literature largely remains descriptive, and long-term empirical studies that measure the magnitude of this transformation over time are still limited (Stephen, 2016; Lemon & Verhoef, 2016).

3.1 Early Period: Information Seeking and eWOM (2005–2015)

In the early stages of social media development, consumer behavior was largely shaped by information seeking and electronic word-of-mouth (eWOM). Social media platforms and online review systems emerged as alternative information sources to traditional marketing communication. Consumers increasingly turned to user-generated content, reviews, and recommendations when evaluating products and services (Dellarocas, 2003; Hennig-Thurau et al., 2004). Empirical findings show that early internet users exhibited different behavioral patterns compared to later users. For example, Chen et al. (2011) demonstrated that the relationship between product price and the tendency to write reviews evolved over time. Similarly, studies indicate that consumers increasingly began to rely on social media and online platforms as primary sources of information prior to purchase, while the importance of traditional information sources declined (Cheung & Thadani, 2012; Erkan & Evans, 2016).

During this period, electronic word-of-mouth communication (eWOM) played a critical role in consumer decision-making. The literature shows that eWOM has strong effects on consumer perceptions, trust, and purchase intentions. These effects vary depending on factors such as source credibility, message valence, and consumer involvement (Cheung & Thadani, 2012; Filieri, 2015). Furthermore, the volume and adoption of eWOM are significant determinants of purchasing behavior (Duan et al., 2008). In addition, online reviews have become a fundamental mechanism in the formation of consumer trust. Research indicates that consumers often perceive online reviews as more credible than firm-generated information (Bickart & Schindler, 2001; Park et al., 2007). The content, accuracy, and positive or negative valence of reviews directly influence consumer decisions; positive reviews increase purchase likelihood, whereas negative reviews can deter consumers (Chevalier & Mayzlin, 2006). In this context, this period is characterized by an information-driven and risk-reduction-oriented consumption pattern.

3.2 Development Period: Interaction and Consumption (2015–2020)

The development period represents the transition from information-based consumption to interaction-based consumption. During this period, social media platforms have evolved into interactive environments that enable real-time and two-way communication between consumers and brands. This transformation has fundamentally reshaped consumer–brand relationships, turning consumers from passive recipients into active participants (Kaplan & Haenlein, 2010; Kietzmann et al., 2011). Research shows that platforms such as Facebook, Instagram, and Twitter facilitate direct communication between consumers and brands and contribute to strengthening emotional connections (Mangold & Faulds, 2009; Dessart et al., 2015). Labrecque (2014) emphasizes that parasocial interaction has significant effects on brand loyalty and information sharing.

During this period, influencer marketing has emerged as one of the most important factors influencing consumer behavior. Studies indicate that influencers significantly affect brand awareness, trust, attitudes, and purchasing behavior (De Veirman et al., 2017; Lou & Yuan, 2019). The effectiveness of influencer marketing largely depends on factors such as credibility, authenticity, and perceived similarity. In particular, micro-influencers tend to generate higher engagement levels (De Veirman et al., 2017; Djafarova & Rushworth, 2017). However, ethical concerns related to transparency and trustworthiness have also been highlighted in the literature (Evans et al., 2017).

In this period, consumer interaction and experience are shaped through cognitive, emotional, and behavioral dimensions. Hollebeek et al. (2014) conceptualize consumer engagement as a multidimensional construct encompassing cognitive processing, emotional connection, and active participation. Content characteristics, perceived value, and community dynamics are key determinants of engagement levels (Brodie et al., 2013; Dessart et al., 2015). Furthermore, a defining feature of this era is the influence of social media on impulsive buying behavior. Several studies demonstrate that social media use increases impulsive purchasing tendencies (Verhagen & van Dolen, 2011; Zhang et al., 2018). This suggests that consumption has become more experiential and spontaneous.

3.3 Current Period: Psychological Well-being and Consumption (2020–Present)

In the current period, the literature focuses not only on the behavioral but also on the psychological effects of social media. In this context, the relationship between social media use and psychological well-being has become an important area of research. Empirical findings indicate that the effects of social media on psychological well-being are complex and bidirectional. Large-scale and meta-analytic studies suggest that there is generally no substantial association between overall social media use and well-being, although small effects have been identified for anxiety, depression, and social well-being (Orben & Przybylski, 2019; Valkenburg et al., 2021). Other studies highlight both positive outcomes, such as enhanced social connection, and negative consequences, including loneliness, cyberbullying, and social comparison (Verduyn et al., 2017; Kross et al., 2013).

Social comparison processes stand out as one of the fundamental mechanisms influencing consumer behavior during this period. Exposure to idealized representations of others' lives on social media increases feelings of inadequacy and shapes consumption decisions (Vogel et al., 2014; Steers et al., 2014). This can lead to increases in conspicuous, impulsive, and compensatory consumption behaviors. Digital addiction and intensive social media use further reinforce these effects. Research shows that heavy social media use is associated with materialism, fear of missing out (FoMO), and compulsive buying behavior (Przybylski et al., 2013; Dhir et al., 2018; Wang et al., 2018).

Furthermore, the literature highlights the relationship between psychological well-being and consumption types. Individuals with higher levels of well-being tend toward experiential and sustainable consumption, whereas lower levels of well-being are associated with materialistic and impulsive consumption patterns (Van Boven & Gilovich, 2003; Brown & Kasser, 2005; White et al., 2019; Šeinauskienė et al., 2016). This indicates that psychological well-being determines not only the quantity but also the type of consumption.

The literature clearly shows that the impact of social media on consumer behavior has evolved through different mechanisms across periods. The first period focused on information seeking and trust-building processes, while the second period represented a transition to interaction- and experience-based consumption. In the current period, consumer behavior is examined together with psychological processes. A holistic perspective reveals that the behavioral and psychological effects of social media are not independent but complementary. These effects vary not only depending on the frequency of use but also on the purpose of use, emotional engagement, and individual motivations (Bekalu et al., 2019; Valkenburg et al., 2021). Therefore, understanding the impact of social media on consumer behavior requires a multidimensional approach that integrates informational, interactive, and psychological factors. This approach provides a more comprehensive explanation of the dynamic nature of digital consumption behavior.

4. DISCUSSION

The findings of this study reveal that the impact of social media on consumer behavior has undergone a significant transformation over time, encompassing not only behavioral but also psychological dimensions. Evidence from the literature shows that in its early stages, social media primarily influenced consumer decisions through information seeking and electronic word-of-mouth communication (eWOM). This is consistent with studies demonstrating that consumers rely on user-generated content to reduce uncertainty and build trust (Bickart & Schindler, 2001; Hennig-Thurau et al., 2004).

With the transition to developmental stages, the role of social media has evolved from being merely an information provider to an interaction-based structure. This transformation can be explained by the shift of consumers from passive information recipients to active participants (Kaplan & Haenlein,

2010; Kietzmann et al., 2011). The rise of influencer marketing and the growth of parasocial interactions have made consumer–brand relationships more emotional and experiential (De Veirman et al., 2017; Labrecque, 2014). These findings support approaches suggesting that consumer engagement consists of cognitive, emotional, and behavioral dimensions (Hollebeek et al., 2014).

One of the most important contributions of this study is the evaluation of the impact of social media on consumer behavior within the context of psychological well-being in the current period. The findings indicate that social media has bidirectional effects on psychological well-being and that these effects are directly reflected in consumer behavior. In particular, mechanisms such as social comparison, fear of missing out (FoMO), and digital addiction appear to increase impulsive and compulsive buying behaviors (Vogel et al., 2014; Przybylski et al., 2013; Dhir et al., 2018). This suggests that social media triggers not only rational but also emotionally and psychologically driven consumption processes.

However, the positive effects of social media should not be overlooked. Elements such as social connection, perceived support, and a sense of community can enhance psychological well-being, which is associated with a shift toward more conscious and sustainable consumption behaviors (Verduyn et al., 2017; White et al., 2019). This finding is consistent with studies demonstrating the relationship between psychological well-being and consumption types (Šeinauskienė et al., 2016). Another important finding is that marketing and psychological well-being studies are often treated separately in the literature, making it difficult to understand the holistic impact of social media on consumer behavior (Kietzmann et al., 2011; Yadav & Rahman, 2017). Furthermore, the predominance of cross-sectional and short-term studies limits the ability to capture the evolution of social media effects over time (van Osch & Coursaris, 2014; Lemon & Verhoef, 2016).

In conclusion, this study demonstrates that the impact of social media on consumer behavior has evolved through three main stages. In the first stage, an information-driven structure dominated, with consumers relying primarily on information seeking and electronic word-of-mouth communication. In the second stage, an interaction- and experience-oriented transformation emerged, with consumers becoming active participants and forming stronger emotional connections with brands. In the current stage, psychological processes have become central, with factors such as social comparison, emotional states, and psychological well-being directly influencing consumer behavior. This three-stage structure clearly illustrates that social media is transforming consumer behavior into an increasingly complex, dynamic, and multidimensional phenomenon.

5. CONCLUSION

This study aims to make a holistic contribution to the literature by examining the evolution of social media's influence on consumer behavior from a psychological well-being perspective. The findings reveal that social media has transformed over time from a simple communication tool into a multidimensional ecosystem affecting all stages of consumer decision-making processes. The study

shows that the influence of social media on consumer behavior has developed in three main stages. In the first stage, information seeking and trust-building processes were prominent, while in the second stage, interaction, experience, and brand relationships gained importance. In the current stage, psychological well-being, social comparison, and emotional processes have become the fundamental determinants of consumption behavior. This finding demonstrates that digital consumption behavior is based not only on cognitive but also on emotional and psychological foundations.

Theoretically, the study combines marketing and psychology literature to address the impact of social media on consumer behavior within a broader framework. This integrative approach reduces the fragmentation in the literature, contributing to a more comprehensive understanding. In particular, the emphasis on the role of psychological well-being in consumer behavior offers a significant area of research for future studies. From a managerial perspective, the findings demonstrate that businesses should develop social media strategies that are not solely focused on interaction and sales, but also consider the psychological well-being of consumers. Marketing approaches that take into account consumers' emotional and psychological needs can contribute to building more sustainable and long-term customer relationships.

However, this study has some limitations. Because it is based on a literature review, it does not include empirical findings, and the heterogeneous nature of existing studies may limit generalizations. Furthermore, the limited number of long-term and comparative studies in the literature makes it difficult to more clearly reveal how the effects of social media change over time. For future research, empirical studies examining the effects of social media use patterns on psychological well-being in different cultural contexts are recommended. Additionally, longitudinal studies will offer the opportunity to analyze the transformation of the impact of social media on consumer behavior over time in greater depth. In conclusion, understanding the relationship between social media and consumer behavior requires a multidimensional approach that considers information, interaction, and psychological processes together. This study makes a significant contribution to the literature by presenting this approach.

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TÜRKİYE İKTİSADİ SAVUNMA PLANI ÖLÇEĞİNDE TOPRAK MAHSULLERİ VERGİSİ

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ÖZET

Türkiye, İkinci Dünya Savaşı'na doğrudan katılmamıştır. Ancak çatışmanın siyasi, ekonomik ve sosyal sonuçlarından derinden etkilenmiştir. Bu sebeple de ülke bir savaş ekonomisi rejimi benimsemek zorunda kalmıştır. Seferberlik ilanı sebebiyle erkek işgücünün önemli bir kısmının üretimden çekilmesi ekonomiyi darboğaza sokmuştur. Ayrıca artan askeri harcamalar, daralan ithalat, enflasyon, karaborsa faaliyetleri ve gıda tedariki sorunları da devlet ve ekonomi üzerinde olağanüstü bir baskı yaratmıştır. Bu koşullar altında hükümet de savunma harcamalarını finanse etmek ve ordunun ve büyük kent merkezlerinin iaşesini (beslenmesini) güvence altına almak ve de ekonomik istikrarı korumak amacıyla güçlü bir devlet müdahalesine dayanan bir ekonomik savunma stratejisi geliştirmiştir. Bu çerçevede Milli Korunma Kanunu, Toprak Mahsulleri Ofisi'nin faaliyetleri, Varlık Vergisi ve Toprak Mahsulleri Vergisi, savaş dönemi ekonomi yönetiminin temel araçları haline gelmiştir. Bu tedbirler arasında Toprak Mahsulleri Vergisi de doğrudan tarım sektörünü hedef alması ve köylüleri ekonomik savunma planının mali yapısına dâhil etmesi nedeniyle özellikle önemli bir yere sahiptir. Verginin ayni yapısı dolayısıyla doğrudan ürünler üzerinden alınması ve Osmanlı dönemi tarımsal vergilendirme biçimlerine benzerliği vardır. Bundan dolayıdır ki vergi birçok çağdaşının ve daha sonraki dönem araştırmacılarının onu "ikinci aşar" olarak nitelendirmesine yol açmıştır. Toprak Mahsulleri Vergisi Türkiye'nin ekonomik savunma planı çerçevesinde kısa vadeli mali ve lojistik amaçlara hizmet etmiştir. Ancak aynı zamanda da önemli olumsuz sonuçlar da doğurmuştur. Devlet-köylü ilişkilerini zayıflatmış, tarımsal üretim teşviklerinde düşüşe katkıda bulunmuş ve kırsal toplumdaki siyasi hoşnutsuzluğu yoğunlaştırmıştır.

Anahtar Kelimeler: *Toprak Mahsulleri Vergisi, İktisadi savunma planı, II. Dünya Savaşı, Millî Korunma Kanunu, Varlık Vergisi.*

JEL Kodları: *N44, N54, N56.*

AGRICULTURAL PRODUCTS TAX WITHIN THE SCOPE OF TURKIYE'S ECONOMIC DEFENSE PLAN

ABSTRACT

Turkey did not directly participate in World War II. However, it was deeply affected by the political, economic, and social consequences of the conflict. Therefore, the country was forced to adopt a war economy regime. The mobilization caused a significant portion of the male workforce to withdraw

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from production, plunging the economy into a crisis. Furthermore, increased military spending, shrinking imports, inflation, black market activities, and food supply problems created extraordinary pressure on the state and the economy. Under these conditions, the government developed an economic defense strategy based on strong state intervention to finance defense expenditures, secure the provisioning of the army and major urban centers, and maintain economic stability. Within this framework, the National Protection Law, the activities of the Agricultural Products Office, the Wealth Tax, and the Agricultural Products Tax became the fundamental tools of wartime economic management. Among these measures, the Agricultural Products Tax holds a particularly important place because it directly targeted the agricultural sector and included peasants in the financial structure of the economic defense plan. Due to its in-kind nature, the tax was levied directly on products and resembled the agricultural taxation methods of the Ottoman period. This is why the tax led many of its contemporaries and later researchers to describe it as the "second tithe." The Agricultural Products Tax served short-term financial and logistical purposes within the framework of Türkiye's economic defense plan. However, it also had significant negative consequences. It weakened state-peasant relations, contributed to a decrease in agricultural production incentives, and intensified political discontent in rural society.

Keywords: *Agricultural Products Tax, Economic defense plan, World War II, National Protection Law, Wealth Tax.*

JEL Codes: *N44, N54, N56*

1. INTRODUCTION

World War II, between 1939 and 1945, was not only a military conflict on a global scale. This war was also a period of total economic struggle in which states mobilized all their resources. Turkey, through its strategic foreign policy moves, managed to remain effectively outside the hot conflict. However, the country could not escape the political, social, and economic turbulence created by the war. This great war, which took place outside its borders, forced Turkey to adopt a position of being "non-combatant but always ready for war." This difficult situation brought with it a severe "war economy" regime that deeply shook the entire economic structure (Erul & Buz, 2020; Özcan, 2020; Şener, 2004; Doğangün, 2025).

Due to the general mobilization declared with the start of the war, the young male population, which was the greatest productive force of Turkey at that time, was withdrawn from the fields and moved to the barracks. Due to this massive loss of workforce, agricultural production dramatically decreased, supply narrowed, and a food (provisioning) crisis emerged. On the other hand, meeting the feeding and logistical expenses of the growing army, eliminating the threat of hunger in urban centers, and curbing rapidly rising inflation and the black market became the state's top priorities. Due to these extraordinary circumstances, the National Protection Law enacted in 1940 abandoned liberal approaches in the

economy and opened the door to a harsh state interventionism (Özcan, 2020; Özer, 2011; Şener, 2004, Doğangün, 2019). The aim of the "Economic Defense Plan" implemented by the government during this period was to close budget deficits and finance defense expenditures by implementing radical tax policies. The Wealth Tax, targeting urban merchants and wealthy individuals, was invented, and in addition, the Agricultural Products Tax (TMV), designed as its rural equivalent and complement, was put into effect. These taxes have been the most strategically critical links in these radical tax policies. The Agricultural Products Tax (TMV), established in 1943 with Law No. 4429, was seen as a similar tax to the "Aşar" tax, which the Republic administration abolished in 1925 to alleviate the heavy burden on the peasantry. This is because, years later, it brought back the method of directly and often in kind (as product) collecting a share from agricultural products (Akman & Solak Akman, 2011; Çomaklı, Koç, & Yıldırım, 2012; Eray, 2017; Doğangün, 2024).

This study does not evaluate the Agricultural Products Tax solely as a source of financial revenue. On the contrary, it considers it as an institutional and social instrument of Turkey's wartime economic defense plan. The main aim of the study will be to focus on why the tax is described as the "Second Aşar" due to its method of collection in kind and its implementation. And it will examine how this practice damaged the political contract between the state and the peasantry. In this context, the legal basis of the TMV (Turkish Agricultural Tax) and the administrative difficulties encountered during its implementation will be examined. And in this context, the lasting effects of the tax on the rural social structure will be analyzed in light of the agricultural policies of the period.

2. TURKEY'S ECONOMIC DEFENSE STRATEGY DURING THE YEARS OF WORLD WAR II

2.1. War Economy, Production Loss and Food Supply Crisis

With the actual outbreak of the Second World War, Turkey quickly declared general mobilization in the face of the intense military threat it felt on its borders. With mobilization, the army's strength was increased to approximately one million people. This situation had very difficult consequences for the Turkish economy, which provided more than half of the national income at that time and was largely based on human and animal power. Because with the dramatic withdrawal of the most productive agricultural workforce from the fields, economic and agricultural activities were put under great strain. Within the scope of mobilization, not only young men were conscripted. In addition, draft animals and transportation vehicles, which were the main engine of agricultural production, were also confiscated by the state. This double loss caused a severe collapse in agricultural production. For example, Turkey, which exported wheat before the war, soon became unable to feed its own population. This sharp decline in production and the resulting decrease in imports due to the closure of international trade routes deepened the supply crisis in the economy. The escalating shortage of goods quickly created severe inflation, leading to hoarding and black market activities becoming commonplace. At this point, the

provisioning of food for large cities and the enormous army became a vital national security issue. Thus, the necessity of rationing bread in major cities arose (Aydın, 2017; Özcan, 2020; Özer, 2011; Şener, 2004).

2.2. Legal and Institutional Tools of State Intervention

In this extraordinary period, when free market conditions had completely collapsed and the food crisis deepened, the government resorted to strict state interventionism to keep the economy afloat. The most fundamental legal basis of this new "economic defense strategy" was the National Protection Law (MKK), which came into effect on January 18, 1940. This law aimed to integrate the civilian economy into military defense needs, granting the government unlimited powers such as seizing production facilities, setting prices, controlling foreign trade, confiscating products, and implementing compulsory labor in mines and agricultural areas. In the institutional sphere, the function of the Soil Products Office (TMO), established in 1938 to protect farmers, completely changed with the war. Based on the powers granted by the MKK, the state began to compulsorily seize a certain percentage of the grain in the hands of producers (with quotas varying between 25 and 50 percent). The Turkish Grain Board (TMO) was tasked with collecting these products at fixed prices far below market value. However, these low purchase prices set by the state lagged far behind the exorbitant prices on the black market. Therefore, villagers preferred to hide their products or sell them on the black market rather than deliver them to the state. This situation severely hampered the state's food supply policy (Erul & Buz, 2020; Özcan, 2020; Şener, 2004).

2.3. Other Extraordinary Tax Policies of the War Period

Increased defense spending led to enormous budget deficits, and the state's efforts to control the market proved insufficient. The increase in the amount of paper money in circulation drove inflation to unprecedented levels. The scarcity of goods in the market fueled hoarding and black market activities, creating a new class of "war profiteers" who made extraordinary profits. The government undertook efforts to absorb this excess money supply from the market, meet the state's urgent cash needs, and tax those who profited unfairly. As a result of these studies, three radical tax regulations that complement each other have been implemented (Erul & Buz, 2020; Özcan, 2020).

2.3.1. Transaction Tax (Value Added Tax)

The Transaction Tax was designed as a consumption/transaction tax levied (indirectly) on industrial and commercial transactions. This tax was collected on goods when manufactured, produced, or imported goods entered commercial circulation and changed hands (at the time of the transaction). With the law passed in 1927 before the war, the general rate of this tax was determined as 6%. During the war period, with the law numbered 3822 (1940), the rate was increased to 12.5%. In the later years

of the war (1941 and onwards), these rates climbed to 15% and 18% in some product groups and luxury consumption. (Erul & Buz, 2020; Özcan, 2020).

The state managed to generate a continuous tax revenue from the market activity of consumer goods through the In-Kind Transaction Tax. However, this tax had to be added to the price at every stage of the production and supply chain. Since this was directly added to costs, it dramatically increased the final sales price of goods reaching the end consumer. Adding this tax to basic necessities, which were already very expensive due to the black market, was devastating for large segments of the population. Because it further fueled inflationary pressure, it severely eroded the purchasing power of low-income urban civil servants and workers in particular (Çomaklı, Koç, & Yıldırım, 2012; Erul & Buz, 2020; Özcan, 2020).

2.3.2. Provisional Income Tax

Another step taken to fill the financial void created by the war economy was the Provisional Income Tax. It came about because the rates of existing income taxes applied in normal periods were insufficient. It specifically targeted traders, industrialists, and high-income self-employed individuals who operated with extraordinary profit margins, especially during wartime (Özcan, 2020).

Unlike the Wealth Tax, it was a tax levied on wealth, not on wealth itself, but directly on the periodic "commercial profit (earnings)" obtained. It aimed to limit the profits of traders who sold goods at exorbitant prices in the black market. In the Provisional Profit Tax, the more "war profits" you earned, the larger the share the state took. As profits increased, the tax rate also increased. In some cases, 50% to 80% of the profit was demanded as tax. These temporary obligations added to the existing Profit Tax Law provided a rapid and continuous cash flow to the state treasury. However, because traders reflected this tax burden in prices and managed to evade the tax, the inflationary cycle could not be broken (Çomaklı, Koç, & Yıldırım, 2012; Özcan, 2020).

2.3.3. Wealth Tax

The harshest and most internationally debated measure of the period was the Wealth Tax, enacted by the Şükrü Saracoğlu government on November 11, 1942. At first glance, the law aimed to tax the excessive and speculative profits created by the extraordinary war conditions, to curb inflation, and to punish black marketeers. The taxpayers mainly consisted of merchants, large real estate owners, brokers, and companies (Erul & Buz, 2020; Subay, 2024).

However, the way the Wealth Tax was implemented caused great outrage. The tax amounts were not based on any objective financial criteria. The tax amounts were determined entirely arbitrarily and at the discretion of local commissions. There was no legal recourse or appeal against the decisions of these commissions. Furthermore, the sending of those who could not pay the astronomical sums to labor camps such as Erzurum-Aşkale was one of the harshest criticisms of this tax. Moreover, the tax burden

was disproportionately placed on non-Muslim minorities. The practice was concentrated in major commercial centers such as Istanbul, Izmir, and Bursa. The Wealth Tax quickly provided a large influx of cash into the treasury, easing the budget. However, due to the deep distrust it created in the markets, it was abolished in 1944 (Erul & Buz, 2020; Özcan, 2020; Subay, 2024).

In conclusion, the Wealth Tax, Provisional Income Tax, and In-Kind Transaction Tax created an unprecedented financial squeeze on commercial life in cities. However, these measures, which drew cash from cities to the state, failed to solve the problem of the army's "physical provisioning" (tangible food stock). This result inevitably shifted the economic defense plan's focus to the country's rural areas, namely the Agricultural Products Tax (Akman & Solak Akman, 2011; Aydın, 2017).

3. THE ESTABLISHMENT AND LEGAL FRAMEWORK OF THE AGRICULTURAL PRODUCTS TAX

3.1. Justifications for the Tax and its Place in Economic Defense

The severe food and budget crisis brought about by the Second World War forced the government to move beyond classical taxation methods. The main motivation behind the establishment of the Agricultural Products Tax (TMV) was to meet the nutritional needs of the army and major urban centers directly from the source (producer). In addition, it aimed to create a sustainable physical stock to finance war expenditures. Within the framework of the economic defense plan of the time, in an environment where cash was losing value and inflation was rising, the practice of collecting taxes "in kind" (as products) was adopted. This ensured that the state secured its food stocks and was not affected by speculative price movements in the market. Thus, the TMV was not considered merely as a financial revenue tool. The Agricultural Products Tax (TMV) was also conceived as a strategic economic defense instrument through which the state intervened in agricultural production and distribution processes using a method "close to confiscation" (Aydın, 2017; Erul & Buz, 2020; Özcan, 2020; Şener, 2004).

3.2. Law No. 4429 of 1943: The First Step and Shortcomings

The legal process of the TMV began with Law No. 4429, "Law on Agricultural Products Tax," adopted on June 4, 1943. The law included all strategic products such as cereals (wheat, barley, corn, etc.), legumes (beans, chickpeas, lentils, etc.), and silkworm cocoons within the scope of taxation. In the first year of implementation, tax rates also exhibited a tiered structure according to the size of the farms and product groups. The aim was to collect lower taxes from small producers and higher taxes from large landowners. This complex rate structure led to administrative confusion, corruption, and complaints of injustice in the field. Furthermore, the estimation methods introduced in the initial version of the law were far from reflecting the actual production of the farmers. This situation created a much heavier pressure on agricultural producers than expected (Law No. 4429, 1943; Akman & Solak Akman, 2011; Aydın, 2017).

3.3. Law No. 4553 of 1944: Standardization and Stricter Complementation

In order to eliminate the administrative shortcomings encountered in the first year of implementation and to make collection more efficient, a new law, No. 4553, was enacted on April 26, 1944. The most critical change with this new regulation was the standardization of the tax rate to 10% without exception for all products and all business sizes. Although the law made it a rule that the tax should be collected "in kind" (in kind), it also opened the door to cash payments in some special cases and for certain products. Law No. 4553 granted tax officials very broad powers of inspection and confiscation. It also introduced severe penalties, including imprisonment, for those who could not pay their tax debts. Thanks to this standardization, the state's collection capacity increased. However, the burden on small farmers became much heavier (Law No. 4553, 1944; Çomaklı, Koç, & Yıldırım, 2012; Ertan, 2014).

3.4. Subject of the Tax, Taxpayer, and Exceptions

According to the provisions of the law, the subject of the Turkish Agricultural Products Tax (TMV) is all agricultural products grown within the borders of Turkey. The taxpayer is the real or legal person who grows these products. The state has granted some exceptions in the law for social and technical reasons. These include products grown in courtyards and gardens subject to building tax, limited quantities of products set aside by the villager for their own personal needs, and model farms and seed stations established by the state to improve agriculture, all of which are exempt from tax. However, the ambiguity of the application limits of these exceptions has left the door open to arbitrary interpretations by field officers. And often, this has led to even the villager's winter provisions being collected within the scope of taxation (Law No. 4429, 1943; Law No. 4553, 1944; Subay, 2024).

3.5. The "Second Tithe" Debate and Ideological Breakdown

The fact that the Aşar tax (TMV) was collected at a rate of 10% and directly as a share (in kind) of agricultural products led to it being described as the "Second Tithe" both in the public opinion of the time and in modern literature. In 1925, the Republic regime proudly abolished the Aşar tax in order to bring the peasantry to modern citizenship and weaken feudal ties. However, the return of this tax in a similar form eighteen years later created a serious ideological contradiction. The administrators of the time stated that the TMV, unlike the Ottoman Aşar, was not collected through the "iltizam" (intermediary tax farmers) system. And they tried to deflect these criticisms by arguing that the tax was collected directly by state officials. However, due to the harsh methods applied by the gendarmerie and tax officials to the villagers during the collection process, the historical traumas created by the Aşar tax were revived in the collective memory, and the tax lost legitimacy in the eyes of the public (Akman & Solak Akman, 2011; Aydın, 2017; Ertan, 2014; Subay, 2024).

4. IMPLEMENTATION PROCESS AND ADMINISTRATIVE DIFFICULTIES

4.1. Structure of Estimation and Determination Commissions and "Desk-Based" Decisions

The most criticized aspect of the Agricultural Products Tax, and the one that created the most pressure on the villagers, was the determination of the amount of tax to be paid by "estimation" before the harvest. According to the law, "Estimation and Determination Commissions" were established in each district and sub-district. The commissions consisted of a tax official, an agricultural official, and local council representatives (village headman or council of elders). However, in practice, these commissions were unable to personally inspect the fields due to personnel shortages, fuel scarcity, and limited transportation options resulting from the war years. Instead, they made "extravagant" yield estimates based on data from previous years or statements from village headmen. This situation led to a tax burden far exceeding the actual production. This, in turn, damaged the trust relationship between the state and the producers from the very beginning (Aydın, 2017; Metinsoy, 2012; Özer, 2011).

The incompetence in the commissions' working methods also had tragic consequences, especially in regions where climatic conditions negatively affected agriculture. Even villagers who could not harvest any crops from their fields due to natural disasters such as drought, locust/pest infestations, or frost were notified of tax debts based on the high estimates made by the commissions months earlier. The villagers' objections to these unfair estimates were often unsuccessful due to bureaucratic inefficiency and pressure from the gendarmerie. Field research shows that local powerful figures (landlords) used their political influence over commissions to lighten their own tax burdens. In contrast, it reveals that unprotected small farmers were taxed far beyond their actual harvest (Metinsoy, 2012; Özer, 2011).

