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Latafat Gardashova,
Rasim Aliyev

THRESHOLD EFFECTS OF GLOBALIZATION ON ECONOMIC GROWTH: INSIGHTS FROM AZERBAIJAN USING REGRESSION AND FUZZY C-MEANS

The object of this research is the relationship between globalization and economic growth in Azerbaijan, analyzed using regression analysis and Fuzzy C-Means (FCM) clustering. While globalization is often linked to economic expansion, its effects in resource-dependent economies remain unclear. This study examines whether increasing globalization, measured by the KOF Globalization Index and its sub-indices (economic, social, and political globalization), positively impacts GDP per capita growth.

Regression analysis reveals significant negative impacts of globalization on GDP per capita growth, with social globalization showing the strongest negative effect (coefficient: –10.93, $p<0.01$), followed by political (–9.55, $p<0.01$) and economic globalization (–5.96, $p<0.05$). Conversely, institutional quality, measured by the rule of law, significantly promotes growth (10.22, $p<0.01$). Fuzzy C-Means clustering further identifies clear nonlinear (threshold) patterns: moderate globalization levels (KOF Globalization Index≈49.36) correspond with the highest average GDP per capita growth (≈14.47), whereas lower (≈32.13) and higher (≈62.52) levels associate with significantly lower or negative growth (–10.91 % and 1.29 %, respectively). These findings indicate that excessive global integration can undermine economic stability in resource-dependent economies at the early stages of industrialization, such as Azerbaijan.

In practice, globalization should be approached strategically. Policymakers must strengthen institutions, enhance long-term investment policies, and prioritize industrial learning before promoting deeper integration. A balanced approach will maximize globalization's benefits while minimizing risks.

Keywords: *Azerbaijan, fuzzy C-Means clustering, threshold effects, economic integration, KOF Globalization Index, resource-dependent economy.*

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1. Introduction

Globalization has been a key focus of economic research for decades, with scholars attempting to quantify its effects through various indices, such as the KOF Globalization Index, New Globalization Index (NGI), and the Kearney/Foreign Policy Index. These indices aim to capture multiple dimensions of globalization and analyze its influence on economic growth, one of the most critical indicators of national economic performance. While globalization is often associated with increased trade, investment, and technological diffusion, its effects on economic growth are highly debated and context-dependent.

In many high- and middle-income countries, globalization has been linked to positive economic outcomes, facilitating access to new markets, attracting foreign direct investment, and fostering innovation [1]. However, in low-income economies, globalization can contribute to economic instability, income inequality, and dependence on external actors [2]. Understanding the specific mechanisms through which globalization affects growth is particularly important for countries like Azerbaijan, which is resource-dependent and undergoing economic transformation. Given Azerbaijan's efforts to diversify its economy, evaluating how different dimensions of globalization impact growth is essential for shaping effective policies that balance global integration and domestic economic stability.

Extensive research, including [3, 4], has linked globalization to economic growth. Early studies using panel data across 123 countries (1970–2000) found a positive correlation. Later research expanded the dataset to nearly all countries, reinforcing these findings.

A study examining Türkiye using the Full Modified Ordinary Least Squares cointegration test found a positive relationship between economic growth and the overall KOF Globalization Index, economic globalization, and social globalization [3]. Similarly, research on five South Asian countries concluded that globalization – measured through the KOF Globalization Index – had a positive long-term effect on economic growth, although social globalization did not exhibit the same positive impact. However, this positive influence was not observed in the short run [4].

Further analysis of 17 Central and Eastern European and Asian countries confirmed that trade and financial globalization played a significant role in promoting economic growth [5]. However, some models suggest that political globalization negatively affects economic growth in lower-middle-income countries, while economic and social globalization do not show a statistically significant impact in these economies [6].

An empirical study focusing on Vietnam (1995–2014) demonstrated that globalization, as measured by the KOF Index, had a positive effect on the country's economic growth, particularly through economic globalization [7]. A more recent study examining African economies over a 40-year period found that social globalization emerged as the strongest predictor of GDP growth in the region [8].

Similarly, a study on Turkic states – including Azerbaijan, Kazakhstan, Kyrgyzstan, Turkmenistan, Türkiye, and Uzbekistan – identified a positive relationship between economic globalization and economic growth. However, the findings indicated a negative association between social globalization and economic performance, suggesting that different dimensions of globalization may have contrasting effects on economic development [9].

The process of globalization has been closely linked with the concept of liberalization (or neoliberalization) for decades [10]. Numerous studies have highlighted the destructive effects of neoliberal policies, especially in the case of developing Southeast Asian countries. Although the impact of the post-Bretton Woods rules of globalization has often been promoted as growth-inducing, the real-world evidence demonstrates that the non-existent or infant industries of developing countries are highly vulnerable to these rules. Exposing them prematurely to global competition can have serious negative consequences for the subject country. A comprehensive study of East Asian economies by Joe Studwell demonstrates that export discipline – where states are closely monitoring exporting capabilities of their industries – can play a more crucial role in economic growth than the overall degree of globalization [11, 12].