4.2. Logistics and Infrastructure Crises: Delivery and Transportation Obligations

Due to the necessity of collecting taxes in kind (as products), collection turned into a complete logistical fiasco. This was because the transportation and storage infrastructure in Turkey at that time was extremely inadequate. According to the law, the delivery of the taxed produce to the warehouses designated by the state (Agricultural Products Office) was left directly to the responsibility and expense of the villagers. However, due to the general mobilization conditions, the trucks and ox carts seized by the army left the villagers without transportation vehicles. Small producers often had to carry sacks of produce on their backs to train stations or office centers tens of kilometers away. Some were also subjected to the superhuman burden of renting expensive vehicles from the black market (Aydın, 2017; Ertan, 2014; Metinsoy, 2012).

The difficulties did not end there for the villagers who managed to reach the delivery points. Due to insufficient personnel and faulty measuring devices (scales), villagers were forced to wait outdoors for days. Thousands of tons of grain, left piled up in station squares or on the ground because there was no suitable enclosed storage area in the delivery centers, rotted and were wasted under rain and mud. These physical losses were often interpreted by officials as "poor product quality" and added to the

villagers' debt. This further exacerbated the villagers' suffering. This situation has gone down in history as an example of administrative incompetence that led to the waste of national wealth in the field, rather than serving the state's goal of building food stocks (Metinsoy, 2012; Özer, 2011).

4.3. Pricing Paradox and "Purchasing Products from the Black Market for Tax Purchases"

The state also set fixed prices (official rates) far below market value to purchase surplus crops beyond those collected by the TMV (Turkish Grain Board). This created a "price gap" crisis for the villagers. During this period, grain prices rose rapidly in the free market and especially in the black market. The state's low purchase prices were insufficient to cover even the basic costs of seeds, fertilizers, and living expenses for farmers. This situation dampened the farmers' enthusiasm for production and triggered a structural crisis that led to a contraction in agricultural capacity (Akman & Solak Akman, 2011; Şener, 2004).

The most tragic phase of the implementation was the situation of small farmers whose total crop yield did not even cover the 10% in-kind tax demanded by the state due to the erroneous decisions of the estimation commissions. These farmers, who fell into debt, resorted to buying wheat at exorbitant prices from large traders or the black market to avoid imprisonment or the seizure of their only ox. And they were forced to deliver this wheat to the state as "tax without payment." This economic squeeze rapidly impoverished small producers and pushed them into the hands of loan sharks. As a result, a rapid process of dispossession and social unrest began in rural areas (Akman & Solak Akman, 2011; Şener, 2004).

5. SOCIO-ECONOMIC AND POLITICAL CONSEQUENCES OF THE TAX

5.1. Class Impact on Rural Social Structure: Impoverishment of Small Farmers and Enrichment of Landowners

The socio-economic devastation caused by the Agricultural Products Tax in rural areas did not affect all segments equally. The tax deepened the class divide between small and medium-sized producers and large landowners (landowners) in an unprecedented way. The arbitrary practices of the estimation commissions, low purchase prices, abuses by tax officials, and logistical difficulties emerged as the most harmful aspects of the tax's implementation. Due to these factors, small farmers, who could barely make ends meet, were literally crushed. In contrast, large landowners, who possessed vast lands, their own transportation vehicles (trucks, tractors), and, most importantly, strong political relationships with local administrators (commission members), managed to turn this process to their advantage (Metinsoy, 2012; Özer, 2011).

Large farmers and landowners, using their influence over commissions, managed to understate their harvests. In this way, they were able to sell a very large portion of their produce tax-free on the black market at exorbitant prices. This group, who became "war profiteers" during the war years,

amassed enormous fortunes. Small farmers, unable to pay their taxes and crushed under heavy state pressure (imprisonment, seizure), suffered a great devastation. Small producers whose produce was insufficient to pay taxes were forced to sell their land, livestock, and agricultural tools to large landowners for next to nothing, or to borrow from moneylenders at high interest rates, in order to pay off their debts or provide for their winter provisions. This process led to the rapid dispossession of small farmers in rural Anatolia. It resulted in the proletarianization of small farmers, reducing them to the status of "semi-sharecroppers" or "serfs" alongside large landowners (Akman & Solak Akman, 2011; Aydın, 2017; Özer, 2011).

5.2. Devastating Impact on Agricultural Production and Capacity

The Agricultural Products Tax, implemented as part of the economic defense plan to ensure food security for the army and cities, has created a result that betrayed its own purpose in the medium and long term. Due to the flawed implementation of the tax, it has virtually undermined agricultural production. The "enthusiasm for production" of the peasant, who understood that a large portion of their produce would be confiscated by the state, that they would be punished by the unfair estimates of commissions, and that they would suffer transportation hardships, was completely broken (Şener, 2004).

Many producers, wanting to avoid the increased tax burden, arbitrary estimates, and selling at a loss, have resorted to reducing their agricultural activities as a rational reflex. Peasants have started to cultivate crops only on small areas sufficient to provide for the minimum sustenance (survival) of their families. Or, landowners have deliberately left a significant portion of their fields fallow. Due to the state's adoption of a punitive "confiscation/tax" regime instead of incentive-based price policies, agriculture has rapidly declined. As a result, Türkiye's agricultural capacity rapidly contracted, cultivated areas shrank, and yields experienced dramatic declines compared to pre-war years (Akman & Solak Akman, 2011; Şener, 2004).

5.3. Political Rupture: The "Second Aşar" Trauma and the Rise of the Democratic Party

Perhaps the most lasting and disruptive effect of the Agricultural Products Tax on the history of the Republic is the major fault line it created in Turkish political life. In the early period of the Republic, the motto "The peasant is the master of the nation" was adopted, and in 1925, the Ottoman Aşar tax, which burdened the peasant, was abolished with great pride. However, the state's re-imposition of this heavy in-kind tax, called the "Second Aşar," on the peasant during the Second World War years deeply shattered that founding political/trust agreement between the state and the rural population (Ertan, 2014; Subay, 2024).

During tax collection, gendarmes descended upon the villages, tax officials ruthlessly collected taxes from the villagers, and the villagers' livestock were confiscated. All of this led to the accumulation of a massive, silent, but intense anger against the One-Party (CHP) government in the rural areas, which

constituted 80% of the population. Following the war (despite the abolition of the tax in 1946), with the transition to a multi-party system, this accumulated social trauma and anger erupted at the ballot box. The Democratic Party (DP), founded under the leadership of Adnan Menderes and Celal Bayar (who was also a landowner), came to power in the 1950 elections with massive and overwhelming support from the rural areas (and with the slogan "Enough, the People Have Spoken"). The most important socio-psychological basis for this electoral victory was the painful memories left on the villagers by the Agricultural Products Tax (Aydın, 2017; Ertan, 2014; Subay, 2024).

6. CONCLUSION

World War II, between 1939 and 1945, created unparalleled devastation on a global scale. This circle of fire, unfolding outside its borders, deeply shook Turkey and pushed it into an economic crisis. Although the state did not actively enter the war, it was forced to implement an "Economic Defense Plan" to protect its national existence, reshaping all socio-economic dynamics of the period with a military logic. The necessity of keeping an army of nearly one million men under arms led to the withdrawal of the productive young male population from the fields, and imports came to a standstill. Therefore, the state faced one of the biggest food supply and inflation crises in the country's history. In this existential crisis, the government also set aside liberal market rules and, with the National Protection Law of 1940, placed the economy under the absolute control of the state. The functioning of the free market was replaced by strict state practices such as production quotas, price fixing, compulsory labor obligations, and product confiscation.

Faced with massive budget deficits caused by the war economy, excessive money printing, and hyperinflation fueled by the black market, the state realized it could not solve the problem with classical fiscal policies and resorted to extraordinary tax tools. Initially, tax regulations such as the Wealth Tax, Provisional Income Tax, and In-Kind Transaction Tax aimed to transfer wealth and profits targeting the commercial bourgeoisie and industrialists in cities, as well as non-Muslim minorities. However, even the cash collected in cities was insufficient to meet the main problem of the war: the "physical provisioning" of the army and the major cities, namely the need for wheat and bread. Due to the black market, farmers avoided selling their produce to the state, forcing the state to turn its attention to the rural areas in the depths of Anatolia. In this context, the compulsory equivalent of the Wealth Tax in the cities became the Agricultural Products Tax (TMV), established in 1943. The applications have shown us that the economic defense strategy emerged not only as a financing tool but also as a strategic survival mechanism that directly seized agricultural products.

The apparent purpose of the TMV (Turkish Agricultural Tax) was based on rational grounds: securing the army's food stocks and combating inflation. However, from the moment the tax was implemented, it turned into a serious administrative and socio-economic crisis. Because the tax was levied in kind (as a product) and directly on the producer, it revived in the minds of the peasants the

"Aşar" tax, which the Republic had proudly abolished in the early years (1925). This tax, referred to as the "Second Aşar" in public opinion and literature, became the most concrete example of how the state's own principle of "The peasant is the master of the nation" was set aside under wartime conditions.

The way the tax was implemented further deepened this ideological trauma. The merit-based assessment process envisioned by the law could not function properly. This was due to bureaucratic inefficiencies and staff shortages created by wartime conditions, resulting in tax assessments based on arbitrary, "desk-based" estimations. Natural disasters (drought, frost, pests) were ignored due to the arbitrary assessments of local commissions, and even peasants who could not harvest their crops were charged with taxes for crops that did not actually exist. As if that weren't enough, the government forced peasants to transport their produce over long distances using their own vehicles (many of which were allocated to the army), causing hardship for the public in queues at office warehouses and through measurement manipulations. Even more tragic was the predicament of the desperate small peasant who could not meet their tax quotas due to the commissions' inaccurate estimates. To avoid imprisonment or the loss of their land, peasants were forced to buy wheat at exorbitant prices on the black market and deliver it to the state free of charge.

From a socio-economic perspective, the Agricultural Products Tax (TMV) exacerbated the existing class inequality in rural Anatolia to incredible proportions. Large landowners and chieftains minimized their tax burden by using their political connections to the commissions. Furthermore, they became "war profiteers" by selling their vast surplus produce, which they had evaded taxes on, on the black market. In contrast, the unprotected small producers, crushed under the pressure of tax officials and gendarmes, either abandoned production and left their land fallow, or were forced to give even their winter provisions and seeds to the state, becoming enslaved to moneylenders. The implementation led to rapid dispossession and impoverishment in rural areas. It also eliminated agricultural subsidies, causing a long-lasting decline in agricultural production across the country.

From a political history perspective, the rupture created by the Agricultural Products Tax in Turkish political life has been far more permanent and profound. The harsh practices experienced during the collection process, such as gendarmerie pressure, official abuses, and animal confiscations, led to the accumulation of immense and silent anger against the state, and especially the single-party (CHP) government of the time, in the rural areas where approximately 80% of the population resided. Even after the end of the war and the transition to a multi-party political system, the social trauma created by this tax, which was abolished in 1946, resonated at the ballot box. Due to these painful and grievous memories left by the Agricultural Products Tax, the rural population turned its back on the single-party government in the 1950 elections and brought the Democratic Party (DP) to power with an overwhelming majority. The Agricultural Products Tax and its harsh practices were the strongest socio-psychological motivations underlying this.

The Agricultural Products Tax, implemented within the framework of Türkiye's extraordinary "Economic Defense Plan" during the Second World War years, achieved a strategic success in the short term by providing provisions for the army. However, in the long term, it crushed small-scale peasantry, collapsed agricultural production, and deepened class inequality. And ultimately, TMV has taken its place in Turkish legal, economic, and political history as the architect of a multifaceted crisis that paved the way for a change in the country's political regime.

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THE PRESTON CURVE: LIFE EXPECTANCY AND RESIDUAL ANALYSIS WITH 2024 GLOBAL DATA

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ABSTRACT

The non-linear relationship between economic development and human progress is one of the central debates in modern economic literature. This study re-examines the link between per capita income and life expectancy at birth within the framework of the Preston Curve using 2024 global data. Based on a sample of 188 countries from the World Bank database, the analysis shows that life expectancy increases rapidly at low income levels, but the marginal effect of income weakens after an approximate threshold of $20,000-$30,000. Non-income factors examined through residual analysis reveal the transformative role of education, income inequality, and environmental conditions in shaping health outcomes. The findings indicate that high-income but high-inequality countries, such as the United States, show negative deviations, whereas countries with stronger human capital performance, such as Vietnam and Spain, diverge positively. The study emphasizes that improving welfare requires inclusive and distribution-oriented development policies rather than a narrow focus on economic growth alone.

Keywords: *Preston Curve, Life Expectancy, Human Capital, Income Inequality, Health Economics.*

JEL Codes: *E20, F60, I10.*

1. INTRODUCTION

The relationship between economic development and human well-being is one of the central questions of development economics. Income growth is usually expected to improve living standards by expanding access to food, housing, sanitation, education, and health services. However, the empirical relationship between income and health outcomes is not linear. The Preston Curve demonstrates that life expectancy rises sharply with income at low income levels but increases more slowly after a certain point (Preston, 2007). Therefore, the same additional dollar of income has a much larger health effect in poorer countries than in richer countries.

This nonlinear pattern is important because it challenges a purely income-based understanding of development. If income alone were sufficient, countries with similar GDP per capita would have very similar life expectancy levels. In reality, some countries live considerably longer than their income level

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predicts, while others perform below expectation despite high income. These deviations suggest that education, inequality, environmental conditions, health system organization, and social policy can shape the extent to which economic resources are converted into longer and healthier lives (Deaton, 2003; Lutz & Kebede, 2018; Wilkinson & Pickett, 2006).

The aim of this article is to evaluate the Preston Curve with 2024 global data and to interpret selected country deviations from the fitted curve. The study is descriptive rather than causal: it does not estimate the independent causal effect of each non-income factor, but uses the curve and residuals as an analytical tool for discussing the broader meaning of development beyond income.

1.1. Theoretical Background: The Preston Curve

The Preston Curve is a cross-country representation of the association between national income and life expectancy. Its core insight is that health improvements are highly responsive to income at low levels of development because income directly finances basic survival conditions, including nutrition, clean water, sanitation, vaccination, and access to primary medical care. In this stage, small improvements in income can remove severe constraints on survival and produce rapid gains in life expectancy. At higher levels of income, however, the curve flattens. This means that further GDP growth continues to matter, but its marginal contribution to life expectancy becomes weaker. Once basic needs and core health infrastructure are largely in place, other factors become increasingly important. These include the distribution of income, educational attainment, preventive health behavior, environmental quality, and the inclusiveness of health systems. For this reason, the Preston Curve is not only a statistical pattern but also a conceptual reminder that development policy should focus on the transformation of income into human capabilities.

2. DATA AND METHOD

The analysis uses 2024 country-level data obtained from the World Bank database. After excluding regional aggregates and observations with missing values for the two main variables, the final sample includes 188 countries. The income variable is GDP per capita measured in purchasing power parity terms and expressed in current international dollars. The health outcome variable is life expectancy at birth, measured in years. The use of purchasing power parity makes cross-country income comparisons more meaningful because it adjusts for differences in domestic price levels.

The first step of the method is a scatter-plot analysis between GDP per capita and life expectancy at birth. A nonlinear fitted curve is added to the graph to represent the expected Preston relationship. The second step is residual analysis. For each country, the residual is calculated as the difference between the observed life expectancy and the expected value implied by the curve. A positive residual means that a country lives longer than expected for its income level, while a negative residual means that it performs below the income-based expectation. These residuals are interpreted as descriptive signals of non-income influences, not as direct causal estimates.

Table 1. Variables and Analytical Strategy

Component	Measurement	Use in the Article
Income	GDP per capita, PPP (current international $)	Horizontal axis and main economic development indicator
Health outcome	Life expectancy at birth (years)	Vertical axis and core human development outcome
Fitted Preston relationship	Nonlinear descriptive curve	Reference line for expected life expectancy by income level
Residual	Observed life expectancy minus expected life expectancy	Indicator of above- or below-expected health performance

Note: The study is based on 2024 country-level World Bank data and includes 188 countries after excluding regional aggregates and missing observations.

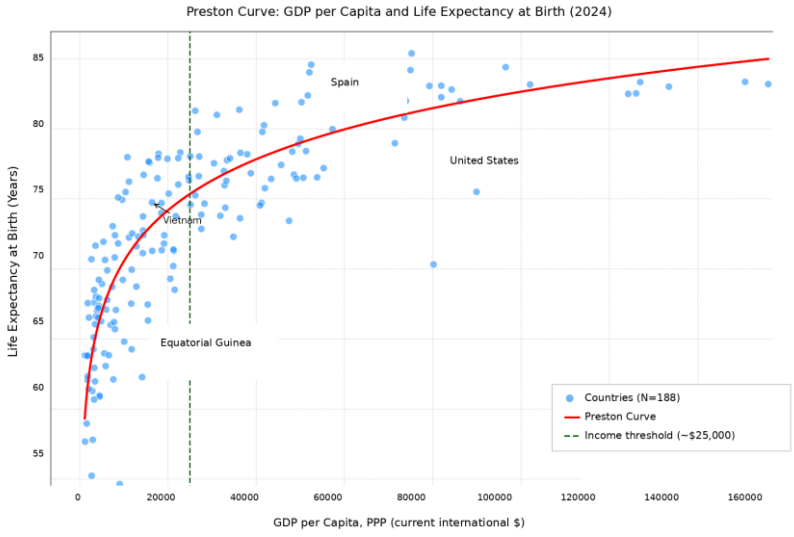
3. FINDINGS

3.1. The Income-Life Expectancy Relationship

Figure 1 shows the global Preston Curve for 2024. The scatter points represent individual countries, while the red fitted curve captures the nonlinear relationship between income and life expectancy. The figure clearly indicates that life expectancy rises steeply at low income levels, especially below the threshold band of roughly $20,000-$30,000. In this range, income growth is closely associated with improvements in basic living conditions and access to essential health inputs.

Beyond this threshold, the curve begins to flatten. This does not mean that income becomes irrelevant; rather, it means that additional income produces smaller gains in life expectancy. The figure also shows that countries with very high income do not automatically achieve the highest life expectancy. The United States, for example, appears below the expected line relative to its income level, whereas Spain achieves a higher life expectancy with a lower income level. Vietnam also performs above the curve, suggesting that non-income factors can compensate for a lower GDP per capita.

Figure 1. Preston Curve: GDP per Capita and Life Expectancy at Birth (2024)



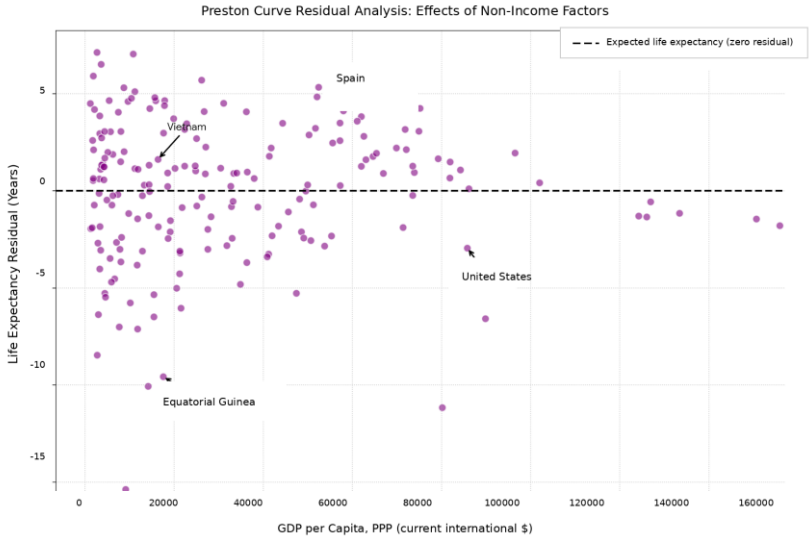
Note: Author's visualization based on World Bank data (World Bank, 2026). The vertical dashed line indicates an approximate income threshold of $25,000.

3.2. Residual Analysis and Non-Income Factors

Figure 2 presents the residual analysis. The zero line indicates the expected life expectancy implied by the Preston Curve. Countries above this line live longer than expected for their income level, while countries below it live shorter than expected. This figure is useful because it shifts the discussion from the level of income to the social and institutional capacity to convert income into health outcomes.

The most important message of the residual analysis is that development outcomes depend on more than aggregate income. Positive residuals may reflect effective public health systems, high levels of education, broad access to basic services, and social cohesion. Negative residuals may reflect inequality, fragmented health access, environmental stress, or weak institutional conversion of economic resources into human development. In this sense, residuals should be read as interpretive indicators of development quality.

Figure 2. Preston Curve Residual Analysis: Effects of Non-Income Factors



Note: Author's visualization based on World Bank data (World Bank, 2026). Residuals are calculated as observed life expectancy minus expected life expectancy from the fitted Preston relationship.

Table 2. Interpretation of Selected Country Deviations

Country	Observed Pattern	Residual Direction	Main Interpretation
United States	High income but lower life expectancy than the fitted curve suggests	Negative	Inequality, unequal health access, and social stress can limit the conversion of income into health (Deaton, 2003; Wilkinson & Pickett, 2006).
Vietnam	Moderate income but higher life expectancy than expected	Positive	Education, health literacy, preventive care, and broad basic services can strengthen health outcomes (Lutz & Kebede, 2018).
Spain	Lower income than some richer countries but higher life expectancy	Positive	A strong social and public-health conversion of income can produce above-expected health performance.
Equatorial Guinea	Resource-rich income position but low life expectancy	Negative	Resource concentration, environmental pressure, and weak social conversion of income can reduce health performance (Majeed & Ozturk, 2020).

Note: The interpretations are descriptive and are based on the residual positions shown in Figure 2 together with the literature discussed in the text.

4. DISCUSSION

4.1. Income Inequality and Social Justice

The negative residual of the United States illustrates that high income does not automatically translate into superior population health. Deaton (2003) emphasizes the close relationship between health, inequality, and economic development. When income gains are unevenly distributed and health care access is unequal, the average level of income can conceal large social differences in exposure to disease, preventive care, and survival opportunities. Wilkinson and Pickett (2006) similarly argue that inequality can affect population health through chronic stress, lower social trust, and unequal access to health-enhancing resources.

From a development perspective, this means that GDP per capita should not be treated as a sufficient indicator of welfare. The distribution of income and the inclusiveness of public services determine whether national income becomes broad-based human development or remains concentrated economic capacity.

4.2. Education and Human Capital

Vietnam and Spain provide useful examples of positive residuals. Both cases suggest that education and human capital can improve health outcomes beyond what would be predicted by income alone. Lutz and Kebede (2018) argue that education is a powerful determinant of health because it increases health literacy, improves decisions about nutrition and hygiene, strengthens the use of preventive services, and supports lower fertility and better child health outcomes. In low- and middle-income settings, these mechanisms can produce life expectancy levels that exceed income-based expectations.

This finding has an important policy implication: investments in education, especially broad-based and gender-inclusive education, are also investments in population health. In the Preston framework, education helps countries move above the curve by making existing resources more effective.

4.3. Environmental Quality and Resource-Based Growth

Negative residuals may also be associated with environmental degradation and the resource curse. Resource-rich countries can experience high income figures without broad improvements in living standards if resource rents are concentrated or if environmental costs are high. Majeed and Ozturk (2020) show that environmental degradation, including air pollution and carbon emissions, is closely related to adverse population health outcomes. Therefore, growth that damages air quality or weakens ecological conditions can reduce the health benefits normally associated with income growth.

This point broadens the interpretation of the Preston Curve. Development requires not only more income but also a sustainable environment in which income gains do not come at the expense of respiratory health, cardiovascular health, and long-term well-being.

5. CONCLUSION

The 2024 global evidence presented in this article confirms the main insight of the Preston Curve: economic growth is strongly associated with life expectancy at low income levels, but its marginal effect weakens as countries become richer. The approximate threshold of $20,000-$30,000 marks a stage at which additional income alone becomes less capable of explaining differences in life expectancy.

The residual analysis shows why the Preston Curve is especially useful for development studies. Countries above the expected line demonstrate that education, public health capacity, social inclusion, and effective institutions can transform income into longer lives. Countries below the line show that inequality, unequal access to health care, environmental degradation, and weak social conversion mechanisms can prevent income from becoming human development.

The central policy conclusion is clear: development strategies should not focus only on GDP per capita. They should also aim to distribute income more fairly, expand educational opportunities, strengthen universal health access, and protect environmental quality. In this broader sense, the Preston Curve shows that the real achievement of development is not income itself, but the ability of societies to convert income into healthier and longer lives.

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ANALYSIS OF THE EXTERNAL BALANCE DYNAMICS AND STRUCTURAL VULNERABILITY OF THE TURKISH ECONOMY WITHIN THE FRAMEWORK OF THE BALANCE OF PAYMENTS (1984-2025)

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ABSTRACT

This article examines Türkiye's external balance dynamics and structural vulnerability within the framework of the balance of payments. It uses a descriptive research design based on annual cumulative balance-of-payments data obtained from the Central Bank of the Republic of Türkiye's Electronic Data Delivery System for 1984-2025. The analysis focuses on the current account balance, trade balance, services balance, selected financing flows, reserve-related adjustment channels, and net errors and omissions. The findings show that Türkiye's current account position is closely associated with the trade balance, while the services surplus substantially offsets but does not fully eliminate the deficit arising from goods trade and income payments. The financing composition also reveals a structural vulnerability: direct investment inflows are relatively more stable, whereas portfolio and other investment flows display stronger volatility. Finally, the large swings in net errors and omissions after the 2010s point to analytical uncertainty in the financing of external imbalances. The article concludes that sustainable external balance requires a structural transformation that reduces import dependency, increases domestic savings, and improves the quality of long-term external financing.

***Keywords**: Balance of Payments, Current Account Deficit, External Balance, Financing Quality, Net Errors and Omissions, Turkish Economy.*

***JEL Classification:** F32, F34, O24.*

1. INTRODUCTION

In an increasingly integrated world economy, trade and financial relations with the rest of the world have become decisive determinants of macroeconomic stability. The balance of payments is therefore not only an accounting statement but also a strategic indicator of a country's international payment capacity, exchange-rate pressures, growth pattern, and exposure to external shocks.

For developing economies such as Türkiye, the external balance problem is particularly important because industrial production and export performance often depend on imported intermediate goods, energy, and technology. Under these conditions, growth episodes may widen the trade deficit and

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translate into current account pressures. The main analytical question is not only whether a country records an external deficit, but also how that deficit is financed and whether the financing structure is sustainable.

The purpose of this article is to transform the existing theoretical discussion into a concise, article-format descriptive study and to deepen the empirical section using the expanded Excel data set. The study covers the period 1984-2025 and evaluates Türkiye's current account dynamics, trade and services balances, financing composition, and net errors and omissions. Because the data file contains national-level time-series observations rather than provincial or regional data, a map is not methodologically appropriate; instead, the article uses time-series graphs and a period-average table.

2. CONCEPTUAL FRAMEWORK

The balance of payments records all economic transactions between residents and non-residents over a specific period according to the double-entry accounting principle. In the BPM6 framework, the core accounts include the current account, capital account, financial account, reserve assets, and net errors and omissions (IMF, 2009). The current account covers the trade in goods and services as well as primary and secondary income flows. The financial account records cross-border financial transactions such as direct investment, portfolio investment, other investment, and reserve-asset changes.

The current account has a direct link with national income and the saving-investment balance. In open-economy macroeconomics, a current account deficit indicates that domestic investment exceeds national saving and that the gap is financed by foreign saving (Krugman et al., 2012). From this perspective, persistent external deficits should not be treated merely as short-term exchange-rate problems; they may reflect deeper structural conditions in production, saving behavior, import dependence, and the composition of capital flows.

The distinction between autonomous and accommodating transactions is also useful for interpreting external imbalances. Autonomous transactions arise from normal trade, income, and capital-flow decisions, while accommodating transactions are used to finance or balance the resulting deficit or surplus. Financing a deficit through long-term direct investment may be less fragile than relying on short-term portfolio flows, because portfolio flows can reverse rapidly in response to global interest rates, risk perception, or domestic uncertainty.

3. DATA AND METHODOLOGY

The empirical part of the article is based on annual cumulative level observations from the CBRT Electronic Data Delivery System (EVDS). The Excel file includes the balance-of-payments summary series for 1984-2026; however, the 2026 row is not used in the main figures because it is not a complete annual observation. Thus, the descriptive analysis is restricted to the full-year period 1984-2025.

The analysis uses six groups of indicators: (i) current account balance, (ii) trade balance and goods exports/imports, (iii) services, primary income, and secondary income balances, (iv) direct investment, portfolio investment, and other investment flows, (v) reserve-related items, and (vi) net errors and omissions. All values are converted from million USD to billion USD for readability.

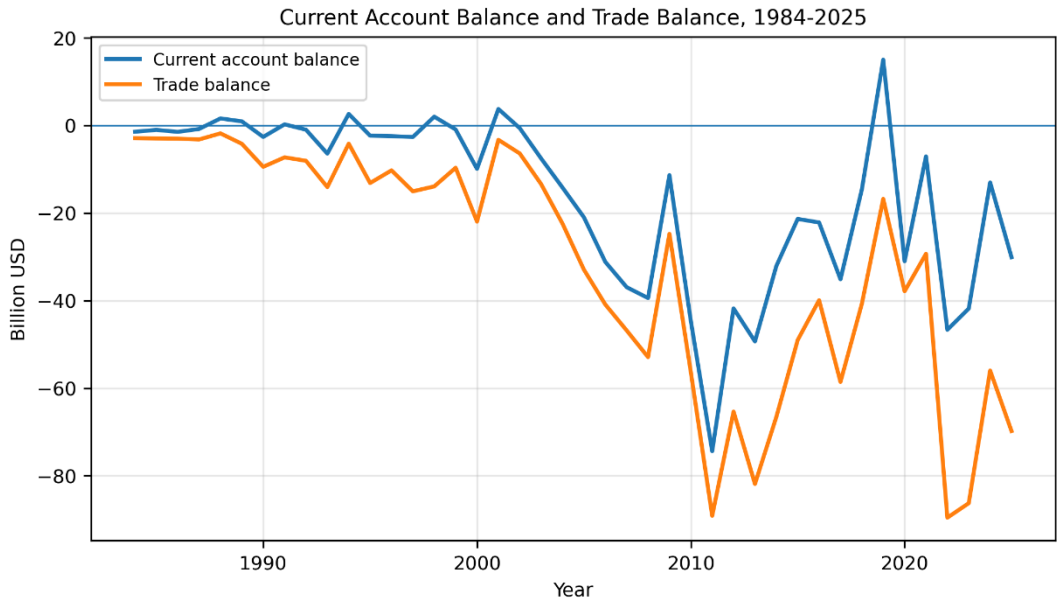
The study does not estimate an econometric model. Its aim is descriptive: to visualize long-term trends, compare subperiod averages, and interpret the observed patterns through the theoretical framework. For financial account subcomponents, the sign is reversed in the financing-flow graph so that positive values represent net inflows into Türkiye. This transformation is made only for ease of interpretation and is explicitly noted in the figure caption.

4. DESCRIPTIVE FINDINGS

4.1. Current Account Dynamics and the Trade Balance

The first descriptive finding is the strong relationship between the current account balance and the trade balance. Over 1984-2025, the current account balance averaged USD -16.1 billion per year, while the trade balance averaged USD -31.5 billion. The correlation between the two series is approximately 0.92, which shows that the goods-trade position is the main driver of Türkiye's external balance in a descriptive sense. The deepest current account deficit in the data is observed in 2011 at USD -74.4 billion, while 2019 records a rare surplus of about USD 15.0 billion.

Figure 1. Current Account Balance and Trade Balance, Values Are in Billion USD. 1984-2025



Source: CBRT EVDS balance-of-payments data; author's calculations.

Figure 1 shows that the trade balance is persistently negative throughout the whole period and that the current account generally follows the same direction. The services surplus and other current account items sometimes soften the deficit, but they do not remove the structural pressure created by

goods trade. The 2001 crisis year, the post-2008 adjustment, the 2018-2019 rebalancing, and the post-2020 period are visible as important turning points in the current account path.

4.2. Exports, Imports and the Goods-trade Gap

The widening of goods trade is visible from the export and import series. In 1984, goods exports were USD 7.1 billion and goods imports were USD 10.0 billion. By 2025, exports increased to USD 270.7 billion, while imports reached USD 340.6 billion. The scale of integration into world markets increased substantially, but import growth remained large enough to maintain a sizeable goods-trade gap.

Figure 2. Goods Exports and Goods Imports, 1984-2025

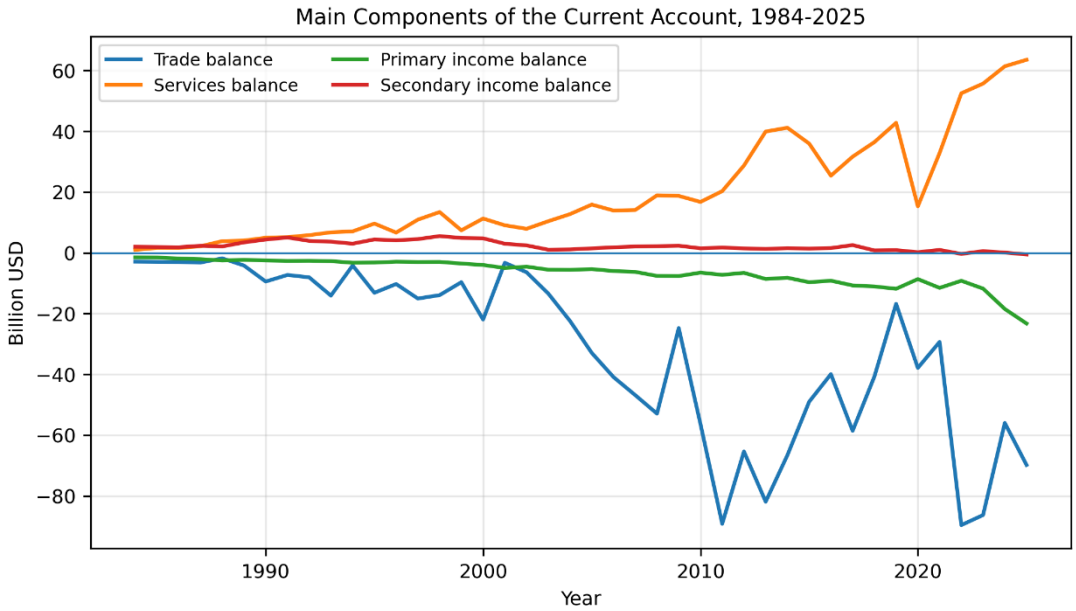


Source: CBRT EVDS balance-of-payments data; author's calculations. Values are in billion USD.

4.3. The Role of Services and Income Balances

The second important finding is the stabilizing role of the services balance. While the trade balance remained deeply negative, the services balance moved in the opposite direction and reached USD 63.5 billion in 2025. This means that tourism, transportation, construction, and other service revenues became an important buffer against the goods deficit. Nevertheless, the primary income balance, which includes investment income payments such as interest and profit transfers, deteriorated over time and reached USD -23.3 billion in 2025. Therefore, the improvement in services was partly offset by income outflows.

Figure 3. Main Components of the Current Account, 1984-2025

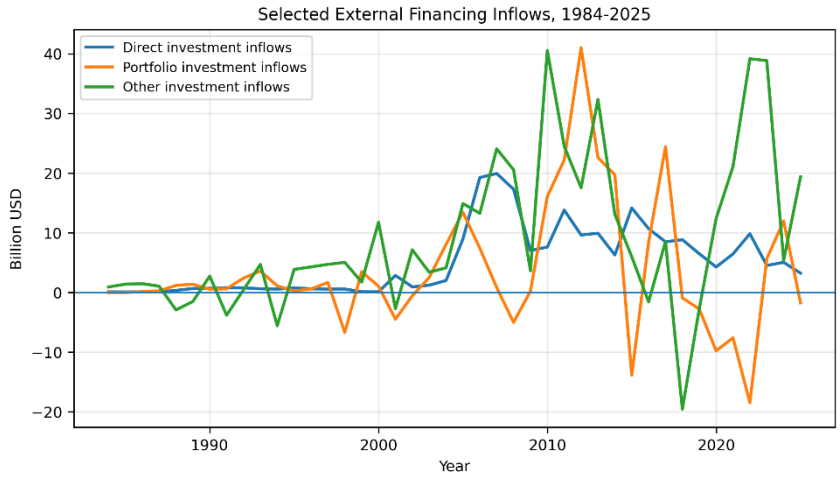


Source: CBRT EVDS balance-of-payments data; author's calculations. Values are in billion USD.

4.4. Financing Quality and Volatility

The sustainability of an external deficit depends not only on its size but also on its financing composition. The data show that direct investment inflows increased strongly in the mid-2000s, especially around the privatization and global liquidity cycle, but later became more limited. In contrast, portfolio investment and other investment flows are much more volatile. For 2001-2025, the standard deviation of direct investment inflows is about USD 5.3 billion, whereas portfolio inflows and other investment inflows have standard deviations of about USD 13.6 billion and USD 14.6 billion, respectively. This gap indicates that short-term and debt-creating financing channels expose the external balance to stronger reversal risks.

Figure 4. Selected External Financing Inflows, Values Are in Billion USD 1984-2025

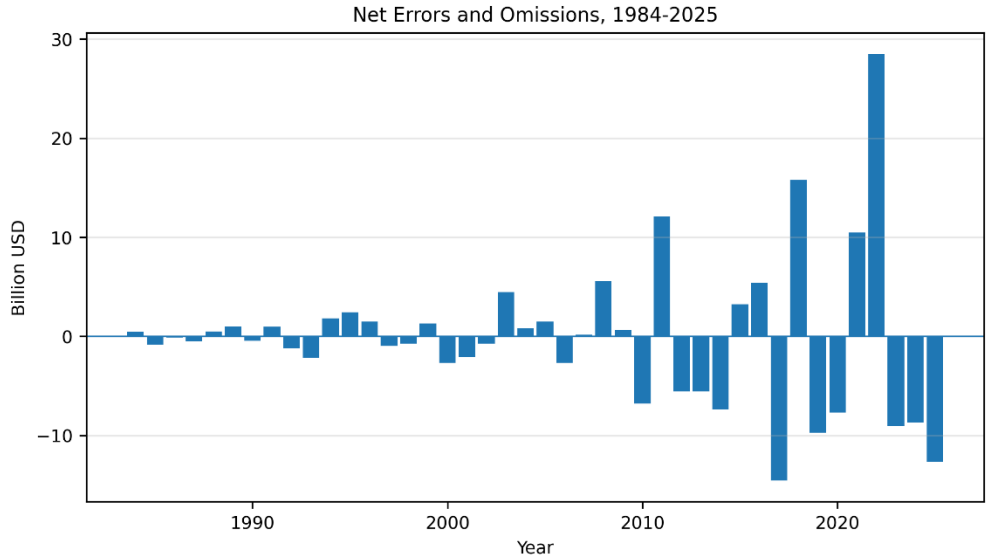


Source: CBRT EVDS balance-of-payments data; author's calculations. Note: Financial account subcomponents are multiplied by -1 so that positive values indicate net inflows.

4.5. Net Errors and Omissions

Net errors and omissions is a balancing item that reflects statistical discrepancies arising from timing differences, data-source inconsistencies, valuation differences, and unrecorded transactions. In small amounts, this item is normal in balance-of-payments statistics. However, the Turkish data show large positive and negative swings after the 2010s. The most striking positive value is observed in 2022, at about USD 28.5 billion, while the item turns sharply negative in some other years, including 2025 at about USD -12.7 billion. These movements do not by themselves identify the source of financing, but they reduce the analytical transparency of the external balance and should be monitored together with reserve movements and capital-flow composition.

Figure 5. Net Errors and Omissions, Values Are in Billion USD. 1984-2025



Source: CBRT EVDS balance-of-payments data; author's calculations.

4.6. Period-Average Comparison

Table 1 summarizes the long-term pattern by dividing the sample into four subperiods. The averages show that the current account deficit deepened substantially after 2001 and was particularly large during 2009-2018. The post-2019 period has a smaller average current account deficit than 2009-2018, largely because the services surplus increased strongly; however, the trade deficit remained large and financing remained volatile.

Table 1. Period Averages of Selected External Balance Indicators

Period	Current account	Trade balance	Services balance	FDI inflows*	Portfolio inflows*	Other investment inflows*	Net errors and omissions
1984-2000	-1.51	-8.54	6.07	0.45	0.68	1.78	0.02
2001-2008	-18.39	-27.39	12.86	9.06	2.78	10.60	0.87
2009-2018	-34.69	-57.23	29.49	9.65	13.99	12.51	-0.26
2019-2025	-22.10	-55.09	46.28	5.70	-3.25	19.08	-1.26

Source: CBRT EVDS balance-of-payments data; author's calculations. Values are in billion USD. * Financial account subcomponents are multiplied by -1 so that positive values indicate net inflows.

5. DISCUSSION

The descriptive results support the view that Türkiye's external imbalance is structural rather than merely cyclical. The current account is closely connected with the trade balance, and the trade balance reflects the high import content of production and consumption. The growth of exports has been impressive, but it has been accompanied by a larger import bill, especially in years of strong domestic demand, energy-price pressure, or exchange-rate adjustment.

The services surplus is a major strength of the Turkish economy. It cushions the goods deficit and contributes to external financing through tourism and related service revenues. However, services alone cannot fully solve the external balance problem when the goods deficit and primary income outflows are large. This is why policy discussions should focus not only on export expansion, but also on domestic value added, energy efficiency, import substitution in strategic intermediate goods, and productivity improvement.

The financing side creates a second layer of vulnerability. Direct investment is generally more stable and can contribute to technology transfer, employment, and production capacity. Portfolio investment and other investment flows, by contrast, are more sensitive to global liquidity, interest-rate differentials, and risk perception. Therefore, a current account deficit financed mainly by short-term or reversible flows can become fragile even when the deficit appears temporarily manageable.

Finally, the volatility of net errors and omissions complicates the interpretation of external financing. Large positive values can temporarily support the balance of payments, while large negative values can signal unexplained outflows or measurement problems. For policy analysis, this item should be treated as a warning indicator rather than as a reliable financing source.

6. CONCLUSION AND POLICY IMPLICATIONS

This article converted the existing course-paper framework into a concise English article and expanded its empirical part using the detailed EVDS Excel data. The descriptive evidence for 1984-2025 suggests that Türkiye's current account dynamics are primarily shaped by the trade balance, while services revenues provide an important but incomplete offset. The period after the 2000s is characterized by deeper current account deficits, larger goods-trade gaps, and stronger dependence on external financing.

The main policy implication is that the external deficit cannot be addressed sustainably through short-term borrowing, reserve use, or administrative restrictions alone. A durable solution requires structural policies that reduce imported input dependency, increase domestic savings, strengthen high-value-added production, and attract more stable direct investment. In addition, improving institutional confidence and reducing uncertainty can help lower the volatility of portfolio and other investment flows.

The study has two limitations. First, it is descriptive and does not claim causal estimation. Second, it uses national-level annual data; therefore, regional mapping or spatial analysis is not possible with this Excel file. Future research may extend the analysis by adding GDP, real exchange rate, energy prices, domestic savings, and external debt indicators, and by estimating econometric models such as ARDL, VAR, or structural break tests.

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APPENDIX A. EVDS SERIES USED IN THE ARTICLE

EVDS code	English label used in the article
TP.ODEAYRSUNUM6.Q1	Current account balance
TP.ODEAYRSUNUM6.Q4	Trade balance
TP.ODEAYRSUNUM6.Q5	Total goods exports
TP.ODEAYRSUNUM6.Q6	Total goods imports
TP.ODEAYRSUNUM6.Q20	Services balance
TP.ODEAYRSUNUM6.Q68	Primary income balance
TP.ODEAYRSUNUM6.Q92	Secondary income balance
TP.ODEAYRSUNUM6.Q102	Direct investment
TP.ODEAYRSUNUM6.Q114	Portfolio investment
TP.ODEAYRSUNUM6.Q136	Other investment
TP.ODEAYRSUNUM6.Q210	Net errors and omissions

Source: Series descriptions included in the uploaded EVDS Excel workbook.

DİJİTAL EKONOMİ: ASİMETRİK ENFORMASYON ALTINDA BİLGİ, GÜVEN VE POLİTİKA TASARIMI

Fatma Nur İMAMOĞLU[*]

Ayhan ORHAN[**]

ÖZET

Dijitalleşme, ekonomik faaliyetleri ve piyasa aktörlerinin davranışlarını kökten yeniden şekillendiren yapısal bir dönüşüm haline gelmiştir. Bilgi asimetrisinin yüksek düzeyde olduğu dijital ortamlarda güven, ekonomik işlemleri etkileyen kritik bir mekanizma olarak ortaya çıkmaktadır. Mevcut literatür ağırlıklı olarak bireysel güven algılarına odaklansa da kurumsal yapıların ve politika çerçevelerinin rolü nispeten daha az araştırılmıştır.

Bu çalışma, kurumsal düzenlemelerin piyasa sonuçlarını nasıl şekillendirdiğine özellikle odaklanarak, dijital ekonomi ile güven arasındaki ilişkiyi politika odaklı bir perspektiften analiz etmeyi amaçlamaktadır. Çalışma, dijital ekonomi dinamiklerini bilgi asimetrisi ve kurumsal iktisat ile bütünleştiren kavramsal ve teorik bir çerçeveye dayanmaktadır. Yöntemsel olarak araştırma; mevcut literatürü ve politika tartışmalarını değerlendiren nitel ve kavramsal bir yaklaşım benimsemektedir.

Bulgular, kamu politikalarının ve düzenleyici mekanizmaların, özellikle gelişmekte olan ekonomilerde, belirsizliği azaltmada ve dijital piyasalarda güveni güçlendirmede çok önemli bir rol oynadığını göstermektedir. Etkili yönetişim yapıları, yalnızca daha verimli piyasa işlemlerini kolaylaştırmakla kalmamakta, aynı zamanda makroekonomik istikrara ve sistemik dirence de katkıda bulunmaktadır.

Sonuç olarak çalışma, küresel rekabet gücünü artırmak ve sürdürülebilir ekonomik büyümeyi sağlamak için iyi tasarlanmış kurumsal çerçeveler aracılığıyla dijital güvenin güçlendirilmesinin elzem olduğunu savunmaktadır. Sonuçlar, asimetrilerin giderilmesinde ve daha güvenilir bir dijital ekonomik ortamın teşvik edilmesinde politika odaklı yaklaşımların önemini vurgulamaktadır.

Anahtar Kelimeler: *Dijital Ekonomi, Dijital Güven, Kurumsal İktisat, Kamu Politikası, Bilgi Asimetrisi.*

Jel KODLARI: *D82, O33, L86.*

DIGITAL ECONOMY: INFORMATION, TRUST, AND POLICY DESIGN UNDER ASYMMETRIC INFORMATION

ABSTRACT

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Digitalization has become a structural transformation that fundamentally reshapes economic activities and the behavior of market actors. In digital environments characterized by high levels of information asymmetry, trust emerges as a critical mechanism influencing economic transactions. While the existing literature predominantly focuses on individual trust perceptions, the role of institutional structures and policy frameworks remains relatively underexplored.

This study aims to analyze the relationship between the digital economy and trust from a policy-oriented perspective, with a particular focus on how institutional regulations shape market outcomes. The study is grounded in a conceptual and theoretical framework that integrates digital economy dynamics with information asymmetry and institutional economics. Methodologically, the research adopts a qualitative and conceptual approach, evaluating existing literature and policy discussions.

The findings suggest that public policies and regulatory mechanisms play a crucial role in reducing uncertainty and strengthening trust in digital markets, particularly in emerging economies. Effective governance structures not only facilitate more efficient market transactions but also contribute to macroeconomic stability and systemic resilience.

In conclusion, the study argues that strengthening digital trust through well-designed institutional frameworks is essential for enhancing global competitiveness and achieving sustainable economic growth. The results highlight the importance of policy-driven approaches in addressing asymmetries and fostering a more reliable digital economic environment.

Keywords: *Digital Economy, Digital Trust, Institutional Economics, Public Policy, Information Asymmetry.*

JEL Codes: *D82, O33, L86.*

1. INTRODUCTION

The rapid acceleration in information and communication technologies during the final quarter of the twentieth century has led to a profound paradigmatic shift in the global economic system. Economic structures grounded in traditional industrial production models are increasingly being replaced by a digitally based ecosystem where the processes of producing, processing, and distributing information occupy a central position. This new order, conceptualized as the digital economy, radically reshapes the behavioral patterns of market actors, transaction costs, and competitive conditions. While the process of digitalization expands cross-border trade volume and facilitates market access, it simultaneously complexifies the transparency and informational structure of markets. In this dynamic process where spatial constraints are eliminated, the sustainability of economic activities becomes heavily dependent on the accuracy of information generated in digital environments and the trust relationships forged around this information.

While the macroeconomic impacts of this transformation are widely debated in the literature, the reflections of hardware and software sectors on productivity constitute a critical area of analysis. Focusing on the sectoral and measurement dimensions of the subject, Nordhaus, in his empirical analysis of the American economy, defines the concept of the "new economy" through accounting data to encompass the machinery, electrical equipment, telecommunications, and software sectors. While emphasizing that a very significant productivity growth occurred in information technology branches, particularly in the late 1990s, he points out that quality adjustments and new goods could not be fully captured by traditional price indices, which in turn caused measurement biases in sectoral productivity trends. The rapid growth of the share of these knowledge-intensive sectors within total gross domestic product theoretically demonstrates the challenges of determining the quality of digital outputs on an ex-ante (pre-transaction) basis, and consequently, the informational turmoil that may emerge in the market (Nordhaus, 2001).

Another distinguishing dimension of the digital economy is the structural shift from production processes toward service-oriented and network-based organizational structures. In examining the theoretical foundations of this structural transformation, when the new economy is modeled through the expansion of variety in the information technologies and service sectors, the model suggests that while the shift in consumer spending toward a continuously expanding array of service varieties triggers high growth rates at the macro level, total factor productivity measured at the firm level remains low, thereby feeding the "productivity puzzle" in the literature. More importantly, it is argued that this variety and specialization in service provision offers providers a monopolistic competitive power and a sphere of economic rent, and that the uncertain nature of these future rents causes excessive stock market volatility in financial markets. This transformation experienced at the sectoral level deepens asymmetric information structures among market actors, thereby increasing the significance of institutional interventions and regulations (Zagler, 2002).

This aforementioned theoretical and empirical background presents the problem of "information asymmetry" as a chronic risk of market failure on platforms where digital economic activities are conducted. The lack of equal information between the buyer and the seller regarding the digital product, service, or data subject to the transaction generates risks of adverse selection and moral hazard in the market. In environments where such informational distortions are high, the concept of "trust" functions almost as an invisible institutional mechanism for the sustainability of economic transactions and the preservation of market efficiency. However, due to the uniquely fluid structure of the digital world, the micro-level perception of trust developed among individual actors (such as user ratings or intra-platform references) remains insufficient on its own to prevent systemic risks and data misuses. This insufficiency necessitates that the process of building and maintaining trust in digital environments be addressed through an institutional perspective beyond individual initiatives.

In line with the fundamental tenets of institutional economic theory, institutions are structures that regulate economic and social interactions, reduce uncertainties, and establish the rules of the game. Consequently, closing the trust gap arising from information asymmetry in the digital economy is only possible through well-designed institutional frameworks and public policy designs. Protecting consumer rights, establishing legal clarity for cybersecurity standards, regulating data privacy, and implementing regulatory mechanisms that prevent unfair competition will lower transaction costs in the market. An effective governance and regulatory framework to be executed by public authorities will reduce uncertainty in digital markets, thereby facilitating rational decision-making at the micro level and reinforcing systemic resilience and financial stability at the macro level. Particularly for emerging economies whose institutional infrastructure is in a state of transition, the design of these regulatory policies becomes a fundamental prerequisite for maintaining global competitiveness.

Accordingly, the primary objective of this study is to analyze the multidimensional relationship among the concepts of the digital economy, information asymmetry, and trust from the perspectives of institutional economics and policy design. By adopting a qualitative and conceptual methodology, the study theoretically filters the role of regulatory public policies in reducing uncertainty, ensuring market efficiency, and supporting sustainable growth paths in digital markets. With the outputs to be obtained, it is aimed to provide concrete and holistic recommendations to policymakers by emphasizing the importance of institutional regulations in building a digital trust ecosystem.

Existing studies predominantly address the digital economy from the perspectives of technology, innovation, and the platform economy; however, they allocate limited space to the holistic evaluation of digital trust within the axis of information asymmetry and institutional regulations. Concurrently, this study aims to fill this specific gap in the literature.

2. LITERATURE REVIEW

The structural transformations experienced in information and communication technologies have fundamentally altered the functioning of traditional economic models and market mechanisms. In the global literature, the phenomenon of the digital economy is addressed through a multidimensional perspective, ranging from technical infrastructure maturity to institutional environmental regulations, and from shifts in the labor market to social quality of life indicators. In this context, pioneering studies examining the theoretical foundations of the digital economy and the socio-economic challenges it encounters are reviewed in chronological order below.

In the study conducted by Antonelli (2003), how information and communication technologies (ICT) interact with heterogeneous production factors and relative price mechanisms in a global open economy is explained through the concept of "composition effects." In this context, it is argued that ICT-based radical innovations possess an inherently capital and skilled-labor-intensive (unskilled labor saving) structure; therefore, potential productivity gains can only reach their highest level (actual

productivity) in advanced economies where these production factors are relatively cheap and abundant, triggering a global "digital divide."

The information asymmetry approach developed by Akerlof (1970) demonstrates that differences in the level of information between buyers and sellers can distort market efficiency, leading to the problem of adverse selection. Conceptualized within the framework of the "Market for Lemons" model, this approach posits that the efficiency of the market mechanism may weaken if high-quality products and services are evaluated under the same conditions as low-quality ones. The inability to fully observe the quality of products, services, and data on a pre-transaction basis in the digital economy renders information asymmetry more visible, demonstrating that the theoretical framework put forward by Akerlof maintains its validity in the analysis of digital platform economies as well.

In the study authored by Brousseau and Pénard (2007), a modular analytical framework is presented, aimed at facilitating the comparison of various business models used in the production of knowledge products and digital services. This framework rests upon the dimensions of the "matching economy," which manages the costs of bringing supply and demand together; the "assembly economy," which consolidates different digital modules into a functional package; and the "knowledge management economy," which generates added value from user feedbacks. It emphasizes that users are no longer merely passive consumers but, on the contrary, have become active actors who affect the distribution of monopolistic competition rents by generating information.

In the research conducted by Bukht and Heeks (2017), the meaning and metrics of the digital economy are examined, defining three core encompassing scopes. The authors conceptualize the core area, where economic output is directly or primarily derived from business models producing digital goods/services, as the "digital sector" (IT/ICT). They define the addition of emerging digital and platform services to this sector as the true "digital economy," while distinguishing the pervasive use of information technologies across all economic domains with the concept of the "digitalised economy."

In the study carried out by Bukht and Heeks (2018), the significance of digital economy processes driven by digital technologies for developing countries and the structural barriers they face are evaluated from a policy perspective. It is stated that countries in the Global South cannot capture the full development potential of digitalization (digital dividends) due to inadequate technical infrastructure, high costs, weak financial institutions, lack of capacity, and regulatory gaps. Furthermore, it is argued that these processes lead to structural disadvantages such as digital exclusion, precarious work (precarity), and cyber risks, thereby advocating for the establishment of flexible and multi-stakeholder governance mechanisms (policy collaboratory).

In the practitioner commentary study presented by Amuso, Poletti, and Montibello (2019), the asymmetric power relations and wage volatility created by crowd-work and platform-based business models in the labor market are examined. While it is noted that digital platforms offer significant

opportunities, such as transcending geographical boundaries to reduce discrimination for disadvantaged groups and integrating small and medium-sized enterprises (SMEs) into global value chains (GVC), it is stated that multi-layered public policy instruments, such as international "smart contract protections" and "underemployment insurance," must be designed against the risks of precarity.

In the book published under the editorship of Ashmarina, Mesquita, and Vochozka (2020), the digital transformation processes of the economy are addressed through a multidimensional and interdisciplinary perspective, encompassing topics such as institutional traps, cybersecurity, legal liability regimes in autonomous systems, export marketing, human capital accounting, innovation management, and digitalization gaps in the education system. While the chapters in the book emphasize that information technologies and Industry 4.0 transformations fundamentally reshape traditional industrial value chain structures, attention is drawn to the fact that infrastructure maturity and legal/ethical regulations must be executed simultaneously for these processes to generate sustainable macroeconomic growth and systemic resilience.

In the systematic literature review conducted by Georgieva, Akimbaeva, Askarova, and Kyzdarbekova (2020), it is argued that the digital economy alone cannot be a prescription for the problems of all socio-economic systems, and that these processes can only create added value when supported by a strong institutional environment, state policies, and organizational cultural transformation (digital culture). The researchers state that despite the potential of end-to-end technologies to increase efficiency in firms, they harbor serious challenges regarding the prioritization of investments and the clarification of monetization tactics of business models; therefore, digital transformation must be planned together with macro and micro-level analog complements.

In the review article written by Tleubergenova and Serimbetova (2023), the potential of digitalization to increase market efficiency by reducing transit costs, eliminating information asymmetry, and utilizing large-scale network effects is discussed at a theoretical level. The authors emphasize that in the post-industrial transformation process, the most advantageous firms are platform structures that possess intellectual/digital resources rather than tangible physical assets (as exemplified by Google, Uber, and Booking). Conversely, they argue that the pace of digital transformation advancing ahead of existing legislation and laws may violate competitive principles, and that special regulatory models must be developed to protect consumer safety.

In the comprehensive bibliometric and systematic literature research conducted by Özbay and Yılmaz Genç (2023), the historical evolution and metamorphosis of concepts such as the "new economy," "e-commerce," "digital currency," and "blockchain" in the academic literature from 1999 to 2023 are filtered. The study reveals that the intrinsic characteristics of the digital economy—such as shapelessness, global reach, moligopolistic/monopolistic platformization, and excessive reliance on intangible assets—render traditional economic theories and antitrust laws dysfunctional. It confirms the

need for an interdisciplinary (philosophical, sociological, and econometric) academic consensus to manage the emerging risks of social polarization, stock market volatility, and data privacy.

In the empirical research conducted by Başol and Yalçın (2024), based on 2022 data from 27 European Union countries, the impact of the Digital Economy and Society Index (DESI) on the Quality of Life Index (QoLI) was tested using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results of the analysis, carried out using SmartPLS 4 software, indicate that the DESI dimensions—comprising connectivity, digital public services, human capital, and the integration of digital technologies—statistically increase the QoLI indicators, which consist of individuals' purchasing power, quality of healthcare services, and cost of living components, at a highly robust and positive level.

The literature generally demonstrates that the digital economy must be addressed not only through its technological dimensions but also through its institutional and governance dimensions. However, while a significant portion of existing studies evaluates digital trust through individual behaviors or technological infrastructure, studies that comprehensively address the role of institutional regulations in reducing information asymmetry remain limited.

3. METHODOLOGY

In this study, a qualitative and conceptual research method has been adopted to examine the relationship between the digital economy and trust from the perspective of institutional regulations and public policies. Rather than grounding the transformations brought about by digitalization on empirical (numerical) data, the research design aims to conceptualize and make sense of these shifts by filtering them through current theoretical debates and the literature.

The methodological process consists of two fundamental steps: First, the link between the problem of information asymmetry in digital environments and the institutional frameworks that serve to mitigate this issue is addressed at a theoretical level. In the second step, the impacts of public policies on macroeconomic stability and market efficiency are examined by evaluating current literature and policy debates. Through these conceptual arguments, the study aims to demonstrate the importance of well-designed institutional rules in constructing a digital economic environment.

The conceptual framework established within the scope of this study is based on the assumption that information asymmetry in the digital economy leads to market failures such as adverse selection and moral hazard, which in turn deepens the issue of digital trust. In the study, it is recognized that institutional regulations and public policies reinforce digital trust, lower transaction costs, and enhance market efficiency by reducing information asymmetry. This process is ultimately projected to contribute to the strengthening of macroeconomic stability and systemic resilience, thereby supporting sustainable economic growth and global competitiveness. The network of conceptual relationships followed in this direction constitutes the core theoretical framework guiding the analysis process of the study.

Within this context, databases such as Web of Science, Scopus, Google Scholar, and relevant international working papers were screened to evaluate studies situated on the axis of the digital economy, information asymmetry, institutional economics, and public policies.