This study seeks to build on these findings by analyzing the impact of globalization on Azerbaijan's economic performance, using a combination of regression analysis and clustering techniques to uncover potential nonlinear patterns in the relationship.

Despite these extensive studies, few have focused exclusively on Azerbaijan, particularly using methodologies that address potential nonlinearities in the globalization-growth relationship. Most studies rely solely on regression-based methods, which may overlook complex interactions and threshold effects. This gap highlights the need for a more detailed investigation of how different dimensions of globalization impact economic performance in Azerbaijan.

The aim of this research is to identify and analyze threshold effects in the relationship between globalization and economic growth in Azerbaijan. To achieve this, the study employs ordinary least squares regression to quantify linear impacts and uses Fuzzy C-Means clustering to detect and interpret nonlinear patterns. Specifically, this study seeks to determine the critical levels at which globalization transitions from beneficial to detrimental for GDP per capita growth, and to examine how distinct dimensions – economic, social, and political globalization – differently affect economic performance.

Scientific Aim: the study seeks to enhance understanding by quantifying linear relationships and detecting nonlinear patterns in the globalization-growth nexus. The research identifies specific threshold levels of globalization and examines how economic, social, and political dimensions distinctly influence economic outcomes, contributing insights beyond traditional linear analyses.

Practical Aim: the findings will provide policy recommendations for Azerbaijan and similar economies. By identifying optimal globalization levels that maximize benefits while mitigating risks, this study will help policymakers design balanced economic strategies. This will make it possible to develop targeted policies that promote economic integration while ensuring domestic economic resilience through institutional reforms, investment strategies, and regulatory improvements.

2. Materials and Methods

2.1. Object of research

The object of this research is the relationship between globalization and economic growth in Azerbaijan, analyzed using regression analysis and Fuzzy C-Means (FCM) clustering. While globalization is often linked to economic expansion, its effects in resource-dependent economies remain unclear. This study examines whether increasing globalization, measured by the KOF Globalization Index and its sub-indices (economic, social, and political globalization), positively impacts GDP per capita growth.

2.2. Data and sample

The primary dataset for this research is the KOF Globalization Index, obtained from the official KOF website [13]. Specifically, the analysis focuses on the overall KOF globalization index (KOFGI), along with its constituent sub-indices: economic globalization (KOFEcGi), social globalization (KOFSoGi), and political globalization (KOFPoGi). To provide a comprehensive understanding of Azerbaijan's economic landscape, key macroeconomic indicators have been retrieved from the World Bank Open Data platform. All data processing and analysis were conducted using Python [14].

2.3. Research design

2.3.1. Regression analysis

To investigate the relationship between globalization and economic growth in Azerbaijan, let's apply an ordinary least squares (OLS) regression model, following the methodological approach outlined in [4]. The dependent variable, GDP per capita growth percent, was winsorized to mitigate the impact of extreme outliers with a 5 % limit applied on both sides. Independent variables included the KOF Globalization Index (KOFGI) and its sub-indices (economic, social, and political globalization), along with a set of macroeconomic control variables. All predictor variables were standardized, and multicollinearity was evaluated using the Variance Inflation Factor (VIF). Variables with high VIF values were examined, and necessary adjustments were made to ensure reliable model estimates. Separate OLS regression models were estimated for the KOFGI index and each of its sub-indices. The regression models take the following forms:

– *Model 1:* Overall KOFGI:

$$GDP\_Growth_t = \beta_0 + \beta_1 KOFGI_t + \beta_2 Controls_t + \varepsilon_t;$$

– *Model 2a:* Economic Globalization (KOFEcGI):

$$GDP\_Growth_t = \beta_0 + \beta_1 KOFEcGI_t + \beta_2 Controls_t + \varepsilon_t;$$

– *Model 2b:* Social Globalization (KOFSoGI):

$$GDP\_Growth_t = \beta_0 + \beta_1 KOFSoGI_t + \beta_2 Controls_t + \varepsilon_t;$$

– *Model 2c:* Social Globalization (KOFPoGI):

$$GDP\_Growth_t = \beta_0 + \beta_1 KOFPoGI_t + \beta_2 Controls_t + \varepsilon_t.$$

In these models:

– GDP_Growth_t is the winsorized GDP per capita growth percent for Azerbaijan in year t.

– $KOFGI_t, KOFEcGI_t, KOFSoGI_t, and\ KOFPoGI_t$ represent the overall globalization index and its respective sub-indices.

– $Controls_t$ include macroeconomic factors such as fertility rate, government consumption, domestic investment, rule of law, and log-transformed inflation.

The models were evaluated based on the statistical significance of coefficients, R-squared, and Root Mean Square Error (RMSE). This approach allows for a comprehensive examination of the individual and aggregate impacts of globalization on economic growth.