4. CONCEPTUAL FRAMEWORK AND POLICY DESIGN

4.1.Information Asymmetry in Digital Markets and the Role of Public Policies in Reducing Uncertainty

Unlike traditional market structures, the process of digitalization has created a dynamic environment where buyers and sellers do not meet in a physical context, and the quality of a product or service can only be fully comprehended at the consumption stage (Zagler, 2002). This situation leads to a profound information asymmetry among economic actors and, consequently, to chronic risks of market failure such as adverse selection and moral hazard (Georgieva, Akimbaeva, Askarova & Kyzdarbekova, 2020). This asymmetric structure further deepens the informational gap between users and large platforms that possess data collection and analysis capacities (Akerlof, 1970; Martens, 2016). In these digital markets where traditional registration and certification mechanisms remain inadequate, informational distortions lead to a "market for lemons" phenomenon, which causes high-quality labor or services to be priced below their actual value (Akerlof, 1970; Fallah, 2026).

Micro-scale solutions developed within digital platforms, such as user reviews, star ratings, or seller references, remain insufficient on their own to ensure security against organized structural risks such as cyber fraud, fake data generation, and data breaches (Brousseau & Pénard, 2007; Timofeeva, 2020). The rapid growth of the share of these knowledge-intensive sectors within total output demonstrates the challenges of determining the quality of digital outputs on a pre-transaction basis; hence, this situation indicates that the ex-ante (pre-transaction) qualitative uncertainty of digital outputs is profound enough to cause measurement biases even at the macro level (Nordhaus, 2001).

Conceptual analyses demonstrate that digital markets cannot generate a completely transparent and secure operational mechanism entirely on their own (Zagler, 2002). At this juncture, public policies and regulatory rules emerge as a fundamental intervention tool that reduces uncertainty by clarifying the flow of information (Bukht & Heeks, 2018). Adapting consumer rights to the digital sphere, updating e-commerce laws, and rendering cybersecurity standards a legal obligation prevent informational distortions in the market (Ashmarina, Mesquita & Vochozka, 2020). It is observed that these clear and binding legal boundaries set by public authorities minimize informational distortions, thereby enabling the formation of a predictable, transparent, and secure commercial space for economic agents (Tleubergenova & Serimbetova, 2023).

4.2. Mechanisms and the Construction of Digital Trust

Within the framework of the fundamental tenets of institutional economic theory, institutions are structures that regulate social and economic interactions, reduce uncertainties, and establish the "rules of the game" (Zagler, 2002). The tendencies of actors in the digital economy to transact in areas such as data sharing, digital payment systems, and intellectual property rights are directly dependent on the existence of an unshakeable legal guarantee (Özbay & Yılmaz Genç, 2023). Regulations protecting data privacy, digital signatures, secure authentication systems, and auditing mechanisms that prevent unfair competition constitute the cornerstones of the institutional infrastructure in the digital ecosystem (Revina, Paulov & Sidorova, 2020).

However, due to the uniquely fluid structure of the digital world, the micro-level perception of trust developed among individual actors (such as user ratings or intra-platform references) remains insufficient on its own to prevent systemic risks and data misuses. Reputation and feedback systems on digital platforms can function as biased, manipulation-prone "black boxes" that are far from transparent (Ranchordás, 2017). Furthermore, the deficiencies in users' authentication processes within these networks and the ability of malicious actors to re-enter the system by changing identities (whitewashing) severely limit the effectiveness of intra-platform trust mechanisms (Turi, 2020).

The institutional mechanisms in question close the trust gap between the parties, thereby increasing the enforceability of digital contracts and significantly lowering transaction costs in the market (Brousseau & Pénard, 2007). The more clearly, deterrently, and inclusively the institutional and legal infrastructure is designed, the more the "digital trust" of economic actors in the system is reinforced (Amuso, Poletti & Montibello, 2019). The findings obtained in this direction reveal that well-structured institutional regulations are the most fundamental driving force that ensures the sustainable growth of the platform economy and digital trade volume by constructing a digital trust ecosystem (Başol & Yalçın, 2024).

4.3. Reflections of Institutional Regulations in Emerging Economies: Macroeconomic Stability and Systemic Resilience

The transformations brought about by digital technologies and the emerging business models arising therefrom harbor both significant opportunities and severe vulnerabilities for emerging economies whose institutional and legal infrastructures have not yet matured (Bukht & Heeks, 2018). Emerging countries display a structure that is more vulnerable to cyber threats, uncontrolled data and capital flows, and unfair competitive conditions created by platform monopolies (Antonelli, 2003). In this context, an effective digital regulation framework established through public policies holds strategic importance for the protection of the economic system at the macro level (Belanova, Kornilova & Sultanova, 2020). In emerging markets where institutional volatility and uncertainty are high, the accurate interpretation of macroeconomic indicators and market movements is only possible through the reliability of institutional anchors and official information channels (Maciel, 2026). For this reason,

instead of top-down and rigid regulations, the formation of flexible institutional frameworks that can adapt to dynamic market processes and protect the consumer without blocking innovation emerges as a critical necessity for macroeconomic stability (Koopman et al., 2015).

Indeed, well-designed public policies and regulatory instruments directly contribute to macroeconomic stability by ensuring the recording of digital financial flows, thereby facilitating the fight against cybercrime, reducing the share of the informal economy, and protecting state tax revenues (Andrianova, 2020). Consequently, the effective and comprehensive implementation of institutional regulations serves as a fundamental safeguard that enhances the systemic resilience capacity of the national economic system against external shocks and financial fluctuations that may stem from the digital economy (Ermolaev, Matveev, Trubetskaya, Lunin & Snarskaya, 2020).

5. CONCLUSION

The process of digitalization has dismantled traditional production and trade patterns in the global economic system, constructing a new knowledge-based and network-oriented market order. Although the potential of knowledge-intensive sectors and innovative service varieties to trigger macroeconomic growth is remarkably high, this transformation simultaneously brings about a structural productivity paradox, platform monopolization, a global digital divide, and risks of precarity in labor markets. In digital environments where the informational structure becomes complexified and parties do not meet physically, the inability to determine output quality prior to a transaction creates a chronic information asymmetry. Faced with this asymmetric structure that leads to market failures such as adverse selection and moral hazard, micro-level solutions like intra-platform user ratings remain insufficient on their own to prevent systemic risks. This situation renders it mandatory to reconstruct the concept of trust—an invisible mechanism for the sustainability of economic transactions—through an institutional approach and by means of public policies. As institutional economic theory points out, the more clearly, inclusively, and deterrently the institutional and legal infrastructure regulating economic interactions and setting the rules of the game is designed, the more the digital trust of actors in the system is reinforced. Particularly for emerging economies that are more vulnerable to technical inadequacies, cyber threats, and platform monopolies, these public regulations function as a core protective shield that enhances macroeconomic stability and systemic resilience capacity against financial fluctuations.

In this direction, to minimize the structural risks brought by the digital economy and to build a sustainable digital trust ecosystem, legal legislation must first be adapted to the pace of digital transformation and flexible governance mechanisms must be established. E-commerce laws and consumer rights should be dynamically updated to encompass next-generation financial technologies, data privacy, and intangible assets in digital environments. To reduce information asymmetry and ex-ante (pre-transaction) qualitative uncertainty on digital platforms, public authorities must develop transparent information-sharing standards and independent auditing mechanisms. Furthermore, to

prevent cyber fraud and data breaches, systems such as end-to-end encryption, digital signatures, and secure authentication must be rendered legal obligations, thereby reinforcing the legal guarantees of the institutional infrastructure.

Another critical step for preserving market efficiency and macroeconomic stability is the renewal of antitrust laws and competition principles according to digital dynamics, which will counteract the monopolistic tendencies generated by big tech firms. These regulations will prevent small and medium-sized enterprises from being crushed under monopolistic platform rents, facilitating their fair integration into global value chains. Simultaneously, to balance the asymmetric power relations and wage volatility deepened in the labor market by the gig economy and crowd-work models, multi-layered social safety nets—such as smart contract protections and underemployment insurance that safeguard worker rights—must be deployed. Moreover, to protect the state's tax base and reduce informality, all financial flows and monetization tactics conducted through platforms must be transparently recorded.

Finally, bridging the global digital divide and ensuring that public regulations translate into macro-level, full-scale productivity is only possible if investments in technological infrastructure are planned alongside analog complements. Particularly, technical infrastructure deficiencies and high costs in emerging countries must be eliminated through public support. For technological investments to transform into clear economic outputs and increases in social welfare, human capital investments must be scaled up, digitalization gaps in the education system must be closed, and a robust digital culture transformation must be encouraged at the organizational level. Sustaining global competitiveness and supporting sustainable growth paths can only be realized through these holistic, flexible, and multi-stakeholder policy designs that solidify the digital ecosystem with legal safeguards.

This study offers a conceptual contribution to the literature by demonstrating that digital trust cannot be explained solely through individual trust relationships, but rather that institutional regulations, public policies, and mechanisms reducing information asymmetry must be evaluated collectively. For future research, empirically testing the proposed conceptual framework through different country cases or panel data analyses will provide significant contributions to the literature.

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AGRICULTURAL HUMAN APPROACH IN SUSTAINABLE GROWTH: A FINTECH-BASED MULTI-COUNTRY COMPARATIVE ANALYSIS

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ABSTRACT

This study introduces the concept of Agricultural Human as a human-centered framework for explaining sustainable agricultural transformation. The study aims to examine how financial technologies, digital capabilities, education, institutional support, and technology adoption jointly contribute to sustainable agricultural growth. A qualitative comparative case analysis was conducted using evidence from Kenya, India, China, and Türkiye. The findings show that countries follow different development paths while reaching a common outcome. Kenya demonstrates the role of financial inclusion, India emphasizes education and continuous learning, China highlights the contribution of digital finance and public policies, and Türkiye reveals that technological potential alone is insufficient without strengthening producers' digital, financial, and institutional capacities. The study concludes that technology and financial innovation are necessary but insufficient conditions for sustainable agricultural growth. Their effectiveness depends on producers' ability to adopt, integrate, and effectively use these opportunities. Accordingly, the Agricultural Human framework places human capacity at the center of agricultural transformation and provides a human-centered perspective for future agricultural policies.

Keywords: *Agricultural Human, Agriculture 4.0; Financial Technologies, Financial Inclusion, Sustainable Agricultural Growth.*

JEL Codes: *Q16, O33, G21.*

SÜRDÜRÜLEBİLİR BÜYÜMEDE TARIM İNSANI YAKLAŞIMI: FİNANSAL TEKNOLOJİLER TEMELLİ ÇOK ÜLKELİ KARŞILAŞTIRMALI BİR ANALİZ

ÖZET

Bu çalışma, sürdürülebilir tarımsal dönüşümü açıklamak amacıyla Tarım İnsanı (Agricultural Human) kavramını insan odaklı bir çerçeve olarak önermektedir. Çalışmanın amacı, finansal teknolojiler, dijital yetkinlikler, eğitim, kurumsal destek ve teknoloji benimsemesinin sürdürülebilir tarımsal büyümeye ortak katkısını incelemektir. Bu kapsamda Kenya, Hindistan, Çin ve Türkiye örnekleri nitel karşılaştırmalı durum analizi yöntemiyle değerlendirilmiştir. Bulgular, ülkelerin farklı gelişim yolları izlemelerine rağmen benzer bir sonuca ulaştığını göstermektedir. Kenya finansal kapsayıcılığın önemini ortaya koyarken, Hindistan eğitim ve sürekli öğrenmenin rolünü, Çin dijital

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finans ve kamu politikalarının katkısını, Türkiye ise teknolojik potansiyelin üreticilerin dijital, finansal ve kurumsal kapasiteleri güçlendirilmeden tek başına yeterli olmadığını göstermektedir. Sonuç olarak teknoloji ve finansal yenilikler sürdürülebilir tarımsal büyüme için gerekli ancak tek başına yeterli değildir. Bu unsurların başarısı, üreticilerin bu fırsatları benimseme, bütünleştirme ve etkin kullanma kapasitesine bağlıdır. Bu doğrultuda Tarım İnsanı yaklaşımı, tarımsal dönüşümün merkezine insan kapasitesini yerleştirmektedir.

Anahtar Kelimeler: *Tarım İnsanı, Tarım 4.0, Finansal Teknolojiler, Finansal Kapsayıcılık, Sürdürülebilir Tarımsal Büyüme.*

JEL Kodları: *Q16, O33, G21.*

1. INTRODUCTION

One of the greatest paradoxes in human history is that, although agricultural production has increased to an unprecedented level, problems related to food security, the sustainable use of natural resources, and rural development have become increasingly visible during the same period. Technological developments over the last half-century have significantly increased agricultural productivity, and production processes have been reshaped through mechanization, automation, and digitalization. Nevertheless, climate change, land degradation, the depletion of water resources, biodiversity loss, and the difficulties experienced by small-scale producers in accessing finance indicate that evaluating agricultural growth solely in terms of production volume is insufficient (Birthal et al., 2015; Ruzzante et al., 2021). Therefore, the primary objective today is no longer merely to increase production but to establish an agricultural production system capable of balancing economic efficiency with environmental and social sustainability (World Commission on Environment and Development [WCED], 1987).

The transformation in agricultural production is explained in the literature through the process of technological development extending from Agriculture 1.0 to Agriculture 4.0. This process has evolved from traditional production based on human labor to mechanization, precision agriculture, and data-driven smart farming systems. Throughout this transformation, the Internet of Things (IoT), big data, artificial intelligence, remote sensing, and blockchain technologies have enabled production processes to be managed more effectively (Wolfert et al., 2017). However, technological progress alone does not guarantee sustainable agricultural development. The transformation of technology into economic, environmental, and social benefits depends on the existence of human capacity capable of using it effectively.

Accordingly, a significant paradigm shift has emerged in the literature. While agricultural success was evaluated for many years in terms of production volume and productivity growth, the concept of sustainable growth has made product quality, the conservation of natural resources, and the improvement of rural welfare integral components of the process. Recent studies show that an increase

in production volume does not always lead to improvements in product quality and sustainability; intensive input use and short-term productivity targets may generate adverse long-term effects on soil health, ecosystem balance, and production quality (Birthal et al., 2015; Ruzzante et al., 2021). Therefore, the main debate regarding sustainable agricultural growth focuses not on producing more, but on how to establish a balanced production model between productivity and quality.

One of the important components of this transformation process is financial technologies (FinTech). Mobile payment systems, digital lending platforms, agricultural insurance, and data-driven financing models support the diffusion of digital agricultural technologies by facilitating small-scale producers' access to financial services (Arner et al., 2017; Beck et al., 2007; Demirgüç-Kunt et al., 2018). Nevertheless, studies indicate that financial access alone is not sufficient; the success of FinTech applications is closely associated with producers' digital literacy, financial knowledge, and capacity to adopt innovations (Ozili, 2018). This suggests that agricultural transformation depends not only on technology and finance but also on the human capacity to use these tools effectively.

Nevertheless, the existing literature largely addresses Agriculture 4.0 technologies, financial inclusion, and sustainable production as separate areas of inquiry. Although the development of technological infrastructure, the expansion of access to finance, and the promotion of sustainable production practices are important, studies that comprehensively examine the digital, financial, and environmental capabilities of producers at the center of this transformation remain quite limited. In other words, the literature includes technology, finance, and sustainability; however, the human factor that brings these three elements together to achieve sustainable transformation has often remained in the background.

To address this conceptual gap, this study proposes the Agricultural Human approach. Agricultural Human refers to a new generation of producers who can effectively use digital technologies, benefit from financial instruments, make data-driven decisions, adopt environmental sustainability as an integral part of production processes, and remain open to continuous learning. Within this framework, the study comparatively examines Kenya, India, China, and Türkiye in terms of FinTech-based agricultural transformation and discusses the central argument that sustainable agricultural growth depends not only on investments in technology and finance but also on developing the Agricultural Human capacity capable of effectively utilizing these investments. In this respect, the study aims to make a conceptual contribution to the literature by bringing together the fields of agricultural economics, financial technologies, and sustainable development within a common human-centered theoretical framework.

2. LITERATURE REVIEW

Agricultural production is not only one of the oldest economic activities in human history but also a dynamic sector that has continuously adapted to economic, technological, and social transformations.

Population growth, urbanization, and increasing global food demand have driven the agricultural sector toward higher productivity and more efficient resource utilization, leading to significant transformations in production techniques. Today, agricultural development is evaluated not only in terms of production volume but also in relation to sustainable growth, product quality, the conservation of natural resources, and rural welfare.

In the literature, agricultural transformation is generally examined in four stages: Agriculture 1.0, Agriculture 2.0, Agriculture 3.0, and Agriculture 4.0. Agriculture 1.0 refers to production systems based on human labor and traditional knowledge, whereas Agriculture 2.0 significantly increased production capacity through mechanization, chemical fertilizers, and modern irrigation techniques. With Agriculture 3.0, precision agriculture practices emerged through the use of global positioning systems (GPS), geographic information systems, remote sensing, and sensor technologies. Today, Agriculture 4.0 is characterized by the integration of big data, the Internet of Things (IoT), artificial intelligence, robotics, cloud computing, and blockchain technologies into agricultural production. According to Wolfert et al. (2017), these technologies not only digitalize production processes but also optimize resource utilization and reduce production risks through data-driven decision-making mechanisms.

Nevertheless, throughout all stages of technological transformation in agriculture, success was evaluated for many years in terms of production volume and productivity. However, with the growing prominence of the concept of sustainable development, the approach focusing solely on production growth has begun to be criticized. While the intensive use of chemical inputs and the excessive consumption of natural resources increase production in the short term, they may also lead to significant long-term problems, such as the deterioration of soil quality, the pollution of water resources, and the loss of biodiversity. Therefore, it is now widely recognized that agricultural success should be evaluated not only in terms of production volume but also in relation to product quality, environmental sustainability, and the efficient use of natural resources. Birthal et al. (2015) and Ruzzante et al. (2021) emphasize that sustainable agricultural growth should be addressed through a holistic approach that goes beyond productivity growth to include the effective use of technologies and the conservation of resources.

This discussion demonstrates that Agriculture 4.0 technologies are not sustainable growth itself but rather tools for achieving sustainable growth. The transformation of the advantages provided by digital technologies into economic and social benefits is directly related to the extent to which these technologies are adopted and effectively utilized by producers. The performance differences observed among producers with access to the same technologies also indicate that agricultural transformation cannot be explained solely from a technological perspective. Accordingly, the central debate in the literature has shifted from the question, *"Which technologies should agriculture use?"* to the question, *"How can the human capacity capable of using these technologies effectively be developed?"*

This approach has gained increasing acceptance in the digital agriculture literature. Klerkx et al. (2019) argue that the success of digital agriculture depends not only on technological infrastructure but also on producers' level of knowledge, learning capacity, institutional support mechanisms, and ability to adapt to innovations. This view is also consistent with Becker's (1993) Human Capital Theory and Rogers' (2003) Diffusion of Innovations Theory. According to Becker, investments in education, knowledge, and skills are among the fundamental determinants of economic growth, whereas Rogers demonstrates that the adoption of technological innovations is influenced by factors such as individuals' educational level, risk perception, and social environment. Therefore, differences in the performance of producers with the same technological infrastructure can be explained more by differences in human capital than by technological differences.

The sustainability of technological transformation is also closely related to access to financial resources. Since the adoption of digital technologies requires substantial investment costs, financial systems have become an integral component of agricultural transformation. Beck et al. (2007) state that well-developed financial systems accelerate economic growth by supporting investment. However, traditional financial systems are known to be inadequate in meeting the credit and financing needs of small-scale producers.

At this point, FinTech applications offer significant opportunities. Arner et al. (2017) define FinTech as the redesign of financial services through digital technologies, whereas Vives (2019) argues that this transformation enhances financial inclusion by supporting the participation of populations previously excluded from the financial system in the economic process. In the agricultural sector, mobile payment systems, digital lending platforms, and data-driven financing models have become important instruments that facilitate small-scale producers' access to finance and support investments in technology. Accordingly, FinTech is regarded not only as the digitalization of financial services but also as a mechanism that promotes the diffusion of agricultural technologies.

Nevertheless, financial technologies alone do not guarantee sustainable transformation. The Global Findex study by Demirgüç-Kunt et al. (2018) shows that increased access to financial services does not necessarily mean that these services are used effectively. Similarly, Ozili (2018) states that the economic impact of digital finance is directly related to users' level of financial literacy, digital skills, and trust in technology. Therefore, technology and finance can contribute to sustainable agricultural transformation only when supported by the human capacity to utilize them effectively.

2.1. Conceptual Gap in the Literature

A review of the existing literature reveals that a substantial body of knowledge has been developed on Agriculture 4.0 technologies, sustainable production, and FinTech applications. However, these studies primarily focus on either technology or finance and do not address the producer at the center of this transformation through a holistic perspective. The development of technological

infrastructure or the expansion of financial access alone does not guarantee sustainable agricultural transformation. The performance differences observed among producers with access to the same technologies and financial instruments clearly demonstrate the decisive role of knowledge, skills, and adaptive capacity.

Therefore, it can be argued that studies integrating technology, finance, and sustainability within the framework of human capital remain limited in the literature. This study addresses this conceptual gap through the Agricultural Human approach. Agricultural Human refers to a new generation of producers who can effectively use digital technologies, benefit from financial instruments, regard environmental sustainability as an integral part of production decisions, remain open to continuous learning, and adapt to change. This approach is based on the assumption that sustainable agricultural growth depends not only on investments in technology and finance but also on the human capacity capable of effectively utilizing these investments.

3. RESEARCH DESIGN AND METHODOLOGY

This study was designed as a qualitative comparative study that evaluates the effects of FinTech applications on producers within the framework of the Agricultural Human approach in the process of sustainable agricultural growth. The main assumption of the study is that agricultural transformation cannot be explained solely by technological developments or financial innovations; rather, the success of this transformation depends on the human capacity capable of adopting these innovations and effectively integrating them into production processes, consistent with the human capital perspective proposed by Becker (1993**)**. Accordingly, the study aims to identify the common dynamics supporting sustainable agricultural growth by comparing countries with different socioeconomic structures and levels of digitalization.

The study adopts a qualitative comparative literature analysis method. This method enables the systematic comparison of different country experiences and the evaluation of findings from the existing literature within a common conceptual framework (Klerkx et al., 2019). The objective of the study is not merely to describe the FinTech solutions implemented in different countries but also to analyze, from a holistic perspective, the effects of these applications on producers' behavior, technology adoption processes, and sustainable agricultural growth. In this respect, the analysis is informed by the theoretical perspectives of technology adoption and diffusion proposed by Rogers (2003).

Within the scope of the study, Kenya, India, China, and Türkiye were selected as case studies. These countries, identified through purposive sampling, represent different dimensions of agricultural digital transformation. Kenya represents the impact of mobile money systems on rural financial inclusion; India represents the role of education and learning processes in the adoption of digital agricultural technologies; China represents a transformation model in which public policies and digital inclusive finance operate together; and Türkiye represents a country undergoing the development of

digital agricultural policies with significant transformation potential. This diversity makes it possible to comparatively evaluate the Agricultural Human approach under different economic and institutional conditions.

The countries were examined using a common analytical framework in terms of:

(i) FinTech infrastructure and financial inclusion;

(ii) producers' digital and technological adaptation;

(iii) public policies and institutional support mechanisms; and

(iv) their contributions to sustainable agricultural growth.

The analytical framework was developed based on the literature on digital agriculture, financial inclusion, technology adoption, and sustainable agricultural transformation (Beck et al., 2007; Demirgüç-Kunt et al., 2018; Wolfert et al., 2017; Klerkx et al., 2019). Accordingly, both successful practices and structural limitations were analyzed within the same evaluation framework.

The study draws on international peer-reviewed journal articles, reports published by international organizations, official institutional publications, and recent policy documents as its data sources. The literature review was based on studies recognized as foundational in the fields of FinTech, financial inclusion, digital agriculture, technology adoption, and sustainable agricultural development. The findings were evaluated comparatively and interpreted within the framework of the Agricultural Human approach. In this respect, the study aims to bring together knowledge generated across different disciplines within a common human-centered conceptual framework.

4. COMPARATIVE COUNTRY ANALYSES

4.1. Kenya: Transformation Driven by Mobile Finance

Kenya is one of the most remarkable country examples in demonstrating the transformative impact of financial technologies on the agricultural sector. For many years, small-scale producers living in rural areas had limited access to basic financial services such as credit, savings, and insurance due to the insufficient number of bank branches, high transaction costs, lack of collateral, and low income levels. This situation not only constrained agricultural investment but also slowed the adoption of new production technologies (Mbiti & Weil, 2011).

In Kenya, the widespread adoption of mobile money systems played a decisive role in overcoming this structural problem. In particular, with the development of the M-Pesa platform, financial services began to be delivered through mobile phones independently of the traditional banking system, significantly increasing financial inclusion in rural areas. Jack and Suri (2014) demonstrate that mobile money systems not only facilitate money transfers but also support the financing of agricultural production by increasing households' resilience to income fluctuations. Similarly, Suri and Jack (2016)

show that mobile finance applications positively influence the investment decisions of small-scale producers and contribute to reducing rural poverty.

Nevertheless, the Kenyan experience also demonstrates that success did not result solely from the establishment of digital financial infrastructure. Producers' trust in technology, the ease with which services could be used in everyday life, and their adaptation to local needs were decisive factors in the widespread adoption of mobile finance applications. According to Aker (2011), mobile technologies support rural development by facilitating access to information, reducing transaction costs, and accelerating decision-making processes. Therefore, in the case of Kenya, the transformation is based not only on technology but also on producers' capacity to adopt and effectively utilize that technology.

The Kenyan experience demonstrates that sustainable agricultural growth cannot be achieved solely through the widespread adoption of financial technologies. Digital financial tools have increased producers' investment capacity and reduced their financial vulnerability; however, the transformation of these gains into sustainable outcomes has been possible only through producers' financial literacy, digital skills, and ability to adapt to new applications. In this respect, Kenya can be regarded as one of the leading country examples demonstrating that sustainable agricultural transformation depends less on technological infrastructure itself than on the human capacity capable of using that infrastructure effectively, thereby illustrating the dimensions of financial capability and digital adaptation embodied in the Agricultural Human approach.

4.2. India: The Role of Education and Human Capital in Technology Adoption

Although India has made significant investments in promoting the diffusion of digital agricultural technologies, this transformation cannot be explained solely by technological infrastructure. Owing to its large agricultural production capacity, the predominance of small family farms, and regional disparities in development, India represents one of the most complex examples of digital transformation. Therefore, the Indian experience demonstrates that access to technology alone is insufficient; rather, producers' educational attainment, digital literacy, and capacity to adopt innovations play a decisive role in the success of this transformation.

In recent years, digital agricultural platforms, mobile applications, and decision support systems have significantly facilitated producers' access to market information, weather forecasts, production recommendations, and financial services. However, the level of utilization of these technologies varies considerably across regions and producer groups. Naik and Krishna (2021) argue that the success of digital agriculture depends not only on technological infrastructure but also on producers' educational level, perceptions of technology, and the effectiveness of agricultural extension services. Similarly, Alamsyah et al. (2024) emphasize that technical training and behavioral transformation must be addressed together for digital applications to generate sustainable outcomes.

The literature indicates that the technology adoption process cannot be explained solely by technical knowledge. Rakholia et al. (2024) demonstrate that farmers' decisions regarding new technologies are influenced not only by economic expectations but also by risk perception, social environment, and previous experience. Likewise, Sharma et al. (2025) argue that trust, willingness to learn, and psychological readiness are as important as technological infrastructure in promoting the adoption of digital agriculture. These findings are consistent with Rogers' (2003) Diffusion of Innovations Theory and indicate that the success of technological innovations depends on the learning and adaptive capacities of the individuals who use them.

The Indian experience also demonstrates that the relationship between FinTech and digital agriculture is strengthened through human capital. While digital payment systems, online lending platforms, and mobile finance applications facilitate producers' access to financial services, the effective use of these instruments largely depends on financial literacy and digital skills. Succena and Dani (2024) state that the sustainable impact of digital finance applications can be achieved only when they are supported by educational programs and agricultural extension activities. This finding indicates that financial inclusion can be achieved not only through the widespread availability of financial instruments but also through the development of producers' capacity to use these instruments effectively.

In conclusion, the Indian case demonstrates that sustainable agricultural transformation depends not only on investments in technology but also on investments in human capital. The benefits generated by digital technologies and FinTech applications increase in proportion to producers' learning capacity, digital literacy, and ability to adapt to change. In this respect, India provides an important country example that clearly illustrates the dimensions of continuous learning, digital capability, and technology adoption embodied in the Agricultural Human approach.

4.3. China: Agricultural Transformation Through Digital Financial Inclusion and Public Policies

China is among the leading countries accelerating agricultural transformation through the simultaneous implementation of digital financial inclusion, smart agriculture technologies, and strong public policies. In recent years, the combined implementation of artificial intelligence, big data, digital agriculture applications, and rural development policies has made China one of the most remarkable examples of technology-driven agricultural transformation. Nevertheless, the existing literature indicates that this success stems not only from advanced technologies but also from the integrated design of technology, finance, and public policies.

One of the fundamental components of China's agricultural transformation strategy is the expansion of digital financial inclusion. The provision of credit, insurance, and payment services through digital platforms to small-scale producers who were previously underserved by the traditional financial system has facilitated the financing of agricultural investments and accelerated access to

technological innovations. Fu and Guo (2025) demonstrate that digital financial inclusion not only improves access to finance but also strengthens producers' willingness to invest in new technologies, thereby supporting agricultural productivity and rural economic vitality. In this respect, FinTech functions as a complementary component of China's digital agriculture policies.

Another distinguishing feature of China's transformation model is the integration of digital technologies with environmental sustainability objectives. Liu et al. (2024) argue that digital technologies enable more efficient management of fertilizer, water, and energy use, thereby increasing resource efficiency while reducing environmental pressures. Similarly, Peng et al. (2023) state that digital applications contribute not only to increasing production volume but also to promoting green agricultural practices. These findings indicate that China regards digital transformation as a key instrument for achieving not only economic growth but also environmental sustainability.

Nevertheless, the literature also demonstrates that strong public policies and advanced technological infrastructure alone are not sufficient. Xu & Wang (2023) emphasize that the success of digital transformation programs is directly related to producers' digital skills, educational attainment, and capacity to adopt new applications. Even in regions with advanced technological infrastructure, technologies have not been utilized to the expected extent among producer groups with low levels of digital literacy. This indicates that digital transformation is not merely a technical process but a structural transformation that must be supported by continuous investment in human capital.

In conclusion, the Chinese experience demonstrates that sustainable agricultural growth cannot be explained solely by investments in advanced technologies or strong public policies. Digital financial inclusion, smart agriculture applications, and environmental sustainability policies provide a strong foundation for transformation; however, the success of these systems ultimately depends on producers' knowledge, skills, and capacity to adapt to change. In this respect, China provides an important country example demonstrating that the Agricultural Human approach should encompass not only digital and financial capabilities but also ecological awareness and institutional adaptability.

4.4. Türkiye: From Digital Agriculture Potential to the Agricultural Human Approach

Although Türkiye possesses significant agricultural production potential due to its climatic diversity, extensive agricultural production structure, and strategic geographical location, it is among the countries where digital transformation has not yet reached the desired level of diffusion at the producer level. In recent years, important policy initiatives have been undertaken in the fields of digital agriculture, smart farming technologies, and financial digitalization. In particular, digital agriculture projects implemented by the Ministry of Agriculture and Forestry have aimed to increase productivity in agricultural production (Republic of Türkiye Ministry of Agriculture and Forestry, 2024). Nevertheless, existing studies reveal that, despite improvements in technological infrastructure, the level of digitalization varies considerably across regions and farm sizes.

In the case of Türkiye, the central debate revolves around why technological potential does not always translate into sustainable agricultural transformation. The literature indicates that this situation cannot be explained solely by inadequate technological infrastructure. Kılavuz & Erdem (2019) identify the small-scale structure of agricultural holdings, lack of knowledge, low levels of digital literacy, and difficulties in accessing finance as the main barriers to the widespread adoption of digital agriculture applications. Similarly, Mutlugün (2014) emphasizes that strengthening agricultural extension services and preparing producers for new technologies are fundamental prerequisites for the digital transformation process.

From the perspective of financial technologies, Türkiye has made significant progress in recent years. Digital banking applications, mobile payment systems, and agricultural financing solutions have facilitated producers' access to financial services. In particular, digital agricultural banking applications and agricultural financing models developed by Ziraat Bank have enabled producers to access credit more rapidly (Ziraat Bankası, 2025). Nevertheless, increased financial access alone does not guarantee technological transformation. The effective use of financial instruments depends on producers' financial literacy, digital skills, and their ability to evaluate investment decisions from a long-term sustainability perspective.

One of the major challenges facing digital agriculture in Türkiye is the insufficient alignment between technology and human capital. Yıldırım et al. (2025) argue that sustainable agricultural development can only be achieved through producers who possess advanced digital capabilities, effectively utilize financial instruments, and are capable of adapting to innovation. These findings indicate that digital transformation in Türkiye should be regarded not merely as a process of technical modernization but as a human-centered transformation process.

Unlike the other country cases, Türkiye simultaneously possesses both high transformation potential and persistent structural challenges. Although significant progress has been made in digital agriculture technologies and FinTech applications, the predominance of small-scale farms, regional development disparities, and differences in producers' levels of digital capability continue to limit the diffusion of transformation. Therefore, the primary policy priority for Türkiye is not merely to increase investments in technology but also to develop producers who can use technology effectively, make informed use of financial instruments, place environmental sustainability at the center of production decisions, and remain open to continuous learning. In this respect, Türkiye provides an important context for evaluating and further developing the applicability of the Agricultural Human approach.

5. DISCUSSION: FROM COUNTRY EXPERIENCES TO THE AGRICULTURAL HUMAN APPROACH

When the experiences of Kenya, India, China, and Türkiye are considered together, it becomes evident that sustainable agricultural growth cannot be explained solely by technological investments or

the widespread adoption of financial instruments. Although the countries examined differ in their economic, institutional, and social structures, they converge on a common conclusion: technology and finance are necessary conditions for sustainable transformation, but they are not sufficient on their own. The transformation of these tools into economic and environmental value depends on the capacity of producers to utilize them effectively.

The country experiences complement one another in illustrating the different dimensions of the Agricultural Human approach. Kenya demonstrates the importance of financial inclusion and digital adaptation; India highlights education, continuous learning, and technology adoption; China emphasizes public policies, digital financial inclusion, and ecological sustainability; and Türkiye underscores the importance of structural transformation and a human-centered policy approach. These findings indicate that agricultural transformation cannot be achieved through a single policy instrument but requires the combined functioning of technology, finance, education, and institutional structures.

The findings also call for a reassessment of the technology-centered transformation perspective that has long dominated the literature. Studies on Agriculture 4.0 have largely focused on the effects of digital technologies on production, the FinTech literature has emphasized financial inclusion, and research on sustainable agriculture has concentrated on environmental performance (Wolfert et al., 2017; Arner et al., 2017; Ruzzante et al., 2021). However, the comparative country analyses demonstrate that the common determinant across these three domains is the human factor. In other words, technology, finance, and sustainability are not independent elements; rather, they contribute to sustainable agricultural growth when integrated through the Agricultural Human approach.

This study also provides a critical perspective on evaluating sustainable growth solely in terms of increases in production volume. Although production growth may generate economic benefits in the short term, sustainable growth cannot be achieved without preserving product quality, ensuring the efficient use of natural resources, and improving rural welfare. For this reason, the Agricultural Human approach places at its center a new generation of producers capable of balancing productivity and quality, effectively utilizing digital and financial tools, adopting environmental sustainability as an integral part of production decisions, and remaining open to continuous learning.

In conclusion, this study demonstrates that sustainable agricultural growth depends not only on investments in technology or financial support mechanisms but also on the development of the human capacity capable of utilizing these investments effectively. Accordingly, future agricultural policies should place greater emphasis not only on investments in digital infrastructure but also on policies that strengthen human capital through education, financial literacy, digital capabilities, agricultural extension services, and environmental awareness.

6. CONCLUSION

This study aimed to demonstrate that sustainable agricultural growth cannot be explained solely by technological developments or financial innovations. Although digitalization and FinTech applications have significantly transformed production processes in the agricultural sector, the comparative country analyses indicate that the success of this transformation depends less on technology itself than on the capacity of producers to utilize it effectively. Accordingly, the Agricultural Human approach proposed in this study provides a conceptual framework that integrates technology, finance, and sustainability from a human-centered perspective.

Although Kenya, India, China, and Türkiye differ in their levels of development and policy approaches, they point to a common conclusion. Kenya demonstrates the importance of financial inclusion; India highlights education and technology adoption; China emphasizes public policies and digital financial inclusion; and Türkiye underscores the significance of structural transformation and producer capacity. Nevertheless, across all country experiences, the common determinant of sustainable success is the presence of producers capable of effectively adopting, integrating, and utilizing digital technologies and financial instruments in production processes.

This study also demonstrates that sustainable agricultural growth should not be evaluated solely in terms of increases in production volume. Along with productivity growth, the preservation of product quality, the sustainable use of natural resources, and the enhancement of rural welfare constitute fundamental components of sustainable growth. Accordingly, the Agricultural Human approach positions a new generation of producers—those who effectively utilize digital technologies, make informed use of financial instruments, place environmental sustainability at the center of production decisions, and remain open to continuous learning—as the principal actors of sustainable transformation.

From a policy perspective, future agricultural strategies should not focus exclusively on investments in digital infrastructure. Promoting digital and financial literacy, strengthening agricultural extension and advisory services, enhancing producers' capacity to adapt to innovation, and supporting investments in human capital should be among the primary policy priorities for sustainable agricultural growth. In other words, future agricultural policies should invest not only in smarter technologies but also in more capable producers who can utilize these technologies effectively.

This study is conceptual in nature and is based on a qualitative comparative analysis. Therefore, its findings are limited to the country cases examined and the literature reviewed. Future research should develop measurable indicators of the Agricultural Human approach, test the framework empirically across different country contexts, and examine its effects on sustainable agricultural growth using quantitative methods. Such research would contribute to refining the proposed conceptual framework and supporting the development of evidence-based agricultural policies.

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KRİPTO PARA VE PARA ARZI İLİŞKİSİ VE TÜRKİYE

Merve ÖNEM*

ÖZET

Dijital paralar bugün dolaşımdaki paraların yaklaşık %90'ını temsil etmektedir. İnternet bankacılığı veya bankanın mobil uygulaması aracılığıyla banka havalesi yaptığınızda, banka veya kredi kartlarınızdan (Paypal veya Google Cüzdan) bir ödeme gönderip, aldığınızda, esas itibariyle 'dijital para işlemi yapıyorsunuz' demektir. Kripto para ise, bir dijital para türüdür ama dijital paradan farklı olarak, kendisi bir para birimidir. En bilineni Bitcoin iken, Ethereum, Bitcoin Cash, Litecoin, Ripple ve IOTA gibi 1000'in üzerinde cinsleri vardır. Kripto para kavramı hayatımıza 2008'den sonra giren, her geçen gün daha çok işlem hacmine sahip olan ve yüksek getirisinden ve hızlı düşüşünden kaynaklı, borsa gibi hareketli olan bir piyasadır. Aralık 2024 itibariyle dolaşımda 10 binden fazla kripto para vardır. Merkeziyetsiz olması, ve gelecekte kullanılacak paranın kripto para olduğuna dair yaygın inanç devletler açısından olumsuz bir tutum sergilemelerini sağlamaktadır.

Anahtar Kelimeler: *Kripto Para, Dijital Para, Bitcoin, Satoshi, Merkez Bankası*

JEL Kodları:

ABSTRACT

Digital currencies today represent approximately 90% of the money in circulation. When you make a bank transfer through internet banking or a bank's mobile application, or when you send or receive payments using your bank or credit cards (such as PayPal or Google Wallet), you are essentially conducting a "digital currency transaction." Cryptocurrency, on the other hand, is a type of digital currency but differs in that it is its own currency. The most well-known cryptocurrency is Bitcoin, but there are over 1,000 other types, including Ethereum, Bitcoin Cash, Litecoin, Ripple, and IOTA.

The concept of cryptocurrency entered our lives after 2008 and has become a market with increasing transaction volumes every day. Known for its high returns and rapid declines, it operates similarly to the stock market. As of December 2024, there are over 10,000 cryptocurrencies in circulation. Its decentralized nature and the widespread belief that cryptocurrencies will be the money of the future have led to negative attitudes among states regarding its adoption.

Keywords: *Cryptocurrency, Digital Currency, Bitcoin, Satoshi, Central Bank*

JEL Codes:

1. GİRİŞ

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Dijital paralar bugün dolaşımdaki paraların yaklaşık %90'ını temsil etmektedir. İnternet bankacılığı veya bankanın mobil uygulaması aracılığıyla banka havalesi yaptığınızda, banka veya kredi kartlarınızdan (Paypal veya Google Cüzdan) bir ödeme gönderip, aldığınızda, esas itibariyle 'dijital para işlemi yapıyorsunuz' demektir. Kripto para ise, bir dijital para türüdür ama dijital paradan farklı olarak, kendisi bir para birimidir. En bilineni Bitcoin iken, Ethereum, Bitcoin Cash, Litecoin, Ripple ve IOTA gibi 1000'in üzerinde cinsleri vardır. Kripto para kavramı hayatımıza 2008'den sonra giren, her geçen gün daha çok işlem hacmine sahip olan ve yüksek getirisinden ve hızlı düşüşünden kaynaklı, borsa gibi hareketli olan bir piyasadır. Aralık 2024 itibariyle dolaşımda 10 binden fazla kripto para vardır. Merkeziyetsiz olması, ve gelecekte kullanılacak paranın kripto para olduğuna dair yaygın inanç devletler açısından olumsuz bir tutum sergilemelerini sağlamaktadır. Bitcoin'in para olup olmadığına dair tartışmalar vardır. Parayı tanımlayan klasik fonksiyonları vardır. Değer saklama, mübadele aracı olma gibi özelliklere sahiptir. Ancak Bitcoin bu özellikleri kapsamakla beraber; paranın kabul edilebilir olması, taşınabilir olması, bölünebilirlik, uzun ömürlü olması gibi özellikleri bünyesinde barındırır. Ancak değerinin istikrarlı olduğu söylenemez. Çok hızlı bir şekilde değerinde ani düşüş ve yükselmeler yaşanmaktadır.

2. KRİPTO PARANIN TARİHİ VE KRİPTO PARA KAVRAMI

Kripto paraya dair ilk temelleri 1982 yılında David Chaum atmıştır. 'Bilgisayar Bilimi' kavramına ilk kez makalede yer veren Chaum'dur. 90'larda W. Scott Stornetto ve Stuart Haber, bir dökümanın imzalanmasında zamanın yayılmasına ilişkin makale yazıyorlar. Daha sonraları (90'ların sonlarına doğru) asıl büyük zincir (blockchain) oluşturmanın atası New York Times Gazetesi diyebiliriz. New York Times Gazetesi, her gün gazeteyi şifreleyerek kayda alıp, diğer günlere ekleyerek kopmaz bir zincir oluşturmuştur. Bu teknoloji özellikle 2018'de The New York Times'ın da katıldığı **News Provenance Project** gibi girişimlerde kullanılmaya başlanmıştır. Bu proje, haberlerin kaynağını doğrulamak ve değiştirilemez bir geçmiş kaydı oluşturmak için blockchain teknolojisini denemiştir.

Satoshi Nakamoto (2008) kullanıcı isimli[1] kişi veya grup tarafından 2008 yılında internet üzerinden yayımlanan 'Bitcoin: Kişiden Kişiye Elektronik Ödeme Sistemi' başlıklı teknik dökümanda (whitepaper) ele alınmış, işlemlerin nasıl gerçekleştirileceği, işlem gizliliğinin nasıl sağlanacağı, sistemin potansiyel saldırılardan nasıl korunacağı ve yazılımın işlem yapan kişileri çifte harcamadan nasıl koruyacağı açıklanmıştır. Söz konusu dökümanın çıkış noktasında, internet üzerinden yapılan alışverişlerde bankacılık sisteminin, güven unsurunu sağlamak üzere yaptığı aracılık fonksiyonu bulunmaktadır. Taraflar arasında ortaya çıkan problemlerde çözüm unsuru olan aracı kurumun, bu pozisyonu dolayısıyla işlem giderlerinin artmasına neden olduğu belirtilmektedir. Satoshi Nakamoto, belirtilen dokümanda iki tarafın üçüncü bir güvenilir kişiye gerek duymadan, güven yerine kriptografik

[1] Satoshi kelimesi, Japonca'da 'bilge, akıllı' anlamına gelmektedir. Satoshi Nakamoto bazı kaynaklara göre bu anlama gönderme yapmakta ve önemli teknoloji şirketlerinden Samsung, Toshiba, Nakamichi ve Motorola'nın isimlerinin bir araya gelmesinden oluşmaktadır. Diğer bazı kaynaklara göre ise bu isim ABD Ulusal Güvenlik Ajansı'ndan (National Security Team) bir ekibe ait kullanıcıdır (Wallace,2011).

kanıta dayalı olarak doğrudan birbirleriyle işlem yapabilecekleri bir elektronik ödeme sistemi önermektedir. Söz konusu ödemede kullanılması önerilen para birimi Bitcoin'dir yani itibari paranın (Merkez Bankası tarafından ihraç edilen paranın) kullanımı söz konusu değildir (Atıcı, 2020: 36).

Finansal işlemlerde kişilerarası güven sağlayıcı finansal merkezler yerine kriptografik kanıta dayalı, üçüncü bir güven sağlayıcı aracıya ihtiyaç duymadan, direkt birbiriyle işlem yapabileceği elektronik sistem daha fazla güvenilirdir. İşlemler zaman damgası sunucularının da katıldığı şifreleme sistemi ile mükerrer işlem yapmaktan oldukça uzaktır. Dolandırıcılık ihtimali düşmektedir. Hesaplar arası işlemlerde limit, sınır düzenlemeleri yoktur. Elektronik para, dijital imza zincirleridir. Kişilerin karşılıklı dijital imzalarının birbirini doğrulaması ile para transferi gerçekleşmektedir (Nakamoto, 2008: 1-2). Nakamoto'nun makalesi ile üçüncü bir taraf/otorite (hükümet, banka vb.) olmadan kriptografik kanıtlara dayalı kişiden kişiye çevrimiçi güvenilir işlem yapma imkanı veren elektronik bir para sistemi önerilmektedir. Kripto para birimleri şeffaftır, matematiksel formüllere dayalıdır. Başarısı ve değeri kullanıcıların fikir birliğine dayanmaktadır. Kripto para birimleri, blok zinciri teknolojisine dayalı dijital paralardır. Dijital ve aracısız ödemeler fikrine dayanan yeni teknolojik yeniliği temsil etmektedir (Massó, vd., 2021: 17).

Kripto paranın üretim sürecine ilişkin Hakan ATABAŞ Blokzinciri Teknolojisi ve Kripto Paraların Hayatımızdaki Yeni Yeri (2018:161) adlı kitabında durumu 'Zamana Karşı' filmine benzetmiş ve tek kullanımlık dijital kumbara olduğunu söylemiştir.[2]

Kripto paralar (sanal paralar) günümüzde alternatif bir para birimi olarak kabul görmeye başlamıştır.

Kripto para (sanal para) piyasası hiçbir devlet tarafından düzenlenmediği için regüle edilememektedir. Merkezi bir yapıya sahip olmadığı için gözetim ve denetim sisteminden bağımsız çalışmakta olup, kontrolü blok zinciri (blockchain) sistemi tarafından gerçekleştirilmektedir. Kripto paraların (sanal paraların) ne kadar üretileceği kripto sistemlerin kuruluşu aşamasında belirlenmiştir. Kripto paralar (sanal paralar) dünya genelindeki oldukça yüksek sayıdaki kişi tarafından bilgisayarlarda matematiksel problemlerin çözümünü sağlayan bir yazılım/program tarafından elektronik ortamda basılmakta olup, bazı büyük bilgisayar yatırımları ile oluşmuş şirketler sanal para işlemlerindeki aracılığı, doğrulamayı veya kriptolojiyi gerçekleştirmekte, sistemin yaşamasını ve devamlılığını sağlamaktadır (Kızıl, Hanişoğlu, Aslan, 2019: 36).

Kripto paralar bireysel kullanım yanında şirketlerinde ödeme aracı olarak kabul etmesiyle birlikte değeri 2008'den beri artmaktadır. Kripto paraların fiyatı sürekli inişli çıkışlı dalgalanmalar yaşasa da hacmi ve birim değerleri yükselmektedir (Dulupçu, 2017: 222)

[2] Filmde insanların bileğine yüklenen bir zaman çipi vardır. Zaman sıfırlandığı anda kişi ölür. Gündelik ihtiyaçlarının ödemesini de bileklerini okutarak, oradaki zamandan yaparlar. Her gün gece yarısı 24 saatlik bir zaman yüklenir. Bu zamanı çeşitli şekillerde ve yerlerde kullanırlar.

Kripto para alım satımlarında işlem yapılan borsa bireylerin işlemlerinden ücret almaktadır. Kripto paralar arz ve talebe göre değer kazanıp değer kaybetmektedir. Arzı artan kripto paraların fiyatı artarken talep düşüp arzı çoğaldığında fiyatı düşmektedir. Dünyanın her yerinden kullanıcısı olan sistemin büyük miktarda alım satım yapan kullanıcı hareketleri fiyatları etkilemektedir. Bu nedenle oldukça riskli bir piyasadır. Çok hızlı bir şekilde kişilerin paraları yüzlerce binlerce kat artarken çok hızlı bir şekilde düşebilmektedir. Kitlesel yatırımcıların bitcoin fiyatı hakkındaki kolektif beklentileri veya toplu inançları, bitcoin'in gerçek fiyat performansına yansımaktadır. Örneğin, eğer insanlar diğer insanların Bitcoin fiyatının düşeceğine inanıyorsa ve düşmeye devam ederse, o zaman insanlar yatırım yapma konusunda çekingen davranacak ve piyasa düşmeye devam edecektir (Lee, 2022: 16-17)

Bitcoin haricindeki kripto paralar altcoin olarak adlandırılmaktadır. Onbinlerce adet kripto para bulunmaktadır. "Ekonomistlere göre kripto paralar, paranın sağlaması gereken özelliklerden; tanınma, değişim aracı olma, taklit edilememe, transfer edilebilme, değer saklama ve homojenlik özelliklerinin tamamını taşımaktadır" (Kayacan ve Anavatan, 2018: 136). Genel olarak kripto paranın arzı önceden belirlenmektedir. Sonradan herhangi bir merkezi otoriteyle değiştirilememektedir. Kripto paralar blok zinciri teknolojisini kullanmaktadır. Kripto para sistemi kesintisiz 7-24 işlem yapma imkanına sahiptir. Geleneksel finansal kurumlar karşısında teknolojik altyapısına bağlı olarak hızlı ve kolay olmasıyla üstünlük sağlamıştır (Karaoğlan vd., 2018: 16-17).

Kripto para piyasasında, yaklaşık 4 trilyon dolara yakın işlem hacmi bulunmaktadır. 2008 yılındaki ABD merkezli mortgage krizinden sonra ortaya çıkan kripto para Bitcoin, 2018 yılındaki pandemi krizinden sonra fazlasıyla talep görmüş ve işlem hacmi artmıştır.

Kripto para piyasasına dair piyasa değerleri tabloları aşağıda verilmiştir:

Tablo 1. Son 30 Günlük Kripto Para Piyasa Değeri



Kaynak: https://coinmarketcap.com/

Tablo 2. Son 1 Yıllık Kripto Para Piyasa Değeri



Kaynak: https://coinmarketcap.com/

Tablo 3. Tüm zamanların Kripto Para Piyasa Değeri



Kaynak: https://coinmarketcap.com/

Bugün itibariyle 10,260 aktif kripto para piyasada işlem görmektedir.[3] Bunların sayısı sıklıkla değişkenlik göstermektedir. Çünkü piyasaya yeni giren veya piyasadan çekilme kararı alan kripto paralar vardır. 10 binden fazla olan kripto paralardan piyasa değeri en yüksek olan ilk piyasaya giren Bitcoin'dir. Onu Ethereum izlemektedir. Genel bir değerlendirme yaparsak, piyasaya sonradan giren firmaların bu anlamda değerinin daha düşük olduğunu görüyoruz.

[3] https://coinmarketcap.com/

Tablo 4. En Çok Yatırım Yapan Kripto Paralar

Piyasa Değerine Göre En Çok Yatırım Yapılan Kripto Paralar

Kripto para birimi	Jeton Sembolü	Piyasa Değeri
Bitcoin	BTC	827,42
Ethereum	ETH	272,32
USDT'yi Bağla	USDT	96,02
Binance Coin	BNB	46,05
Solana	SOL	42,23
Dalgalanma	XRP	28,58
ABD doları	ABD doları	26,15
Kardano	ADA	17,34
Çığ	AVAX	12,92
Dogecoin	DOGE	11,45

Kaynak: coinwire.com

3. KRİPTO PARA VE DİJİTAL PARA AYRIMI

Kripto ve dijital paralar, rakamsal olarak piyasada varlık gösteren fakat elle tutulmayan paralardır.

Dijital paralar bugün dolaşımdaki paraların yaklaşık %90'ını temsil etmektedir. İnternet bankacılığı veya bankanın mobil uygulaması aracılığıyla banka havalesi yaptığınızda, banka veya kredi kartlarınızdan (Paypal veya Google Cüzdan) bir ödeme gönderip, aldığınızda, esas itibariyle 'dijital para işlemi yapıyorsunuz' demektir. Kripto para ise, bir dijital para türüdür ama dijital paradan farklı olarak, kendisi bir para birimidir. En bilineni Bitcoin iken, Ethereum, Bitcoin Cash, Litecoin, Ripple ve IOTA gibi 1000'in üzerinde cinsleri vardır. Tüm dijital para birimleri belirli kuruluşlar ve kurumlar tarafından düzenlenir ve izlenir. Merkezidirler. Yani işlemler her saniye ülkelerin merkezi bankaları ve diğer tanınmış devlet kurumları gibi belirlenmiş kurumlar tarafından takip edilir. Arkalarında yasal çerçeve ve destek vardır. Dünya çapında geçerlidir. Kripto paralar ise merkezi olmayan, düzensiz ve değerini belirleyen bir kurum bulunmayan paralardır. Bunlar ilgili şifreleme topluluğu tarafından yönlendirilir. Arkalarındaki destek merkezi ya da hukuki değildir. Dünya çapında geçerli değillerdir. Ancak belli bir çerçeve kabul edilirler (Nebil, 2018:19-20).

3.1. Bitcoin'in Ortaya Çıkışı

2008 yılında Satoshi Nakamoto tarafından kaleme alınan "A Peer-to-Peer Elecronic Cash System" makalesi finansal ödemelerin kişiden kişiye elektronik para sistemi ile yapılabileceğini anlatmaktadır. Nakamoto (2008), finansal işlemlerde üçüncü bir güven sağlayıcı aracıya ihtiyaç duymadan kişilerin direkt birbiriyle işlem yapabileceği, kişilerarası güven sağlayıcı finansal merkezlere bağlı olmadan kriptografik kanıta dayanan elektronik sistemlerin daha fazla güvenilir olduğunu belirtmektedir. İşlemler zaman damgasının sağladığı şifreleme sistemi ile mükerrer işlem yapmaktan

oldukça uzaktır. Dolandırıcılık ihtimali düşmektedir. Hesaplar arası işlemlerde limit, sınır düzenlemeleri yoktur. Kişilerin karşılıklı dijital imzalarının birbirini doğrulaması ile para transferi gerçekleşmektedir (Nakamoto, 2008). Bu sistemin ürünü Bitcoin, blok zincir alt yapısına dayalı ilk kripto para birimidir. Bitcoin, Satoshi Nakamoto tarafından 2008'de icat edilmiş 3 Ocak 2009'da işlem yapılabilir hale getirilmiş olup toplamda 21 milyon adettir. Nakamoto, 10 Ocak tarihinde, Hal Finney'e Bitcoin göndererek ilk işlemi yapmıştır. Mayıs 2010'da Bitcoin ile alınan pizza, yapılan ilk alışveriştir. Bu alışverişle kripto paralarla yani dijital alan ile gerçek hayat arasındaki ilk ilişki kurulmuştur.

Bitcoin arzı 21 milyon adet ile sınırlıdır. Mart 2018 itibarıyla 16,9 milyon adedi ihraç edilmiştir. 2140 yılına kadar yeni bitcoin ihracı devam edecektir. Ancak sürekli azalarak ihraç edileceğinden 2035-40 yılı gibi tamamına yakını arz edilmiş olacaktır.

Bitcoin ihracı yeni blok üretilmesiyle gerçekleşir. Sistem her blok üreten madenciye, daha önce de belirttiğimiz üzere ödül verir. Bu ödül tutarı en başta 50 adet Bitcoin'di. Yaklaşık 4 yılda bir ödül miktarı yarıya inmektedir. 2020 Mayıs ayına kadar ödül tutarı 12,5 bitcoin olacak. Her 210.000 blok ihracından sonra (yaklaşık her 4 yılda bir) ödül tutarı yarıya inecektir. (Güven 2018:101)

Bitcoin 2008'de kendiliğinden ortaya çıkmadı (Swartz, 2018, s. 2). Bitcoin, doğuşu derinleşen ekonomik bir krizin buna bağlı olarak kurumlara olan güvenin erozyona uğraması ile eş zamanlı, güvenilmeyen üçüncü tarafı ortadan kaldırmak için ortaya çıktı. Bitcoin, teknolojik ilerlemenin sosyal ve politik durumların birleşmesinin bir ürünü ve sonucu olarak ortaya çıkmıştır. Kripto paraların yaptığı mülkiyet hakkında geleneksel sosyal yapılara ihtiyaç duymadan bir aktörden diğerine güvenli ve değişmez bir şekilde aktarabileceğinin güvenini vermektedir (Hayes, 2019, s. 4).

Bitcoin Para Mıdır?

Parayı tanımlayan klasik fonksiyonları vardır. Değer saklama, mübadele aracı olma gibi özelliklere sahiptir. Ancak Bitcoin bu özellikleri kapsamakla beraber; paranın kabul edilebilir olması, taşınabilir olması, bölünebilirlik, uzun ömürlü olması gibi özellikleri bünyesinde barındırır. Ancak değerinin istikrarlı olduğu söylenemez. Çok hızlı bir şekilde değerinde ani düşüş ve yükselmeler yaşanmaktadır.

Bitcoin'in Yeraltı Ekonomisi ile İlişkisinin Sorgulanması

Bitcoin'e getirilen ilk itirazlar ve eleştiriler, yeraltı ekonomisinde kullanılması ve takip edilememesidir. Bu durumla ilgili Vedat Güven kitabında şöyle der (Blokzincir - Kripto Paralar - Bitcoin: Satoshi Dünyayı Değiştiriyor: 2018;32-33) :

'Bitcoin işlemlerinin kaydedildiği Blokzincir'e bakarsanız, geçmiş tüm işlemlerin kaydedilmiş olduğunu görürsünüz. Dolayısıyla bir Bitcoin'in üretildiği andan şu ana kadar hangi hesaptan hangi hesaba aktarıldığını bire bir görebilirsiniz. Yani Bitcoin işlemleri şeffaf bir şekilde takip edilebilir. Burada kast edilen, hesap sahiplerinin kim olduğunun kolayca belli olmamasıdır. Bitcoin işlemleri

anonimdir. Yani işlemleri görmek ve takip etmek mümkündür ancak kimler tarafından yapıldığı ortada değildir.

'Bu özelliğinden dolayı kara para aklama veya yeraltı ekonomisinde kullanılıyor olması haklı bir sıkıntıdır. Silkroad isimli internet sitesi 2011 yılında kuruldu ve 2013 ile 2014'te iki kere kapatıldı. Bu sitede çeşit çeşit uyuşturucu, silah, kiralık katil, kopya kredi kartı, çocuk pornosu gibi her türlü illegal ürünü bulmak mümkün idi. İşlemlerde Bitcoin kullanılıyor olması Bitcoin'e leke çaldı. Ancak burada yanlış olan hizmetin kendisidir; Bitcoin kullanımı değil.'

Bir parayı kullanan kişiler, o parayı iyi ya da kötü amaçlarla kullanıyor olabilir. Burada anlatılmak istenen de Bitcoin, kayıt dışı ekonomide kullanılıyor diye bir para birimini yasaklamak doğal bir davranış değildir. Bu mantıki çerçeve dolar ya da euro açısından benzer sonuçlar doğurmuyorsa Bitcoin açısından da doğurmamalıdır. Kayıt dışı ekonominin dünyada çok büyük olduğu biliniyor. Dolar ve euro para birimiyle yapılıyorsa, doları ya da euroyu da yasaklayalım demek kadar olağandışı bir durumdur.

3.2. Kripto Para Transferi Nasıl Gerçekleşir?

Kripto para transferlerini (aslında paranın sahibinin değişmesidir) reel bir örnekle mantığını anlatalım. Örneğin İrem, Merve'ye para gönderecekse, ilk önce Merve'nin açık anahtarını öğrenir. 'Bu paranın yeni sahibi artık Merve'dir' yazar ve bu mesajı Merve'nin açık anahtarıyla kilitler. Burada aslında para transferi yapılmış olmuyor, paranın sahibi değişiyor. Merve de bu parayı mesela Seran'a göndermek isterse, ilk önce Seran'ın açık anahtarını öğrenir. Kendi özel anahtarı ile mesajın kilidini açar ve 'Bu para artık Seran'ındır' diye değiştirdiği mesajı yine Seran'ın açık anahtarı ile kilitler. Böylece paranın sahipliği Merve'den Seran'a geçmiş olur.

3.3. Banka ve Bitcoin İlişkisi

Bitcoin ve kripto paralarla ilgili kişiler, bugün işlem yaparken yine de büyük oranda banka ile işlem yapmak zorundalar (elden nakit alımlar hariç). Bitcoin'e sahip olmanın birkaç yolu var. Bitcoin direkt olarak parayla satın alınabilir, madencilik faaliyetlerinde kazanılabilir ya da Bitcoin borsalarında nakdi parayla takas gerçekleştirilebilir. Sonrasında da bu paralar borsa vasıtasıyla kullanıcıların banka hesaplarına yatırılır. Bitcoin satın almak için önce takas sitesinde hesap açmak ve o hesaba para yüklemek gerekir. Bu işlem de yine bankalar aracılığıyla yapılır.

Aralık 2024 itibariyle küresel olarak yaklaşık 33,628 Bitcoin ATM'sinden nakit para ile Bitcoin alınabilmekte veya yine nakit para karşılığında Bitcoin satılabilmektedir. [4]

Blokzincir (Blockchain)

Blokzincir teknolojisiyle; internet güvenliği uygulamaları, bankacılık uygulamaları, tedarik zinciri uygulamaları, sigortacılık uygulamaları, kişisel ve toplu ulaşım için geliştirilebilecek

[4] www.cointelegraph.com

uygulamalar, online veri saklama, vakıf ve bağış işlemleri, kamu uygulamaları, sağlık uygulamaları, enerji yönetimi, fikri mülkiyet ve telif hakkı uygulamaları, emlak ve tapu uygulamaları, akıllı şehirler, dijital kimlik, akıllı sözleşmeler ve hukuki yapılarının incelenmesi, eğitim uygulamaları konularında kullanım da mümkündür (Nguyen ve Dang, 2018: 484-485).

Blok zincir ve kripto paralar konuları, uluslararası akademik literatürde daha fazla çalışma yapılan bir konu haline gelmektedir. Web of Science'da blok zincir ve kripto para konularında sosyal bilimler alanında yapılan çalışmalar 2015-2020 yılları arasında 120 kat ve atıf sayısı 2.600 kat artmıştır. Blok zincir ve kripto para konulu yayınların en çok yapıldığı ülkeler finansal ve ekonomik olarak güçlü ülkelerdir. Blok zincir ve kripto para konularında sosyal bilimlerin alt disiplinlerinden işletme finansmanı ve ekonomi alanları en fazla çalışma yapan alanlardır (Çizmecioğlu ve Akman, 2021: 13). Blok zinciri ve kripto paralar konularında uluslararası literatürde çalışma yapan disiplinlerle Türkiye'de çalışma yapan disiplinler paralellik göstermektedir. Yine Web of Science verilerine göre kripto varlıklar alanında çalışma yapan ülke sayısı 72'dir. Türkiye, 12 yayınla yayın yapan ülkeler arasında 9. sırada yer almaktadır (Ancarlı, vd., 2023: 67).

Birçok kişi, blok zinciri ve finans teknolojisini, hizmet sunmaya yönelik yeni bir teknoloji olarak görüyor; CD-ROM'lara benzer bir şey gibi. Aslına bakarsanız bu, teknolojinin finans sistemi üzerindeki etkisi; internetin, medya ve reklam şirketleri üzerindeki etkisine benzeyecek. Ekonominin temelinde gerçekleşecek böylesine köklü bir değişim, bu sistemden geçinen yerleşik şirketler için ciddi sorun yaratacak. Bu değişime hazırlanmak, araştırma ve geliştirmeye yatırım yapmayı gerektiriyor. Bunu yapanlar, ortaya çıkmakta olan bu yeni finans sisteminde büyümeyi başarabilir (Ito, Narula ve Ali 2020: 70).

Blockchain'in en güçlü taraflarından biri merkezi bir sisteme bağlı olmaması, dağıtık yapıda çalışmasıdır. Birbirlerine direkt ve bir şebeke üzerinde bağlı bilgisayarlar aracılığıyla kesintisiz çalışır. Blockchain yapısında bilgisayarlar dağıtık bir yapı ile birbirlerine bağlıdırlar, kompleks bir yapı ile tek bir merkeze bağlı olmadıkları için sistem hatası, elektrik kesintisi veya siber saldırılar sonucu tamamen devre dışı kalmaları pek mümkün değildir (Özalp 2018:314)

Satoshi'ye Göre Mükerrer Harcamalar Nasıl Önlenir?

Elektronik paranın bir kişiden bir kişiye gerçekten gitmesini ve de doğru şekilde gitmesini dijital imzalarla sağlıyoruz.

Bir kişinin olmayan parasını göndermesini veya mevcut parasını iki kere gönderememesini ise her işlemde o hesabın bakiyesine değil de o paranın çıktığı hesaba, oraya nereden girdiğine, oraya da nereden girdiğine baka baka ilk üretildiği köke kadar kontrol ederek sağlıyoruz.

Bu amaçla kullanıcıların ve sistemin kendisinin, geçmişe yönelik tüm yapılan işlemleri görebilmelerini sağlıyoruz.

Bu işlemler blokların içerisine kaydediliyor ve blok doldukça yeni bir blok üretiliyor.

Her bloğun çıktısının parmak izi bir sonraki bloğun girdilerinden birisidir. Tüm blokları sırayla bu şekilde birbirlerine bağlıyoruz. Geçmişteki bir kaydın değiştirilmesi, silinmesi veya bir kayıt eklenmesi durumunda o bloğun çıktı parmak izi değişecektir.

Bir bloğun çıktı parmak izi değişince, sonraki bloğun girdilerinden birisi değişmiş olacağından, bu bloğun da çıktı parmak izi değişecektir ve bu durum zincirin en son bloğuna kadar devam edecektir.

Bu sebeple geçmişe yönelik her türlü müdahale aleni olacaktır.

Sistemde birbirinden farklı iki zincir olduğunda, hangi zincir uzunsa algoritmalar diğerini yani kısa olanını yok eder.

Her blok üretimi için yoğun bir iş yapılmaktadır (İş İspatı; PoW). Bloğun hesaplanacak olan çıktı parmak izi (özet değer) belli bir değerden küçük olsun şeklinde bir kıstas koyarak uygun özet değerin kolay bulunamaması ve bulunması için harcanacak sürenin 10 dakika olması hedeflenmektedir.

Böylece kötü niyetli bir madencinin yapmış olduğu değişiklik kaç blok öncesinde ise o kadar kalan blok sayısı kadar 10 dakikalık iş yapmak gerekecek. Bu esnada orijinal zincir daha da uzayacak. Kötü niyetli kullanıcı bir türlü orijinal zinciri yakalayıp da geçemeyecektir.

Kötü niyetli kullanıcının hesaplama gücü tüm sistemin hesaplama gücünün %51'inden fazla ise, kötü amaçlı terminal hedefine ulaşılabilir ve tüm sistemi göçertebilir.

Bu sayede geçmişe yönelik yapılacak bir değişikliğin işe yaramaması, mükerrer harcamanın engellenmesini sağlanmış olacaktır (Güven 2018: 95-96).

4. KRİPTO PARA VE DÜNYA GENELİNDE TÜRKİYE

Coinwire'in yaptığı araştırmaya göre; 'Kripto para ticaretinde Avrupa, küresel işlem hacminin %37,32'sini oluşturarak lider konumda. Türkiye ve Hindistan ise dünyada sırasıyla 2. ve 3. sırada yer alırken, her iki ülkenin ticaret hacmi 1 trilyon doları aşıyor. Binance, 136 ülkenin 100'ünde hakimiyet kurarak en çok kullanılan kripto para borsası olarak zirvede yer alıyor. Küresel kripto para ticaret hacmi, 2023'ten bu yana %42 oranında artarak önemli ölçüde arttı. Son üç yılda, pazar, dijital varlıkların küresel ölçekte artan kabulünü ve benimsenmesini yansıtarak etkileyici bir şekilde %89 oranında büyüdü. Avrupa, küresel kripto para birimi işlem değerinin %37,32'sini oluşturarak bu gelişen pazarda lider olarak ortaya çıktı. Avrupa, ilerici düzenleyici çerçeveler ve teknoloji meraklısı bir halk nedeniyle kripto inovasyonu ve yatırımı için bir merkezdir. Avrupa'nın hemen ardından Asya, dünya kripto para birimi işlem değerine %36,17 katkıda bulunarak ikinci sırada yer almaktadır. Yüksek mobil penetrasyon, sağlam bir teknoloji altyapısı ve artan kurumsal ilgi, bölgenin hızla benimsenmesine katkıda bulunan faktörlerdir.' (coinwire.com).

4.1. Kripto Para ve TCMB

Kripto paralar 2 ana noktada merkez bankaları ile karşı karşıya gelmektedir. Bunlardan ilki kripto paraların merkez bankaları tarafından piyasaya sürülen ve onların kontrolünde olan banknotun yerini alıp almayacağıdır. İkincisi ise bu paraların para politikası uygulamasında üstleneceği işlevdir. Kripto paraların bugüne kadarki gelişimine baktığımızda merkez bankasının klasik banknotunun taşıdığı (MBKB) tasarruf ve değişim aracı olma işlevini yerine getirdiğini görmekteyiz. (Çolak, 2018: 64).

Kripto paranın otorite, para ve toplum arasındaki ilişkilerin tarihteki en önemli bozulmayı yaşattığını düşünebiliriz (Cossu, 2022: 604). Blok zinciri teknolojinin amacı, parasal işlemleri denetlemek ve doğrulamak için aracılara veya banka veya devlet gibi üçüncü taraflara olan ihtiyacı ortadan kaldırmaktır (Lee, 2022: 4).

T.C. Merkez Bankası'nın 16 Nisan 2021'de Resmi Gazete'de de yayımlanan 'ÖDEMELERDE KRİPTO VARLIKLARIN KULLANILMAMASINA DAİR YÖNETMELİK'te 'Kripto varlıklar, ödemelerde doğrudan veya dolaylı şekilde kullanılamaz. Kripto varlıkların ödemelerde doğrudan veya dolaylı şekilde kullanılmasına yönelik hizmet sunulamaz,' denilmiştir.[5]

5. SONUÇ

Kripto ve dijital paralar, finans dünyasında devrim niteliğinde bir dönüşümü temsil etmektedir. Dijital paralar, mevcut finansal sistemlerin bir parçası olarak merkezi bir otoriteye bağlı, izlenebilir ve yasal çerçevede işlerken; kripto paralar merkeziyetsiz, anonim ve yenilikçi bir yapıya sahiptir. Bitcoin, bu yeni nesil para birimlerinin öncüsü olarak ekonomik krizlere ve güven erozyonuna bir tepki olarak ortaya çıkmıştır. Blokzincir teknolojisine dayalı yapısı, güvenlik, şeffaflık ve aracıya ihtiyaç duymayan işlemlerle finansal sistemde yeni bir paradigmaya işaret etmektedir.

Ancak Bitcoin'in hızlı değer dalgalanmaları, yeraltı ekonomisiyle ilişkilendirilmesi ve yasal düzenlemeler konusundaki belirsizlikler, bu yeniliğin önünde önemli zorluklar oluşturmaktadır. Bununla birlikte, Bitcoin ve diğer kripto paraların, geleneksel finansal araçlara alternatif sunması ve teknolojik altyapısıyla mülkiyet, transfer ve ödeme sistemlerini dönüştürme potansiyeli göz ardı edilemez.

Gelecekte, kripto paraların ve dijital finans teknolojilerinin nasıl bir yasal ve sosyal çerçeveye oturacağı, bu devrimin kalıcı etkilerini belirleyecektir. Şu anki tabloda, bu yeniliklerin riskleri ve fırsatlarının dengelenmesi, küresel finansal sistemin geleceğini şekillendirecek kritik bir süreç olarak karşımızda durmaktadır.

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[5] www.tcmb.gov.tr. İlgili yönetmelik 2021 yılında çıkmış, aynı yıl içinde Türkiye CoinTr'yi kurmuştur. Bugün halihazırda Merkez Bankası'nın yeni kripto para çalışmaları vardır.

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İSLAMİ FİNANS VE REEL EKONOMİK ÇIKTILAR: KAVRAMSAL BİR ÇERÇEVE VE ARAŞTIRMA GÜNDEMİ

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ÖZET

Bu çalışma, İslami finansın reel ekonomik çıktıları ne zaman ve nasıl etkilediğini açıklamaya yönelik mekanizma temelli bir çerçeve geliştirmektedir. Çalışma, İslami finansı homojen bir kurumsal etiket olarak ele almak yerine, kanonik sözleşmelerde içkin olan özellikler ile gerçek dünyadaki hukuki, bilgisel ve düzenleyici kısıtlar altında ortaya çıkan uygulama-denge çıktılarını birbirinden ayırmaktadır. İslami finans yazınını; finans, sözleşmeler, finansal içerme ve etik yatırımın daha geniş iktisadıyla birleştiren ve önemli ölçüde genişletilmiş bir literatür temeline dayanan çalışma, beş temel aktarım kanalı tanımlamaktadır: risk paylaşımı, varlığa dayalılık ve maddilik, devredilmiş izleme ve yönetişim, finansal içerme ve etik ya da sürdürülebilirlik odaklı sermaye tahsisi. İslami finans; dayanıklılığı güçlendirebilir, erişimi genişletebilir, yatırım kalitesini artırabilir ve finansı üretken faaliyetle daha yakından ilişkilendirebilir; ancak bu etkiler sözleşme bileşimine, kurumsal kaliteye, Şer'i yönetişime, hukuki uygulanabilirliğe, likidite altyapılarına ve uygulamanın biçimden ziyade özü ne ölçüde yansıttığına bağlıdır. Çalışma ayrıca sukuk, kurumsal ve Şer'i yönetişim, devredilmiş ticari risk, yeşil ve sürdürülebilirlik sukuku ile İslami finans ve Sürdürülebilir Kalkınma Amaçları arasındaki ilişkiye dair daha güncel tartışmaları da kapsamaktadır. Sonuç bölümündeki araştırma gündemi, yalnızca kurum düzeyindeki İslami etiketlere dayanmak yerine sözleşmesel öze odaklanan test edilebilir hipotezler, ölçüm stratejileri ve ampirik tasarımlar önermektedir.

Anahtar Kelimeler: *İslami Finans, İslami Bankacılık, Sukuk, Risk Paylaşımı, Finansal İçerme, Şer'i Yönetişim, Reel Ekonomi, Ekonomik Büyüme.*

Jel KODLARI: *G21, G23, E44, O16, Z12.*

ISLAMIC FINANCE AND REAL ECONOMIC OUTCOMES: A CONCEPTUAL FRAMEWORK AND RESEARCH AGENDA

ABSTRACT

The paper develops a mechanism-based framework for explaining when and how Islamic finance affects real economic outcomes. Rather than treating Islamic finance as a homogeneous institutional label, the paper distinguishes between features embedded in canonical contracts and implementation-equilibrium outcomes generated under real-world legal, informational, and regulatory constraints.

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Building on a substantially expanded literature base that combines Islamic finance scholarship with the broader economics of finance, contracts, inclusion, and ethical investing, the paper identifies five principal transmission channels: risk sharing, asset-backing and materiality, delegated monitoring and governance, financial inclusion, and ethical or sustainability-oriented capital allocation. Islamic finance can strengthen resilience, widen access, improve investment quality, and align finance more closely with productive activity, but these effects depend on contract composition, institutional quality, Shariah governance, legal enforceability, liquidity infrastructures, and the extent to which practice reflects substance rather than form. The paper also incorporates more recent debates on sukuk, corporate and Shariah governance, displaced commercial risk, green and sustainability sukuk, and the relation between Islamic finance and the Sustainable Development Goals. The concluding research agenda proposes testable hypotheses, measurement strategies, and empirical designs centered on contractual substance, rather than relying on institution-level Islamic labels alone.

Keywords: *Islamic Finance, Islamic Banking, Sukuk, Risk Sharing, Financial Inclusion, Shariah Governance, Real Economy, Economic Growth.*

JEL Codes: G21, G23, E44, O16, Z12.

1. INTRODUCTION

Islamic finance is often introduced as interest-free finance, but that description is analytically insufficient for evaluating its economic consequences. The more consequential question is whether the contractual, governance, and allocative features associated with Islamic finance alter the way savings are mobilized, risks are distributed, investments are selected, and shocks are absorbed. A large empirical literature compares Islamic and conventional institutions in terms of profitability, efficiency, asset quality, market power, stability, and crisis performance, yet many studies still treat "Islamicness" as a bank label rather than as an observable bundle of contractual mechanisms (Beck et al., 2013; Abedifar et al., 2013; Hassan & Aliyu, 2018; Grira & Labidi, 2021).

This paper argues that the core research problem is not simply whether Islamic finance is "better" or "worse" than conventional finance. The central analytical question is therefore not whether Islamic finance is inherently superior or inferior to conventional finance, but under which institutional and contractual conditions it can generate distinctive real-sector outcomes. That question requires a framework linking principles, instruments, intermediate financial mechanisms, and macro or developmental outcomes. It also requires explicit recognition of the persistent gap between normative theory and prevailing practice, a gap emphasized by Aggarwal and Yousef (2000), El-Gamal (2006), Khan (2010), Miah and Suzuki (2020), and several IMF and IFSB reports (Lopez-Mejia et al., 2014; Kammer et al., 2015; Islamic Financial Services Board, 2025).

The revised contribution of this paper is fourfold. First, it reconstructs the paper around clearer principles-to-outcomes architecture. Second, it embeds Islamic finance in the wider economics of

contracts, intermediation, financial development, and ethical investing, drawing on canonical contributions by Stiglitz and Weiss (1981), Diamond (1984), Hart and Moore (1994), Hart (1995), Levine (1997, 2005), Beck et al. (2007), and Renneboog et al. (2008). Third, it substantially expands the literature coverage on sukuk, corporate and Shariah governance, competition, displaced commercial risk, and sustainability-linked Islamic finance. Fourth, it reformulates the research agenda around measurable institutional substance rather than formal classification alone.

2. LITERATURE AND ANALYTICAL FOUNDATIONS

The modern Islamic finance literature emerged from a normative project that sought to align financial intermediation with Islamic legal and ethical commitments. Foundational texts emphasized the prohibition of riba, the discouragement of gharar and maysir, the requirement that finance be tied to lawful economic activity, and the desirability of risk-sharing arrangements such as mudarabah and musharakah (Usmani, 2021; Vogel & Hayes, 1998; El-Gamal, 2006). Within that normative tradition, finance is expected to serve the real economy, restrain exploitative contractual forms, and support social justice through fairer distributions of risk and return.

Yet early analytical work also showed why actual intermediation might drift away from pure profit-and-loss sharing. Aggarwal and Yousef (2000) formalized the incentive problems associated with investment financing under asymmetric information. Mirakhor and Zaidi (2007) clarified the logic of PLS contracts, but the broader economics literature suggests why these contracts are hard to scale in banking systems characterized by monitoring costs, moral hazard, weak disclosure, and incomplete enforcement (Stiglitz & Weiss, 1981; Diamond, 1984; Holmstrom & Tirole, 1997). This tension helps explain why debt-like instruments have dominated practice in many jurisdictions.

Subsequent scholarship gradually moved from doctrinal exposition to empirical assessment. Comparative studies evaluated Islamic banks' profitability, capitalization, efficiency, competition, and resilience (Čihák & Hesse, 2010; Beck et al., 2013; Khediri et al., 2015; Weill, 2011; Alharbi, 2017). Macro-level work examined whether Islamic banking development is associated with banking deepening, macroeconomic efficiency, financial inclusion, and growth (Gheeraert, 2014; Gheeraert & Weill, 2015; Imam & Kpodar, 2016; Hachicha & Ben Amar, 2015). At the same time, critical voices continued to emphasize the possibility that contemporary Islamic finance may reproduce conventional risk transfer under Shariah-compliant legal packaging rather than transform the underlying economic logic (Kuran, 2004; El-Gamal, 2006; Khan, 2010).

The current state of the literature therefore requires synthesis rather than another binary comparison. The key analytical task is to separate design-intent claims from implementation-equilibrium outcomes and then identify the institutional moderators that determine which one dominates in practice.

3. TRANSMISSION CHANNELS FROM ISLAMIC FINANCE TO REAL ECONOMY

At the level of design intent, Islamic finance contains several features that could matter economically. The first is state-contingent risk sharing. In principle, PLS contracts convert fixed debt claims into contingent claims linked to project outcomes, with implications for leverage, default dynamics, and the allocation of downside risk (Mirakhor & Zaidi, 2007). The second is materiality or real-asset linkage. By requiring transactions to be connected to identifiable assets or genuine trade, Islamic finance seeks to limit purely notional or excessively leveraged claims (Usmani, 2021; Kammer et al., 2015). The third is screening. Islamic investment constraints exclude certain sectors and often impose leverage and liquidity filters, which can alter portfolio composition, factor exposures, and the distribution of capital across activities (Derigs & Marzban, 2008, 2009). The fourth is governance. Because Shariah compliance introduces an additional layer of oversight, Islamic institutions face an expanded governance structure involving boards, Shariah supervisory boards, auditors, and standard setters (Grais & Pellegrini, 2006; Mollah et al., 2017; Safiullah & Shamsuddin, 2018).

These design features suggest several potential channels from Islamic finance to the real economy. Finance theory identifies risk pooling, savings mobilization, monitoring, and resource allocation as the central functions through which finance affects growth and welfare (Bodie & Merton, 2000; Levine, 1997, 2005). If Islamic finance meaningfully changes these functions, then it can plausibly influence real outcomes. If, however, the same functions are reproduced through economically debt-like claims benchmarked to conventional rates, then large differences should not be expected.

This distinction is analytically central. The right object of analysis is not the institutional label but the economic content of the claims being created. That is why a mechanism-based approach is superior to a label-based one. A bank can be formally Islamic while relying overwhelmingly on short-term murabaha, limited risk sharing, weak asset transfer, and conventional benchmarks. Conversely, a narrower but more substantively risk-sharing and asset-linked segment may have more distinctive real effects than a much larger formally Islamic sector dominated by replication.

3.1. Risk-sharing Mechanisms

The most distinctive theoretical claim associated with Islamic finance is that replacing fixed obligations with state-contingent claims can reduce leverage-driven fragility. In conventional contract theory, debt disciplines borrowers but also creates threshold effects, liquidation pressure, and insolvency externalities when projects underperform (Hart & Moore, 1994; Williamson, 1988). A system with a larger role for equity-like or partnership contracts should, in principle, distribute shocks more smoothly and lower the probability that modest cash-flow disruptions trigger defaults, fire sales, or credit crunches.

Islamic finance theory therefore places substantial weight on mudarabah and musharakah as superior modes of financing. Mirakhor and Zaidi (2007) and Hussain et al. (2016) link this architecture

to broader claims about resilience and stability. Empirical studies partly support the expectation that Islamic banks can exhibit lower credit risk or stronger capitalization in some settings. Čihák and Hesse (2010) find that small Islamic banks appear financially stronger than comparable conventional banks in several environments. Beck et al. (2013) document higher capital-asset ratios and better asset quality for Islamic banks on average. Abedifar et al. (2013) similarly find lower credit risk among small Islamic banks, especially in countries with predominantly Muslim populations.

However, these findings do not automatically validate the full risk-sharing thesis. They may instead reflect conservative balance-sheet structures, customer behavior, or selection effects rather than a deep prevalence of PLS contracts. Miah and Suzuki (2020) show how the "murabaha syndrome" emerges as a structural equilibrium response: banks, depositors, and regulators often prefer debt-like forms because they are easier to price, monitor, standardize, and defend in legal disputes. Khan (2010) makes the broader critique that much of the industry remains economically close to conventional finance despite distinct terminology and formal constraints.

The implication is that the risk-sharing channel is best treated as conditional. Its expected macro benefits are strongest when contract composition meaningfully shifts toward contingent claims and when accounting, disclosure, investor protection, and adjudication systems are strong enough to make those claims enforceable. Without those complements, the risk-sharing promise may remain primarily aspirational.

3.2. Asset-backing and Materiality

A second major claim is that Islamic finance ties finance more closely to real activity. In theory, asset-backing or transaction-backing imposes discipline on credit creation, constrains excessive leverage-on-leverage structures, and anchors financing in identifiable economic transactions (Usmani, 2021; Kammer et al., 2015). If genuine, this should improve investment quality by limiting speculative expansion detached from underlying productive assets.

The distinction between asset-based and asset-backed structures is central here. Policy reports repeatedly note that many Islamic financial instruments, especially in capital markets, do not necessarily confer robust claim rights over underlying assets in a bankruptcy-relevant sense (Lopez-Mejia et al., 2014; Hussain et al., 2016). The legal architecture of transfer, recourse, beneficial ownership, and insolvency treatment matters. A transaction may reference an asset while still leaving the economic risk profile close to an unsecured or conventionally benchmarked claim.

This debate is particularly visible in sukuk literature. Zulkhibri (2015) reviews the operational and legal diversity of sukuk structures and emphasizes the gap between theoretical distinctiveness and practical heterogeneity. Godlewski et al. (2013) and Alam et al. (2013) show that capital-market reactions to sukuk differ from those to conventional bond issuance, suggesting that investors do not treat all sukuk as exact substitutes. Said and Grassa (2013), Smaoui and Nechi (2017), and Smaoui et al.

(2020) further indicate that sukuk market development can influence market structure, growth, and bank risk in non-trivial ways.

From a real-economy perspective, the materiality channel is likely to operate through investment quality rather than quantity alone. When financing is credibly linked to real assets, project appraisal, collateral discipline, and monitoring may improve. But if asset references are largely formal and legal claims remain weak, then materiality can become symbolic rather than economically transformative. Future work should therefore measure enforceable asset linkage rather than simply classify instruments by nominal structure.

3.3. Governance and Delegated Monitoring

A third channel concerns monitoring and governance. Islamic finance potentially changes not only contractual payoffs but also the internal governance architecture of financial institutions. In addition to conventional boards and regulators, Islamic banks and funds rely on Shariah supervisory boards or comparable compliance mechanisms. In principle, this extra layer can improve monitoring by scrutinizing contract design, disclosure, and admissibility. It may also create reputational capital that strengthens trust among customers who would otherwise remain outside the formal system (Grais & Pellegrini, 2006; Mollah et al., 2017).

The governance evidence is mixed but important. Mollah et al. (2017) find that the governance structure of Islamic banks has distinct implications for risk-taking and performance relative to conventional banks. Safiullah and Shamsuddin (2018) show that Islamic banks differ from conventional banks across several risk dimensions and that Shariah supervisory board characteristics matter for insolvency and operational risk. More recent work also points to the importance of board design, advisory-board characteristics, and corporate-governance arrangements in shaping bank performance and risk behavior (Aslam & Haron, 2021; Haddad & Souissi, 2022; Nomran et al., 2018).

Governance, however, can also add complexity and coordination costs. Multiple approval layers may slow innovation, increase compliance costs, or create interpretive fragmentation across jurisdictions. Differences between centralized and decentralized Shariah governance regimes matter greatly. Malaysia's relatively standardized governance environment, for example, differs from more fragmented systems in which institutional boards issue divergent rulings. These differences affect contract standardization, dispute resolution, market depth, and investor confidence (Krasicka & Nowak, 2012; Lopez-Mejia et al., 2014; Islamic Financial Services Board, 2006, 2024).

The real-economy implication is straightforward: where Shariah governance is credible, professional, and integrated into broader prudential oversight, it can reinforce trust, reduce ambiguity, and improve screening. Where it is weak, fragmented, or performative, it may raise form-compliance costs without materially improving investment decisions.

3.4. Financial Inclusion and Savings Mobilization

Islamic finance may also matter by serving populations and firms that are voluntarily excluded from conventional finance for religious reasons. This inclusion channel is among the most policy-relevant and empirically plausible mechanisms. Demirguc-Kunt et al. (2014) use global survey evidence to show that Muslim adults are less likely, on average, to hold formal accounts and that religion is a non-trivial stated reason for exclusion in several countries. Naceur et al. (2017) argue that Islamic banking can therefore act as an avenue for financial inclusion in OIC economies, while Imam and Kpodar (2016) identify improved access to deposits as one of the main channels through which Islamic banking supports growth.

The inclusion argument has two distinct layers. The first is extensive margin inclusion: bringing previously excluded households into formal savings, payments, and deposit systems. The second is productive inclusion: expanding access to working capital, trade finance, and investment finance for SMEs and entrepreneurs. These layers should not be conflated. A system may attract deposits from faith-excluded savers without necessarily translating those deposits into productive and inclusive financing.

Evidence on SMEs is particularly relevant because Islamic banking is often claimed to be relationship-oriented and better aligned with small-firm financing. Aysan et al. (2016) find that participation banks in Turkey are more inclined toward SME financing than conventional banks, with comparable portfolio quality. Wajdi Dusuki (2008) similarly emphasizes the potential interface between Islamic banking and microfinance. Yet this positive narrative again depends on product design. If SME financing is dominated by short-term trade-based contracts with high collateral expectations, inclusion may increase at the deposit margin while remaining limited at the entrepreneurial margin.

The inclusion channel should therefore be modeled as a joint function of religious compatibility, product affordability, transparency, and institutional trust. Where these conditions are met, Islamic finance can mobilize dormant savings, widen formal participation, and support capital accumulation. Where they are absent, the mere availability of Islamic products may not generate large real effects.

3.5. Ethical Screening and Sustainability Allocation

Islamic finance also differs from conventional finance through negative screening and, increasingly, through sustainability-oriented allocation. The screening component excludes activities deemed impermissible and often applies leverage, receivables, and liquidity screens in capital markets. In economic terms, this changes the investable universe and can affect diversification, cost of capital, and the sectoral distribution of funding (Derigs & Marzban, 2008, 2009).

This channel resembles, but is not identical to, the broader literature on socially responsible investment. Renneboog et al. (2008), Statman (2000), Bollen (2007), and Hong and Kacperczyk (2009) show that values-based screening can change investor demand, expected returns, and pricing in

predictable ways. Islamic screening differs because it combines moral exclusion with contract-form restrictions and balance-sheet filters. As a result, its real effects depend on how strongly it shifts capital away from highly leveraged or harmful sectors and whether the remaining universe provides adequate diversification.

Recent work on sustainable and green sukuk adds a further dimension. Green and sustainability sukuk seek to combine Shariah-compliant structuring with earmarking for environmental or social projects. Institutional evidence suggests this segment is growing and becoming more standardized (International Capital Market Association et al., 2024; London Stock Exchange Group, 2024; Bennett & Coyle, 2025). Review studies also indicate that green sukuk has become a bridge between Islamic finance and ESG or SDG agendas, though the academic literature remains fragmented (Harahap et al., 2023; Alkadi, 2024; Lee et al., 2025).

The key analytical point is that ethical screening does not automatically lower risk or improve welfare. It changes exposures. Excluding certain sectors may reduce some tail risks while increasing concentration elsewhere. The sustainability branch of Islamic finance therefore raises an empirical question rather than settling it in advance: do green and sustainability sukuk expand productive financing for transition, infrastructure, and climate adaptation in ways that are additional, scalable, and credibly monitored?

4. INSTITUTIONAL CONSTRAINTS AND IMPLEMENTATION EQUILIBRIUM

4.1. Divergence between Theory and Practice

A central theme running through the literature is the divergence between Islamic finance in theory and Islamic finance in practice. That divergence is not an accident; it is often an equilibrium outcome. Contract choice reflects the interaction among customer preferences, bank incentives, accounting rules, supervisory expectations, tax treatment, legal enforceability, benchmark pricing, and liquidity management constraints. If debt-like forms minimize information problems and fit existing regulatory templates, they will tend to dominate even in systems that normatively value PLS.

This helps explain the persistence of murabaha-heavy balance sheets documented by Miah and Suzuki (2020) and the broader skepticism voiced by El-Gamal (2006), Khan (2010), and Kuran (2004). It also explains why some comparative studies find only modest or mixed differences between Islamic and conventional institutions despite strong normative claims. In many systems, Islamic banks compete in dual-banking environments against entrenched conventional institutions, face the same depositor expectations for smooth returns, and benchmark pricing to conventional reference rates. The result is an incentive structure that compresses functional differences.

4.2. Liquidity Constraints and Financial Infrastructure

Two additional factors intensify the implementation problem. The first is liquidity management. Islamic banks operate under constraints arising from the relative scarcity, uneven availability, or shallow trading depth of Shariah-compliant liquidity instruments. IMF and IFSB reports repeatedly identify this as a structural bottleneck with implications for monetary transmission, risk management, and balance-sheet strategy (Lopez-Mejia et al., 2014; Hussain et al., 2016; Kammer et al., 2015; Islamic Financial Services Board, 2023). The second is displaced commercial risk, whereby banks under competitive pressure smooth returns to investment account holders to prevent withdrawals, thereby muting the intended risk-sharing properties on the liability side (Rouetbi et al., 2023).

Once these constraints are recognized, the research agenda becomes clearer. Rather than assuming intrinsic superiority, research should focus on identifying the institutional reforms, governance arrangements, and financial infrastructures that enable Islamic finance to realize its distinctive design features.

The macroeconomic literature offers qualified support for the proposition that Islamic finance can matter for development. Gheeraert (2014) finds that the expansion of Islamic banking is associated with broader banking-sector development rather than merely displacing conventional banks. Gheeraert and Weill (2015) report that Islamic banking development is associated with macroeconomic efficiency, though the relation appears nonlinear. Imam and Kpodar (2016) find that Islamic banking supports growth mainly through capital accumulation and improved financial inclusion, while Hachicha and Ben Amar (2015) identify positive effects in the Malaysian case.

These findings are important but must be interpreted carefully. Growth regressions and cross-country panels remain vulnerable to omitted institutional differences, measurement problems, and the challenge of isolating whether observed effects stem from Islamic finance itself or from correlated reforms, resource endowments, or broader financial deepening. The strongest conclusion that can be sustained from the current literature is not that Islamic finance universally raises growth, but that it can do so under supportive institutional and compositional conditions.

The stability literature points in a similar direction. Hasan and Dridi (2011), Farooq and Zaheer (2015), Beck et al. (2013), and Abedifar et al. (2013) all identify channels through which Islamic banks may display resilience during stress, including lower deposit flight, stronger capitalization, different asset exposure, and behavioral trust effects. Loan-level evidence from Pakistan also suggests that religious identity and social-network enforcement can affect repayment outcomes (Baele et al., 2014). Yet not all comparative studies point in the same direction, and some differences appear to be strongest for small banks, specific countries, or crisis sub-periods.

For a paper focused on real economic outcomes, the correct inference is therefore conditional heterogeneity. Islamic finance can support growth, intermediation, and stability, but not uniformly and not independently of governance, legal structure, and contractual substance.

5. CAPITAL MARKETS AND SUSTAINABILITY

5.1. Sukuk and Real-sector Investment

Sukuk deserve separate treatment because they provide a bridge between banking, capital-market development, and long-horizon investment. In theory, sukuk can widen the financing base for infrastructure and corporate investment while preserving Shariah-compliant structures. This makes them particularly relevant for public investment, project finance, and the mobilization of long-term savings.

The literature suggests at least three real-economic pathways. First, sukuk can deepen domestic capital markets by broadening instrument diversity and attracting investors who avoid conventional debt. Second, they can support large fixed-capital projects that exceed the practical scope of bank intermediation. Third, they can reinforce credibility where legal structures align economic claims with identifiable assets and cash flows. Smaoui and Nechi (2017) provide cross-country evidence that sukuk market development is associated with economic growth. Zulkhibri (2015) synthesizes theoretical and empirical literature and emphasizes the need to move beyond descriptive work toward stronger identification. Smaoui et al. (2020) and Mimouni et al. (2019) show that sukuk-market development can affect bank performance and risk, implying system-wide interactions rather than isolated capital-market effects.

At the same time, the sukuk literature illustrates the broader substance-versus-form dilemma. Different structures vary considerably in recourse, tradability, ownership transfer, and bankruptcy implications. Consequently, not all sukuk have the same developmental content. Future empirical work should therefore disaggregate sovereign from corporate sukuk, domestic from international issuance, and green or social from conventional sukuk. It should also distinguish whether proceeds finance new productive assets, refinance existing liabilities, or primarily serve treasury management purposes.

5.2. Islamic Finance and Sustainable Development

A growing literature reconnects Islamic finance with broader developmental objectives through maqasid al-Shari'ah, shared prosperity, and the Sustainable Development Goals. The World Bank and Islamic Development Bank Group (2016) present Islamic finance as a possible catalyst for shared prosperity, while OECD (2020) highlights its relevance to development finance. More recent reviews explicitly connect Islamic finance to sustainability frameworks, green investment, and social outcomes (Harahap et al., 2023; Slamet, 2020; Alkadi, 2024).

This line of work is valuable because it broadens the assessment beyond narrow bank performance measures. If Islamic finance is evaluated only by profitability or market share, its distinct normative ambitions are lost. A more appropriate framework also asks whether Islamic finance supports inclusive investment, environmental stewardship, social risk-sharing, and distributive fairness. The maqasid

literature and the sustainability turn both point in this direction, although much of the work remains conceptual or bibliometric rather than causal and measurement rich.

The main challenge is operationalization. Researchers need credible indicators for welfare-relevant outcomes: SME access, resilience of vulnerable households, infrastructure quality, climate-finance additionality, and the distribution of risk between capital providers and entrepreneurs. Without such measures, claims that Islamic finance advances maqasid or SDGs remain normatively attractive but empirically under-specified. The next generation of research should therefore connect moral objectives to measurable institutional and developmental outcomes.

6. CONCEPTUAL FRAMEWORK

6.1. A Mechanism-based Conceptual Framework

The literature reviewed above supports a layered framework:

Principles -> contract design -> balance-sheet composition -> intermediate mechanisms -> real outcomes. (1)

At the principles layer, Islamic finance imposes restrictions and positive obligations concerning riba, gharar, maysir, lawful activity, and real-activity linkage. At the contract-design layer, these principles are translated into debt-like trade or lease structures, equity-like PLS contracts, investment-account arrangements, and a range of sukuk structures. At the balance-sheet layer, actual practice determines the mix between murabaha-style financing, participatory contracts, fee-based services, liquidity buffers, and capital-market exposure. At the intermediate-mechanism layer, this mix shapes leverage, screening, monitoring, withdrawal behavior, competition, and governance. Only then, at the final layer, do observable real outcomes emerge: growth, inclusion, resilience, investment quality, and sectoral allocation.

This framework has two analytical advantages. First, it makes room for heterogeneity. Two countries with similar Islamic-banking market shares can generate different outcomes if their contract mix, governance quality, legal infrastructure, and capital-market depth differ. Second, it clarifies what should be measured. Many empirical papers use aggregate Islamic-bank assets or market share as the key regressor. Those indicators are useful but insufficient. Better measures would include the PLS share of assets and liabilities, the legal robustness of asset transfer, the structure and authority of Shariah boards, the depth of sukuk markets, the availability of Islamic liquidity instruments, and the degree of benchmark dependence on conventional rates.

In short, the decisive variable is not formal identity but economic substance. That principle should organize future research.

6.2. Testable Hypotheses

A more rigorous research agenda should begin with measurement before causality. Four measurement priorities are especially important. First, risk-sharing intensity should be captured directly through contract composition on both asset and liability sides. Second, materiality should be measured through enforceable asset linkage rather than nominal reference to assets. Third, Shariah governance should be operationalized through authority, board composition, centralization, and standard adoption. Fourth, inclusion should distinguish deposit outreach from productive financing outreach.

With these measures in hand, several testable hypotheses follow.

Hypothesis 1: Higher substantive PLS intensity is associated with lower crisis sensitivity and smoother credit adjustment, but only where legal enforcement, disclosure quality, and accounting transparency are strong.

Hypothesis 2: Islamic finance improves growth primarily through inclusion and capital accumulation rather than through generic financial deepening alone. This effect should be stronger in environments with larger populations that are voluntarily excluded from conventional finance.

Hypothesis 3: Genuine asset-backed or strongly transaction-linked financing is associated with better investment quality and lower volatility than economically equivalent but formally compliant structures.

Hypothesis 4: Stronger Shariah governance and greater standardization increase the real effectiveness of Islamic finance by reducing legal ambiguity, compliance uncertainty, and reputational fragility.

Hypothesis 5: Sukuk-market development raises productive investment only when issuance is linked to new investment projects or infrastructure formation rather than refinancing alone.

Hypothesis 6: Ethical and sustainability-oriented Islamic instruments alter capital allocation in ways that can reduce some tail risks but may also generate concentration effects; the net effect is therefore empirical and should be studied at the portfolio and sector levels.

Methodologically, the most promising designs include regulatory discontinuities, staggered adoption of centralized Shariah governance, branch-level comparisons within dual-banking systems, loan-level repayment and pricing analyses, and issue-level sukuk datasets linked to post-issuance investment outcomes. Difference-in-differences designs around reforms, combined with contract-level data, are especially important because they move the literature away from institution labels and toward mechanism identification.

7. CONCLUSION

Islamic finance can influence real economic outcomes, but not by virtue of label alone. Its potential distinctiveness lies in a set of mechanisms - risk sharing, materiality, governance, inclusion,

and ethical allocation - that may alter the way finance interacts with production, investment, and risk. Whether those mechanisms are activated in practice depends on contract composition, legal enforceability, liquidity infrastructures, governance quality, and the competitive environment in which institutions operate.

The most important implication of this analysis is therefore methodological as much as substantive. Future research should stop asking whether Islamic finance, in the abstract, is growth-enhancing, stable, inclusive, or ethical. Instead, it should ask which Islamic financial arrangements, operating under which institutional conditions, generate which real outcomes through which mechanisms. That reframing preserves the normative ambitions of Islamic finance while subjecting them to disciplined empirical scrutiny.

If literature advances in that direction, the debate can move beyond broad claims and counterclaims. Islamic finance will then be evaluated neither as a rhetorical ideal nor as a simple legal variant of conventional finance, but as a heterogeneous institutional field whose developmental effects depend on measurable structures and choices.

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THE IMPACT OF TRADE OPENNESS ON GOVERNMENT SIZE: TESTING THE COMPENSATION AND EFFICIENCY HYPOTHESES IN KYRGYZSTAN

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ABSTRACT

Globalization, with its economic, political, and social dimensions, makes the integration of countries into the international system inevitable. This process also gives rise to economic risks. Trade openness can make a country's economy vulnerable to external shocks. For developing countries, especially the smaller countries that broke away from the Soviet bloc, overcoming the obstacle is challenging. The tendency to increase public spending and the overall size of the public sector to limit the economic risks arising from trade openness is referred to in the literature as the compensation hypothesis. Conversely, the view that trade openness leads to a contraction of the public sector by increasing competitive pressure is referred to as the efficiency hypothesis. This study examines the influence of trade openness on government size in Kyrgyzstan from 1990 to 2024. The Fourier Autoregressive Distributive Lag cointegration test is applied by including economic growth as a control variable. The findings indicate that the variables are cointegrated. In the long run, increased trade openness is associated with a rise in government size, while economic growth tends to reduce it. An increase of 1% in trade openness leads to a 0.28% expansion in the public sector, whereas a 1% increase in growth results in a 0.21% contraction. In conclusion, the compensation hypothesis is found to be valid for the Kyrgyz economy, while the efficiency hypothesis is not supported.

Keywords: *Compensation Hypothesis, Efficiency Hypothesis, Government Size, Trade Openness.*

JEL Codes: *C12, F14, H11.*

1. INTRODUCTION

In the aftermath of the Soviet Union’s collapse, belief in communism largely disappeared, and the world transitioned from a bipolar to a unipolar system. This development has had numerous political and social consequences and has also led to an increase in trade between countries. Kyrgyzstan, one of the countries that broke away from the Eastern Bloc, saw its foreign trade volume's share of its gross domestic product rise from 72% in the early 1990s to 99% at the end of the 1990s, and reach a peak of 146% in 2008 (World Bank, 2026).

Cameron (1978) stated that the degree of openness of the economy to international markets is one of five factors explaining the growth in the scope of government activities. This study found that countries with high foreign trade volumes, such as the Netherlands, Denmark, Norway, and Sweden,

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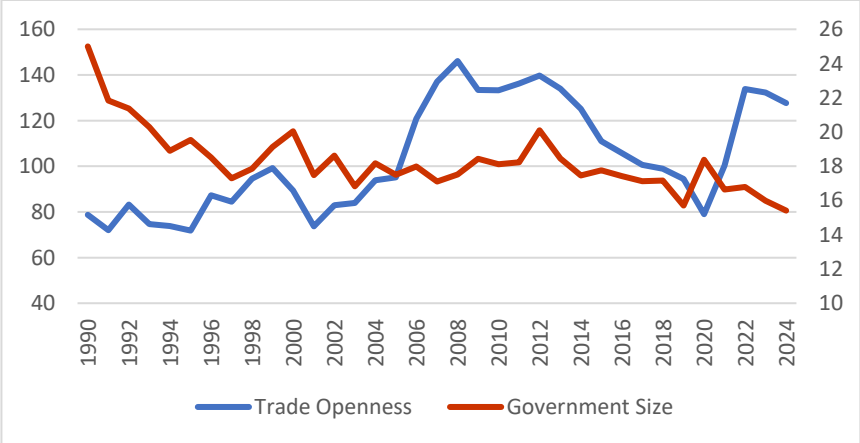
also have high government revenues. In contrast, countries with low foreign trade volumes, such as the United States, Japan, Italy, Spain, Australia, Germany, and France, also have low government revenues. This approach, known as the compensation hypothesis, argues that greater economic openness promotes industrialization, which in turn generates a range of economic and political dynamics that contribute to the expansion of the public sector. Rodrik (1998) empirically tested this hypothesis and concluded that it is valid. Faced with the economic risks and uncertainties created by increasing international trade, the state is trying to protect society by expanding social security, income transfers, and welfare programs.

On the other hand, according to Schulze and Ursprung (1999), increasing openness creates a competitive environment that forces governments to lower tax rates to attract capital. This, along with globalization, tends to reduce the size of the public sector by limiting public revenues. This approach, which posits an inverse relationship between trade openness and the size of the public sector, is known as the efficiency hypothesis. This hypothesis, in contrast to the compensation hypothesis, is a supply-side rather than a demand-side approach.

Trade liberalization is part of globalization, and it's very difficult to resist it. Genschel (2004) addressed the relationship between globalization and the welfare state and examined three different approaches: Globalization theory, globalization skeptics, and revisionism. The first approach argues that globalization weakens the welfare state, the second approach denies the impact of globalization, and the third approach defines globalization as both a consequence and part of the solution to the problems of the welfare state. The effects of globalization are thought to vary depending on countries, periods, and institutional conditions.

Kyrgyzstan, one of the four independent Turkic republics in Central Asia, like Kazakhstan, exhibits a more open trade structure compared to Turkmenistan and Uzbekistan. The country has implemented trade reforms through privatization and business restructuring, reduced trade barriers to increase trade volume, supported international integration, and sought to lower trade costs (Mazhikeyev et al., 2015).

Figure 1. Trade Openness and Government Size in Kyrgyzstan



Source: World Bank (2026)

Figure 1 shows the trends in trade openness and public sector size in Kyrgyzstan. Trade openness remained largely unchanged during the 1990s. However, it increased rapidly in the 2000s, peaking in 2008. Although it began to decline after the global financial crisis, it has increased again following the Covid-19 pandemic. Government size, in general, tends to decrease steadily.

The main objective of this study is to test the validity of the compensation and efficiency hypotheses for Kyrgyzstan. For this purpose, time series from 1990 to 2024 are analyzed using a Fourier-based cointegration test that takes into account both hard and soft transition structural breaks. The remainder of the paper is organized as follows: the first part covers the relevant literature, followed by a description of the data and methodology. Subsequently, the empirical findings are discussed, and the paper concludes with a summary of the results and their implications.

2. LITERATURE REVIEW

Some studies in the literature show that trade openness does not play a role in increasing the size of the public sector. Liberati (2007) investigated the relationship between trade openness and government spending for 20 selected countries using regression analysis. The study, which used time series data from 1967 to 2003, showed that trade openness reduces government spending, meaning the compensation hypothesis is invalid and the efficiency hypothesis is valid. Benarroch and Pandey (2012) analyzed 119 selected countries for the period 1972–2000. Findings from the Granger causality test indicated that the compensation hypothesis was invalid. Sener et al. (2015) investigated Türkiye for the period 1975–2013. In the study, which used the Johansen-Juselius cointegration and Granger causality tests, no relationship was found between the variables.

Numerous studies in the literature have shown that the compensation hypothesis is valid. Zakaria and Shakoor (2011) studied Pakistan for the period 1947–2009, while Lin et al. (2014) investigated 92 small developing countries between 1985 and 2010. Both studies, using regression analysis, found that trade openness increases the size of the government and that the compensation hypothesis is valid. Aregbeyen and Ibrahim (2014) evaluated Nigeria for the period 1970–2012, and Islam et al. (2022) evaluated Saudi Arabia for the period 1985–2019. These studies, employing the ARDL bounds test approach, found that trade openness is associated with increased government spending. Aztimur et al. (2023) analyzed China for the years 1990-2021. Findings from Fourier ADL cointegration and Hacker-Hatemi-J causality tests indicated that trade openness increased government size. Bharati et al. (2023) investigated 137 selected countries for the period 2000-2016 using regression analysis. The results indicate that trade openness affected government size but did not affect education, health, and military expenditures.

Some studies have reached different conclusions depending on the country. Turan and Karakas (2016) investigated the period from 1960 to 2011 using the ARDL bounds test approach. Accordingly,

the efficiency hypothesis is valid for Türkiye, and the compensation hypothesis is valid for Korea. Bayrakdar and Soyyiğit (2021) analyzed 6 Turkic republics between 1997 and 2017 using the Westerlund panel cointegration test. Their findings showed that the efficiency hypothesis was valid for Azerbaijan, Tajikistan, and Turkmenistan, while the compensation hypothesis was valid for Kyrgyzstan. Tekin et al. (2023) examined 11 Central and Eastern European countries for the period 1996-2021 using the Konya Bootstrap Granger causality test. As a result, it was observed that the compensation hypothesis was valid in four countries, while the efficiency hypothesis was valid in only one country.

3. DATA SET

The study employs annual time-series data covering the period from 1990 to 2024, yielding a total of 35 observations for each variable. All data were obtained from the World Bank database. Three variables are included in the model. Trade openness, which serves as the main explanatory variable, is measured by Trade (% of GDP). Government size is represented by General government final consumption expenditure (% of GDP). In addition, economic growth is incorporated as a control variable and is measured by GDP (constant 2015 US$). The natural logarithms of all variables were used in the empirical analysis.

4. METHODOLOGY

In this study, the cointegration approach developed by Banerjee et al. (2017) is employed to analyze the relationship between the variables. Extending traditional cointegration tests with Fourier functions can lead to improved test performance (Pascalau et al., 2022). The model under investigation is given in Equation (1).

$$GOV_t = \alpha_0 + \alpha_1 sin\left(\frac{2\pi k^* t}{T}\right) + \alpha_2 cos\left(\frac{2\pi k^* t}{T}\right) + \alpha_3 GOV_{t-1} + \alpha_4 TRA_{t-1} + \alpha_5 GDP_{t-1} + \alpha_6 \Delta GOV_{t-1} + \alpha_7 \Delta TRA_{t-1} + \alpha_8 \Delta GDP_{t-1} + \varepsilon_t \quad (1)$$

Here, *GOV* represents the dependent variable, *TRA* and *GDP* are the independent variables, and sin *and cos* are trigonometric terms that capture possible structural breaks. ε_t stands for the error term, *t* for the trend, *T* for the sample size, and *k* for the frequency value.

$$\alpha_3 = 0 \quad (2)$$

$$\alpha_3 < 0 \quad (3)$$

Equation (2) represents the null hypothesis that there is no long run relationship between the variables, and equation (3) stands for the alternative hypothesis that there is a long run relationship between the variables. The test statistic is obtained using equation (4):

$$t_{ADL}^F = \frac{\hat{\alpha}_3}{se(\alpha_3)} \quad (4)$$

Here, $\hat{\alpha}_3$ represents the ordinary least squares estimator of α_3, and $se(\hat{\alpha}_3)$ represents the standard error of $\hat{\alpha}_3$. Banerjee et al. (2017) determined the critical values. If test statistic is greater than the critical value, the null hypothesis is rejected.

5. FINDINGS

A unit root test was applied to check the stationarity of the time series, and the results are reported in Table 1.

Table 1. ADF Unit Root Test Results

Variable	Lag	t-stat.	Prob.
GOV	4	-1.316819	0.6085
TRA	0	-1.517956	0.5126
GDP	0	0.950471	0.9950
DGOV	0	-9.295850*	0.0000
DTRA	0	-5.155814*	0.0002
DGDP	0	-2.652191***	0.0932

Note: * and *** correspond to significance at the 1% and 10% levels, respectively. The Akaike Information Criterion (AIC) is employed to select the optimal lag length.

According to the ADF unit root test results, the test statistics for the GOV, TRA, and GDP variables at their level values are not statistically significant, indicating that these series are non-stationary and contain a unit root. However, when the first differences of the variables are considered, the DGOV and DTRA series become stationary at the 1% significance level, while the DGDP series becomes stationary at the 10% significance level. These findings indicate that all three variables are non-stationary in levels but become stationary after first differencing, implying that they are integrated of order one, I(1). Therefore, cointegration analysis can be employed to investigate the existence of long run relationships among the variables, and the results are reported in Table 2.

Table 2. FADL Cointegration Test Results

Dep. Variable	Indep. Variables		Optimal k	Minimum AIC	FADL Test Stat.
GOV (1)	TRA (3)	GDP (1)	5	-3.096708	-5.201501*

Note: * corresponds to statistical significance at the 1% level. The maximum lag length is set to 4.

According to the FADL cointegration test results, a long run relationship was found between the dependent variable GOV and the independent variables TRA and GDP. The fact that the test statistic is significant at the 1% significance level indicates cointegration between the variables. This result reveals that these variables move together in the long run and have an equilibrium relationship. DOLS was used to estimate the long run coefficients, and the results are reported in Table 3.

Table 3. DOLS Estimation Results

Variable	Coef.	Std. Error	t-Statistic	Prob.
TRA	0.280384	0.056175	4.991218*	0.0003
GDP	-0.214312	0.031949	-6.707966*	0.0000
C	6.439602	0.529887	12.15278*	0.0000
SIN	0.053754	0.011045	4.866634*	0.0004
COS	-0.000358	0.007434	-0.048219	0.9623

Note: * corresponds to statistical significance at the 1% level. The maximum lag length is set to 4.

In the DOLS model, since the logarithms of the variables have been taken, the TRA and GDP coefficients are interpreted as elasticity. Accordingly, a 1% increase in the TRA variable increases GOV by approximately 0.28%, while a 1% increase in GDP decreases GOV by approximately 0.21%. These results show that TRA has a positive effect on GOV, while GDP has a negative effect. The constant term and the cosine term are also statistically significant.

6. CONCLUSION

The findings of this study offer significant implications when evaluated within the framework of two fundamental hypotheses explaining the impact of globalization and trade openness on the public sector. In the case of Kyrgyzstan, the study examines the effect of increased trade openness on the size of the public sector in a small, developing transition economy following the collapse of the Soviet Union. The results indicate that the compensation hypothesis holds for the Kyrgyz economy. According to this hypothesis, the public sector expands to offset the economic risks arising from increased openness. Conversely, the efficiency hypothesis is not supported; that is, the shrinking effect of increased competitive pressure on the public sector is not confirmed in the specific case of Kyrgyzstan.

In the empirical analysis, the FADL cointegration test was used for the period 1990-2024, and economic growth was included in the model as a control variable. The findings revealed a long run cointegration relationship between the variables. According to the long run coefficients, a 1% increase in trade openness increases the size of the public sector by approximately 0.28%, while a 1% increase in economic growth reduces the public sector by approximately 0.21%.

The findings of this study do not align with the results of Liberati (2007), who found the efficiency hypothesis to be valid, nor with those of Benarroch and Pandey (2012) and Sener (2015), who found the compensation hypothesis to be invalid. However, they are consistent with the findings of Zakaria and Shakoor (2011), Lin et al. (2014), Aregbeyen and Ibrahim (2014), Islam et al. (2022), Aztimur et al. (2023), and Bharati et al. (2023), which support the validity of the compensation hypothesis. Furthermore, the findings of Bayrakdar and Soyyiğit (2021), a study specifically on Kyrgyzstan, which also confirms the compensation hypothesis, directly support the results of this study. In this respect, the

findings are consistent with the approach in the literature that defends the validity of the compensation hypothesis.

These results confirm the effect of trade openness in increasing public spending, while growth plays a contractionary role in the public sector. Economic growth, by relatively shrinking the public sector, is consistent with the strengthening of market mechanisms and the private sector taking on a more effective role in resource allocation. In this context, it can be stated that the growth process has the potential to create a more efficient economic structure by reducing the state's weight in the economy.

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AKILLI LOJİSTİK KÖY: KOCAELİ DE KURULMASI PLANLANAN AKILLI LOJİSTİK KÖYÜN SWOT ANALİZİ İLE DEĞERLENDİRİLMESİ

Zehra GÖNÜL*

ÖZET

Bu çalışmada lojistik kavramı; tarihsel gelişimi, günümüzdeki stratejik önemi ve dijital dönüşümün sektöre etkileri çerçevesinde incelenmiştir. Araştırmada öncelikle lojistik köylerin ortaya çıkış nedenleri, gelişim süreci ve lojistik faaliyetler açısından taşıdığı önem ele alınmış, ardından teknolojik gelişmelerin etkisiyle ortaya çıkan akıllı lojistik köy modeli değerlendirilmiştir.

Küreselleşmeyle birlikte üretim ve ticaret ağlarının genişlemesi, mal ve bilgi akışının daha etkin yönetilmesini gerekli kılmıştır. Bu süreçte lojistik, taşımacılığın ötesine geçerek bütünleşik bir yapıya dönüşmüştür. Farklı ulaşım türlerini bir araya getiren lojistik köyler ise yük hareketlerinin daha verimli yönetilmesini sağlayan önemli merkezlerdir.

Endüstri 4.0 ile birlikte lojistik sektöründe dijitalleşme hız kazanmış ve Nesnelerin İnterneti, yapay zekâ ile büyük veri gibi teknolojilerin entegrasyonu sonucunda akıllı lojistik köy kavramı ortaya çıkmıştır. Veri odaklı çalışan bu merkezler, operasyonel verimliliği artırırken kaynak kullanımının daha etkin yönetilmesine olanak sağlamaktadır.

Türkiye, Asya ve Avrupa arasındaki stratejik konumuyla lojistik faaliyetler açısından önemli avantajlara sahiptir. Güçlü sanayi altyapısı, liman bağlantıları ve ulaşım ağlarıyla öne çıkan Kocaeli'nin lojistik köy potansiyeli SWOT analizi ile değerlendirilmiştir. Analiz sonucunda bölgenin güçlü ve zayıf yönleri ile fırsat ve tehditleri ortaya konularak, Kocaeli'nin akıllı lojistik sistemler içerisindeki potansiyel rolü incelenmiştir.

Anahtar Kelimeler: *Uluslararası Lojistik, Lojistik Köy, Akıllı Lojistik Köy, Dijital Dönüşüm, Kocaeli, SWOT Analizi.*

JEL Kodları:

SMART LOGISTICS VILLAGE: SWOT ANALYSIS OF THE SMART LOGISTICS VILLAGE PLANNED FOR KOCAELİ

ABSTRACT

This study the development of the logistics sector, emphasizing its historical progression, contemporary strategic relevance, and the transformative power of digital technologies. The research first addresses the reasons for the emergence of logistics villages, their development process, and their

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significance for logistics activities. Furthermore, it assesses the smart logistics village paradigm that has evolved alongside modern technological breakthroughs.

With globalization, the expansion of production and trade networks has necessitated more efficient management of the flow of goods and information. In this process, logistics has evolved beyond transportation into an integrated structure. Logistics villages, which bring together different modes of transportation, are important centers that enable more efficient management of freight movements.

With Industry 4.0, digitalization in the logistics sector has accelerated, and the integration of technologies such as the Internet of Things, artificial intelligence, and big data has resulted in the concept of smart logistics villages. These data-driven centers increase operational efficiency while enabling more effective management of resource utilization.

Turkey, with its strategic location between Asia and Europe, possesses significant advantages in terms of logistics activities. Kocaeli, which stands out with its strong industrial infrastructure, port connections, and transportation networks, has been evaluated for its logistics village potential through a SWOT analysis. The analysis revealed the region's strengths and weaknesses, as well as opportunities and threats, and examined Kocaeli's potential role within smart logistics systems.

Keywords: *International Logistics, Logistics Village, Smart Logistics Village, Digital Transformation, Kocaeli, SWOT Analysis*

JEL Codes:

1. GİRİŞ

Küreselleşme süreciyle birlikte pazar sınırlarının ortadan kalkması, üretim, dağıtım ve tüketim faaliyetlerinin çok uluslu bir yapıya bürünmesine yol açmıştır. Firmalar arasındaki rekabetin küresel ölçekte arttığı günümüz piyasa koşullarında, ham madde tedarikinden nihai ürünün tüketiciye ulaştırılmasına kadar olan sürecin hızlı, güvenli ve düşük maliyetle yönetilmesi sürdürülebilirliğin temel şartıdır. Bu ortamda lojistik süreçler, işletmeler açısından rutin bir operasyon olmanın ötesine geçerek doğrudan pazar gücünü ve rekabet avantajını belirleyen stratejik bir unsur konumuna gelmiştir. Günümüzde lojistik; yalnızca taşımacılık faaliyetlerini değil depolamayı, stok yönetimini, gümrük süreçlerini ve ileri düzey bilgi akış mimarilerini içeren bütünleşik bir sistemi ifade etmektedir. Dolayısıyla tedarik zincirinin merkezinde yer alan lojistik verimlilik, modern kurumsal başarının en somut göstergelerinden biridir.

Uluslararası ticaret hacmindeki artış ve maliyet baskıları, lojistik operasyonların dağınık yapılar yerine entegre merkezlerde toplanmasını zorunlu kılmıştır. Bu ihtiyacın bir sonucu olarak ortaya çıkan lojistik köyler; kara, deniz, demir ve havayolu taşımacılığını tek bir fiziki alanda bir araya getiren büyük ölçekli ekosistemlerdir. Farklı taşıma ağlarının entegre bir şekilde çalışması, operasyonel süreçleri disipline ederken maliyetleri düşürmekte ve hizmet kalitesini artırmaktadır. Ticari faydalarının yanı sıra

bu merkezler, kuruldukları bölgelerin makroekonomik yapısını da doğrudan etkilemektedir. Bölgesel yatırımları teşvik eden, yerel ticareti canlandıran ve önemli bir istihdam alanı yaratan lojistik köyler, bölgesel kalkınmanın temel dinamikleri arasında yer almaktadır.

Endüstri 4.0 süreciyle birlikte lojistik sektörü de kapsamlı bir dijital dönüşüm evresine girmiştir. Geleneksel operasyonel yönetim modelleri; büyük veri, yapay zekâ temelli çözümler ve otonom sistemlerin sektöre entegre olmasıyla birlikte yapısal bir dönüşüm sürecine girmiştir. Bu teknolojik araçların sektöre entegre edilmesiyle birlikte, geleneksel lojistik merkez anlayışı yerini "akıllı lojistik köy" yaklaşımına bırakmaya başlamıştır. Veri odaklı bir yapıyla işletilen bu yeni nesil merkezler; süreçlerin anlık takibine, kaynakların minimum hatayla optimize edilmesine ve geleceğe yönelik tahminleme yeteneklerinin geliştirilmesine imkân tanımaktadır. Ayrıca akıllı lojistik köyler; enerji tasarrufu, karbon ayak izinin azaltılması ve operasyonel şeffaflık gibi sürdürülebilirlik hedeflerine ulaşmada önemli bir rol üstlenmektedir.

Kıtaları birbirine bağlayan jeostratejik konumuyla Türkiye, küresel ticaret koridorlarının en kritik düğüm noktalarından birini oluşturmaktadır. Ülke genelinde sanayi üretiminin ve ana ulaşım hatlarının merkezinde yer alan Marmara Bölgesi ise lojistik hareketliliğin en yoğun olduğu bölgedir. Bu bölge içinde Kocaeli; gelişmiş liman kompleksleri, organize sanayi bölgeleri, demiryolu bağlantıları ve otoyol ağlarının kesişim noktasında bulunması nedeniyle lojistik yatırımlar için oldukça elverişli bir yapıya sahiptir.

Bu çalışma, lojistik ve lojistik köy kavramlarını tarihsel gelişim süreciyle ele alarak, dijitalleşmenin sektörel dinamikler üzerindeki dönüştürücü etkisini incelemektedir. Bu kapsamda akıllı lojistik köy yaklaşımının teorik temelleri analiz edilmiş ve bu dönüşümün uygulama alanı olarak Kocaeli örneği seçilmiştir. Çalışmanın uygulama aşamasında, Kocaeli'nde kurulması planlanan bir akıllı lojistik köy projesinin potansiyeli SWOT analizi yöntemiyle incelenmiştir. Bölgenin güçlü yönleri, sahip olduğu stratejik fırsatlar ve karşılaşabileceği potansiyel riskler bilimsel kriterlerle değerlendirilmiştir. Çalışma sonucunda, Kocaeli'nin geleceğin dijital ticaret ağlarında nasıl öncü bir aktör haline gelebileceğine yönelik stratejik bir yol haritası sunulması amaçlanmaktadır.

2. LİTERATÜR TARAMASI

Lojistik sektörü, küresel ticaret hacminin artması, dijital teknolojilerin gelişmesi ve tedarik zincirlerinin karmaşık hale gelmesiyle birlikte önemli bir dönüşüm sürecine girmiştir. Geleneksel lojistik anlayışının yerini; bilgi teknolojileri, otomasyon sistemleri, yapay zekâ, büyük veri analitiği ve nesnelerin interneti (IoT) gibi yenilikçi uygulamaların desteklediği akıllı lojistik sistemleri almaktadır. Bu dönüşüm yalnızca işletmelerin operasyonel verimliliğini artırmakla kalmamakta, aynı zamanda ülkelerin uluslararası rekabet gücünü de doğrudan etkilemektedir. Bu nedenle son yıllarda akıllı lojistik köyler, sürdürülebilir taşımacılık ve dijital lojistik uygulamaları akademik çalışmalarda yoğun olarak ele alınan konular arasında yer almaktadır.

Literatürde akıllı lojistik uygulamalarını ele alan çalışmaların önemli bir bölümü, dijital dönüşüm teknolojilerinin lojistik süreçlere sağladığı katkılar üzerine yoğunlaşmaktadır. Karlı ve Tanyaş (2020), Kurt ve Akçacı (2024), Çelik (2020), Atabey ve Dindar (2022) ile benzer nitelikteki araştırmalar; büyük veri analitiği, nesnelerin interneti, yapay zekâ, siber-fiziksel sistemler ve otomasyon teknolojilerinin lojistik operasyonların daha hızlı, izlenebilir ve entegre biçimde yürütülmesine katkı sağladığını ortaya koymaktadır. Bu çalışmalar, dijital teknolojilerin yalnızca operasyonel maliyetleri azaltmakla kalmadığını, aynı zamanda karar verme süreçlerini destekleyerek müşteri memnuniyetini, hizmet kalitesini ve kaynak kullanım etkinliğini artırdığını göstermektedir. Özellikle Lojistik 4.0 yaklaşımı kapsamında geliştirilen akıllı sistemlerin, tedarik zinciri boyunca gerçek zamanlı veri paylaşımını mümkün kılarak işletmelere önemli rekabet avantajları sunduğu vurgulanmaktadır.

Lojistik köy kavramını inceleyen çalışmalar ise bu merkezlerin yalnızca depolama ve taşımacılık faaliyetlerinin yürütüldüğü alanlar olmadığını, aynı zamanda farklı ulaşım türlerini bütünleştiren, lojistik hizmet sağlayıcılarını tek merkezde toplayan ve tedarik zincirinin koordinasyonunu kolaylaştıran stratejik yapılar olduğunu ortaya koymaktadır. Dumlu (2022), Aydın ve Öğüt (2008), Şahin ve Toramanlı (2016) ile Elgün ve Aşıkoğlu (2016) tarafından gerçekleştirilen araştırmalar, lojistik köylerin maliyetleri azaltma, zaman yönetimini iyileştirme, çevresel sürdürülebilirliği destekleme ve uluslararası ticarette rekabet gücünü artırma açısından önemli avantajlar sağladığını belirtmektedir. Bununla birlikte Avrupa'daki lojistik köylerin çok modlu taşımacılık entegrasyonu, planlama ve yönetim açısından daha gelişmiş olduğu; Türkiye'deki lojistik köylerin ise özellikle altyapı, dijitalleşme ve entegrasyon konularında gelişime ihtiyaç duyduğu ifade edilmektedir.

Kentsel lojistik ve sürdürülebilir lojistik üzerine gerçekleştirilen araştırmalar da akıllı lojistik köylerin önemini destekleyen bulgular ortaya koymaktadır. Erturgut, Ustalı ve Bolat (2018), yoğun nüfuslu şehirlerde lojistik faaliyetlerin planlı biçimde yönetilmesinin trafik yoğunluğunu azaltabileceğini, çevresel etkileri sınırlayabileceğini ve dağıtım süreçlerinin etkinliğini artırabileceğini belirtmektedir.

Benzer şekilde sürdürülebilir lojistik yaklaşımını ele alan çalışmalar, yeşil lojistik uygulamalarının enerji verimliliği, karbon emisyonlarının azaltılması ve çevresel performansın geliştirilmesi açısından önemli katkılar sağladığını ortaya koymaktadır. Bu nedenle akıllı lojistik köylerin yalnızca ekonomik değil, çevresel ve sosyal sürdürülebilirlik hedefleri bakımından da stratejik yatırımlar olduğu değerlendirilmektedir.

Genel olarak literatür incelendiğinde; dijital dönüşüm teknolojileri ile desteklenen akıllı lojistik köylerin, lojistik süreçlerin daha etkin yönetilmesine, maliyetlerin azaltılmasına, hizmet kalitesinin artırılmasına ve ülkelerin uluslararası rekabet gücünün geliştirilmesine önemli katkılar sunduğu konusunda ortak bir görüş bulunduğu görülmektedir. Buna karşın Türkiye'de akıllı lojistik köylerin planlanması ve uygulanmasına yönelik bölgesel ölçekli çalışmaların sınırlı olduğu dikkat çekmektedir.

Bu çalışma, Kocaeli'nin sahip olduğu stratejik konum, güçlü sanayi altyapısı, liman kapasitesi ve ulaşım ağlarını SWOT analizi çerçevesinde değerlendirerek literatürdeki bu boşluğa katkı sunmayı amaçlamaktadır.

3. ARAŞTIRMANIN VERİ KAYNAKLARI

Bu çalışmanın temel amacı, Kocaeli ilinde kurulması planlanan akıllı lojistik köyün uygulanabilirliğini SWOT analizi kapsamında değerlendirmek ve bölgenin lojistik potansiyelini ortaya koymaktır**.** Araştırma alanı olarak Kocaeli'nin seçilmesinde; Türkiye'nin en önemli sanayi ve lojistik merkezlerinden biri olması, stratejik coğrafi konumu, gelişmiş ulaşım altyapısı, yüksek dış ticaret hacmi ve çok modlu taşımacılık imkânlarına sahip olması etkili olmuştur.

Çalışmada kullanılan veriler, nitel araştırma yaklaşımı doğrultusunda ikincil veri kaynaklarından elde edilmiştir. Bu kapsamda ulusal ve uluslararası literatürde yer alan akademik çalışmalar, kitaplar, tezler, bilimsel makaleler, strateji belgeleri ve sektörel raporlar incelenmiştir. Bunun yanı sıra, Kocaeli'nin lojistik altyapısı, liman kapasitesi, organize sanayi bölgeleri, karayolu ve demiryolu bağlantıları ile yük taşımacılığına ilişkin güncel veriler ilgili kamu kurum ve kuruluşlarının yayımladığı resmi istatistik ve raporlardan yararlanılarak değerlendirilmiştir.

Araştırmada kullanılan veri seti; Kocaeli'nin coğrafi özellikleri, ulaşım altyapısı, liman faaliyetleri, sanayi yapısı, lojistik merkezleri, dijital dönüşüm uygulamaları ve sürdürülebilir lojistik göstergelerini kapsamaktadır. Elde edilen veriler SWOT analizi çerçevesinde sınıflandırılarak güçlü yönler, zayıf yönler, fırsatlar ve tehditler başlıkları altında değerlendirilmiştir. Böylece Kocaeli'nin akıllı lojistik köy kurulumu açısından sahip olduğu mevcut potansiyel ile geliştirilmesi gereken alanlar bütüncül bir bakış açısıyla analiz edilmiştir.

Çalışmada kullanılan temel veri kaynakları Tablo 1'de gösterilmektedir.

Tablo 1. Çalışmada Kullanılan Veri Kaynakları

Veri Türü	İçeriği
Akademik Kaynaklar	Kitaplar, tezler, ulusal ve uluslararası bilimsel makaleler
Resmî Kurum Verileri	TÜİK, T.C. Ulaştırma ve Altyapı Bakanlığı, TCDD, Sanayi ve Teknoloji Bakanlığı, Kocaeli Büyükşehir Belediyesi verileri
Lojistik Verileri	Liman kapasitesi, yük taşımacılığı, organize sanayi bölgeleri, ulaşım altyapısı
Bölgesel Veriler	Kocaeli'nin coğrafi konumu, sanayi yapısı ve lojistik altyapısı
Analiz Çerçevesi	SWOT analizi kapsamında güçlü yönler, zayıf yönler, fırsatlar ve tehditler

Bu veri seti, Kocaeli'nin lojistik potansiyelinin değerlendirilmesi ve akıllı lojistik köy kurulmasına yönelik stratejik önerilerin geliştirilmesi için araştırmanın temel veri altyapısını oluşturmaktadır.

4. YÖNTEM

Bu çalışmada, Kocaeli ilinde kurulması planlanan akıllı lojistik köyün SWOT analizi çerçevesinde değerlendirilmesi amacıyla nitel araştırma yöntemi benimsenmiştir. Araştırmanın temel amacı, Kocaeli'nin mevcut lojistik potansiyelini ortaya koymak, bölgenin akıllı lojistik köy yatırımı açısından güçlü ve zayıf yönlerini belirlemek, ayrıca gelecekte karşılaşılabilecek fırsat ve tehditleri stratejik bir bakış açısıyla değerlendirmektir.

Araştırmada veri toplama yöntemi olarak doküman analizi kullanılmıştır. Bu kapsamda lojistik köyler, akıllı lojistik sistemleri, dijital dönüşüm, sürdürülebilir lojistik, bölgesel kalkınma ve lojistik planlama konularında yayımlanmış ulusal ve uluslararası bilimsel makaleler, lisansüstü tezler, kitaplar, kongre bildirileri ve sektörel raporlar incelenmiştir. Bunun yanında Kocaeli'nin lojistik altyapısına ilişkin veriler; Türkiye İstatistik Kurumu (TÜİK), T.C. Ulaştırma ve Altyapı Bakanlığı, TCDD Taşımacılık A.Ş., Sanayi ve Teknoloji Bakanlığı, Kocaeli Büyükşehir Belediyesi ile ilgili kamu kurum ve kuruluşlarının yayımladığı güncel istatistikler, stratejik planlar ve faaliyet raporlarından elde edilmiştir.

Araştırmanın temel analiz yöntemi olarak SWOT (Strengths, Weaknesses, Opportunities, Threats) analizi tercih edilmiştir. SWOT analizi, bir bölgenin veya yatırım projesinin iç ve dış çevre faktörlerini sistematik olarak değerlendirmeye imkân sağlayan stratejik bir analiz tekniğidir. Bu yöntem sayesinde Kocaeli'nin lojistik altyapısı, coğrafi konumu, ulaşım ağları, liman kapasitesi, organize sanayi bölgeleri, lojistik merkezleri, dijital dönüşüm potansiyeli ve sürdürülebilir lojistik uygulamaları bütüncül bir bakış açısıyla analiz edilmiştir.

Analiz sürecinde öncelikle literatür taraması ve resmî kurum verileri doğrultusunda Kocaeli'nin lojistik yapısı ayrıntılı olarak incelenmiştir. Daha sonra elde edilen bulgular karşılaştırmalı olarak değerlendirilmiş ve iç çevre faktörleri güçlü yönler ile zayıf yönler, dış çevre faktörleri ise fırsatlar ve tehditler başlıkları altında sınıflandırılmıştır. Böylece Kocaeli'nin akıllı lojistik köy yatırımı açısından mevcut durumu sistematik bir çerçevede değerlendirilmiştir.

Araştırma kapsamında oluşturulan SWOT matrisi, literatürden elde edilen bulgular, resmî kurum verileri ve Kocaeli'nin bölgesel lojistik göstergeleri esas alınarak araştırmacı tarafından hazırlanmıştır. Bu yönüyle çalışma, yalnızca mevcut lojistik altyapıyı ortaya koymakla kalmayıp, Kocaeli özelinde akıllı lojistik köy planlamasına yönelik stratejik bir değerlendirme sunması bakımından literatüre özgün katkı sağlamaktadır. Elde edilen bulgular doğrultusunda bölgenin lojistik rekabet gücünü artırmaya yönelik öneriler geliştirilmiş ve gelecekte gerçekleştirilecek lojistik yatırımlarına rehberlik edebilecek stratejik çıkarımlara ulaşılmıştır.

5. BULGULAR VE TARTIŞMA

5.1. Kocaeli'nin Lojistik Potansiyelinin Değerlendirilmesi

Kocaeli, sahip olduğu stratejik coğrafi konum, güçlü sanayi altyapısı ve gelişmiş ulaşım ağı sayesinde Türkiye'nin en önemli lojistik merkezlerinden biri konumundadır. Marmara Bölgesi'nde yer alması ve Avrupa ile Asya arasındaki ana ulaşım koridorları üzerinde bulunması, ilin ulusal ve uluslararası yük taşımacılığındaki önemini artırmaktadır. Özellikle İstanbul'a yakınlığı, gelişmiş liman altyapısı ve sanayi üretim kapasitesi, Kocaeli'ni akıllı lojistik köy yatırımları açısından avantajlı bir bölge haline getirmektedir.

Kocaeli'nin lojistik potansiyelini belirleyen en önemli unsurlardan biri ulaşım türlerinin büyük ölçüde bir arada bulunmasıdır. İl; karayolu, demiryolu ve denizyolu taşımacılığının entegre olarak kullanılabildiği nadir bölgelerden biridir. TEM Otoyolu, D-100 Karayolu, Kuzey Marmara Otoyolu ve Gebze-Orhangazi-İzmir Otoyolu gibi ana ulaşım aksları bölgenin erişilebilirliğini artırırken, mevcut demiryolu hatları ile planlanan Yeni Kuzey Demiryolu Hattı'nın lojistik faaliyetlere önemli katkılar sağlaması beklenmektedir. Ayrıca Köseköy Lojistik Merkezi'nin intermodal taşımacılık kapasitesi, bölgenin lojistik rekabet gücünü destekleyen önemli unsurlar arasında yer almaktadır.

Denizyolu taşımacılığı açısından değerlendirildiğinde Kocaeli, Türkiye'nin en yoğun liman bölgelerinden biridir. Körfez çevresinde faaliyet gösteren ticari limanlar, ithalat ve ihracat faaliyetlerinin önemli bir bölümünü karşılamakta ve sanayi üretiminin küresel pazarlara ulaştırılmasında kritik rol üstlenmektedir. Bununla birlikte, limanlar ile demiryolu bağlantılarının istenilen düzeyde olmaması ve yük taşımacılığının büyük ölçüde karayoluna bağımlı olması, bölgenin geliştirilmesi gereken yönleri arasında değerlendirilmektedir.

Kocaeli'nin sahip olduğu organize sanayi bölgeleri, üretim tesisleri, teknoloji geliştirme alanları ve lojistik işletmeleri de akıllı lojistik köy kurulması açısından önemli avantajlar sağlamaktadır. Bölgede yer alan sanayi kümelenmeleri yüksek yük üretim potansiyeli oluştururken, dijital dönüşüm uygulamalarının yaygınlaşması ve akıllı lojistik teknolojilerine yönelik yatırımlar lojistik süreçlerin daha verimli yönetilmesine katkı sağlamaktadır. Ayrıca Türkiye Ulaştırma 2053 vizyonu, demiryolu yatırımları, yeşil lojistik uygulamaları ve dijital lojistik sistemlerine yönelik politikalar da Kocaeli'nin gelecekte bölgesel bir lojistik üs olma potansiyelini güçlendirmektedir.

Ancak bölgenin sahip olduğu avantajların yanında bazı yapısal sorunlar da bulunmaktadır. Karayolu ağırlıklı yük taşımacılığı nedeniyle oluşan trafik yoğunluğu, liman çevresindeki ulaşım problemleri, demiryolu bağlantılarındaki yetersizlikler, çevresel baskılar ve deprem riski lojistik faaliyetlerin sürdürülebilirliği açısından dikkat edilmesi gereken temel konular arasında yer almaktadır. Bu nedenle Kocaeli'nde kurulması planlanan akıllı lojistik köyün yalnızca fiziksel bir lojistik merkez olarak değil, aynı zamanda dijital teknolojiler, sürdürülebilir ulaşım sistemleri ve çok modlu taşımacılık anlayışıyla desteklenen entegre bir lojistik ekosistemi olarak planlanması büyük önem taşımaktadır.

Kocaeli'nin mevcut lojistik yapısı, güçlü sanayi altyapısı ve stratejik konumu dikkate alındığında, akıllı lojistik köy projesinin bölgenin lojistik performansını artırabilecek önemli bir yatırım olduğu değerlendirilmektedir.

5.2. Kocaeli Bölgesi Lojistik Potansiyelinin Swot Analizi

Ekte yer alan anket formu aracılığıyla ilgili kurum ve kişilerden elde edilen veriler doğrultusunda, Kocaeli'nde kurulması planlanan lojistik serbest bölgenin güçlü yönleri, zayıf yönleri, fırsatları ve tehditleri belirlenmiş ve SWOT analizi kapsamında tablolaştırılmıştır.

Tablo 2. SWOT Analizi

KOCAELİN'DE KURULMASI DÜŞÜNÜLEN LOJİSTİK KÖYÜN SWOT ANALİZİ İLE DEĞERLENDİRİLMESİ	
GÜÇLÜ YÖNLER	**ZAYIF YÖNLER**
• Avrupa ve Asya arasındaki stratejik konumda yer alması • İstanbul, Bursa ve Sakarya gibi önemli ekonomik merkezlere yakınlığı • Gelişmiş liman altyapısına sahip olması • Kara, deniz, demiryolu ve havayolu ulaşım ağlarının bir arada bulunması • Kuzey Marmara Otoyolu ve TEM Otoyolu bağlantılarına sahip olması • Türkiye'nin en yüksek konteyner ve dış ticaret hareketlerinden birine sahip olması • Güçlü sanayi ve üretim altyapısının varlığı • Organize sanayi bölgelerinin yoğunluğu SAYI* • Köseköy Lojistik Merkezi gibi mevcut lojistik altyapı deneyimine sahip olması • Yüksek dış ticaret hacmi • Ulusal ve uluslararası pazarlara kolay erişim	• Karayolu taşımacılığına yüksek düzeyde bağımlılık • Kent içi trafik yoğunluğunun lojistik faaliyetleri olumsuz etkileyebilmesi • Yüksek arazi ve yatırım maliyetleri • Çevresel baskıların giderek artması • Liman ve ulaşım altyapısında zaman zaman yaşanan kapasite sorunları • Farklı kurumlar arasındaki koordinasyon eksiklikleri • Dijital lojistik uygulamalarının yeterince yaygın olmaması • Depolama alanlarının bazı bölgelerde yetersiz kalabilmesi • Şehirleşme baskısının lojistik yatırımlarını sınırlandırması • Artan işletme maliyetleri • Intermodal taşımacılığın istenen düzeyde gelişmemiş olması • Afet risklerine karşı lojistik altyapının tam olarak hazırlıklı olmaması
TEHDİTLER	**FIRSATLAR**
• Küresel ekonomik krizler ve ticaret daralmaları • Jeopolitik riskler ve uluslararası ticaret gerilimleri	• Akıllı lojistik teknolojilerinin yaygınlaşması • Endüstri 4.0 uygulamalarının lojistik sektörüne entegrasyonu • E-ticaret hacmindeki hızlı büyüme

• Rakip lojistik merkezlerin sayısının artması • Enerji maliyetlerindeki yükseliş • Çevre mevzuatlarının maliyetleri artırması • Enflasyon ve finansman maliyetlerinin yükselmesi • Doğal afet riski (özellikle deprem riski) • İklim değişikliği kaynaklı çevresel ve operasyonel riskler • Küresel tedarik zincirlerinde yaşanabilecek aksaklıklar • Liman ve ulaşım altyapılarında oluşabilecek kapasite yetersizlikleri • Teknolojik dönüşüme uyum sağlanamaması durumunda rekabet gücünün azalması • Nitelikli lojistik personeli temininde yaşanabilecek zorluklar	• Türkiye'nin uluslararası ticaret koridorlarındaki öneminin artması • Yeni Kuzey Demiryolu Hattı projeleri • Demiryolu taşımacılığına yönelik yatırımların artması • Lojistik sektörüne yönelik devlet teşvikleri • Türkiye Ulaştırma 2053 vizyonu kapsamında lojistik yatırımların desteklenmesi • Yeşil lojistik ve sürdürülebilir taşımacılık uygulamalarının gelişmesi • Yabancı yatırımcı ilgisinin artma potansiyeli • Yapılması planlanan Güney Marmara otoyolunun bursa sanayisinin güçlü entegrasyonuna katkısı • Bölgesel istihdamın artırılmasına katkı sağlaması • Bilişim vadisi ve ARGE merkezlerinin bölgede bulunması

6. SONUÇ

Bu çalışmada, Kocaeli ilinde kurulması planlanan akıllı lojistik köyün uygulanabilirliği SWOT analizi yöntemiyle değerlendirilmiştir**.** Araştırmada, Kocaeli'nin coğrafi konumu, gelişmiş sanayi altyapısı, çok modlu ulaşım olanakları, liman kapasitesi ve lojistik sektöründeki stratejik rolü dikkate alınarak bölgenin güçlü ve zayıf yönleri ile gelecekte karşılaşabileceği fırsatlar ve tehditler ortaya konulmuştur.

Araştırma bulguları, Kocaeli'nin Türkiye'nin en önemli lojistik merkezlerinden biri olduğunu ve akıllı lojistik köy yatırımı açısından önemli avantajlara sahip bulunduğunu göstermektedir. Bölgenin Avrupa ile Asya arasında stratejik bir geçiş noktasında yer alması, güçlü organize sanayi bölgelerine sahip olması, gelişmiş liman altyapısı ve karayolu, demiryolu ile denizyolunun bir arada kullanılabildiği çok modlu taşımacılık sistemi, akıllı lojistik köy uygulamalarının başarıyla hayata geçirilmesini destekleyen temel unsurlar olarak öne çıkmaktadır.

Bununla birlikte, karayolu taşımacılığına olan yüksek bağımlılık, trafik yoğunluğu, liman bağlantılarındaki altyapı eksiklikleri, çevresel sürdürülebilirlik sorunları ve deprem riski gibi faktörler bölgenin geliştirilmesi gereken yönleri arasında yer almaktadır. Bu nedenle, akıllı lojistik köy planlamasında yalnızca fiziksel altyapının değil, dijital teknolojilerin, intermodal taşımacılık

uygulamalarının, yeşil lojistik politikalarının ve akıllı ulaşım sistemlerinin de bütüncül bir yaklaşımla ele alınması önem taşımaktadır.

SWOT analizi sonucunda belirlenen fırsatlar doğrultusunda, Türkiye'nin lojistik politikaları, Ulaştırma 2053 Vizyonu, dijital dönüşüm uygulamaları ve sürdürülebilir lojistik yaklaşımları Kocaeli'nin ulusal ve uluslararası lojistik rekabet gücünü artırabilecek önemli gelişmeler olarak değerlendirilmektedir. Bununla birlikte, küresel ekonomik dalgalanmalar, jeopolitik riskler, çevresel düzenlemeler ve artan rekabet gibi tehditlerin de stratejik planlama süreçlerinde dikkate alınması gerekmektedir.

Sonuç olarak, Kocaeli'nin mevcut lojistik altyapısı ve sahip olduğu stratejik avantajlar doğrultusunda akıllı lojistik köy kurulumu için yüksek potansiyele sahip olduğu değerlendirilmiştir. Bölgenin lojistik performansının artırılması amacıyla demiryolu bağlantılarının güçlendirilmesi, liman-ulaşım entegrasyonunun geliştirilmesi, dijital lojistik teknolojilerine yönelik yatırımların artırılması ve sürdürülebilir lojistik uygulamalarının yaygınlaştırılması önerilmektedir. Bu doğrultuda gerçekleştirilecek yatırımların hem Kocaeli'nin hem de Türkiye'nin uluslararası lojistik ağlarındaki rekabet gücüne önemli katkılar sağlayacağı düşünülmektedir.

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