2.3.2. Fuzzy C-Means clustering analysis

In addition to regression analysis, a Fuzzy C-Means (FCM) clustering methodology was employed to analyze the patterns and relationships

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between globalization indices and economic growth. This approach allows for a more nuanced understanding of how economic and social globalization dimensions, along with macroeconomic factors, influence GDP growth.

2.4. Methodology

The analysis employs a Fuzzy C-Means (FCM) clustering technique to investigate patterns in globalization indices and their relationship with economic growth. The target variable for this analysis is GDP per capita growth percent, while the input variables are grouped into the following models:

– *Model 1:* includes only the overall KOF Globalization Index (KOFGI).

– *Model 2:* combines KOFGI with macroeconomic control variables such as inflation, rule of law, GDP per capita, fertility rate, government consumption, and domestic investment.

– *Model 3:* considers the economic, social, and political sub-indices of KOFGI (KOFEcGI, KOFSoGI, KOFPoGI).

– *Model 4:* includes the sub-indices combined with macroeconomic control variables.

In the preprocessing stage, winsorization was applied to mitigate the effect of outliers, with a 5 % adjustment for GDP growth and a range of 1 % lower to 25 % upper for inflation. The data was then normalized using Min-Max scaling to ensure comparability across variables. The clustering process was carried out with three clusters, using a fuzziness coefficient (m) of 2, an error tolerance of 0.005, and a maximum of 1,000 iterations. Following the methodology developed by [15] and improved by [16], the FCM algorithm minimizes the following objective function:

$$J_m = \sum_{i=1}^{n} \sum_{j=1}^{c} u_{ij}^m \| x_i - v_j \|^2, \quad (1)$$

where x_i represents the i-th data point, v_j is the j-th cluster center, u_{ij} is the membership degree of x_i in cluster j, and m is the fuzziness coefficient. The cluster centers are updated iteratively as:

$$v_j = \frac{\sum_{i=1}^{n} u_{ij}^m x_i}{\sum_{i=1}^{n} u_{ij}^m}, \quad (2)$$

and the membership degrees are recalculated using:

$$u_{ij} = \left(\sum_{k=1}^{c} \left(\frac{\| x_i - v_j \|}{\| x_i - v_k \|} \right)^{\frac{2}{m-1}} \right)^{-1}. \quad (3)$$

The abovementioned formulas serve as the reference for the Fuzzy C-Means clustering models, the results of which are discussed in Section 3.2. The equations presented ensure methodological transparency and allow readers to replicate the clustering procedure accurately.

3. Results and Discussion

3.1. Regression models

The findings revealed, as shown in Table 1, that globalization indices (overall and its subindices) had significant negative impacts on growth, with coefficients ranging from -5.96 (economic) and -10.93 (social), highlighting their substantial influence. Rule of law consistently emerged as a positive driver, with coefficients up to 10.22, while fertility rate negatively influenced growth, with coefficients as low as -7.69. Domestic investment showed a positive effect in a model. The models' explanatory power is evidenced by high R-squared values, reaching up to 0.745, and RMSE as low as 5.95. These metrics emphasize the statistical significance and robustness of the models in capturing the relationships between the specified variables.

Table 1

Regression analysis of globalization indices and macroeconomic variables on GDP per capita growth in Azerbaijan

Variable	Model 1 (KOFGI)	Model 2 (KOFEcGI)	Model 3 (KOFSoGI)	Model 4 (KOFPoGI)
Intercept	2.655* (1.334)	2.655* (1.461)	2.655** (1.214)	2.655* (1.311)
KOF index	–9.237*** (3.018)	–5.964** (3.046)	–10.927*** (2.707)	–9.547*** (2.938)
Fertility rate	–6.528** (2.747)	–4.066 (2.790)	–5.816** (2.166)	–7.692** (2.909)
Government consumption (% of GDP)	–2.753 (2.443)	–3.206 (2.682)	–2.651 (2.211)	–2.840 (2.390)
Domestic investment (% of GDP)	2.409 (1.502)	3.701** (1.574)	0.821 (1.495)	2.205 (1.489)
Rule of law	7.713*** (2.533)	5.951** (2.685)	10.216*** (2.561)	6.763*** (2.277)
Log(inflation)	–0.780 (1.576)	–0.920 (1.729)	–0.891 (1.435)	–0.559 (1.548)
R–squared	0.692	0.631	0.745	0.702
Root mean square error (RMSE)	6.54	7.16	5.95	6.42

Notes: Standard errors are in parentheses; * – $p<0.1$, ** – $p<0.05$, *** – $p<0.01$

3.2. FCM models

The Fuzzy C-Means clustering analysis revealed nonlinear relationships between globalization indices, macroeconomic variables, and GDP per capita growth in Azerbaijan, with distinct patterns across the models.

Model 1, using KOFGI as the input variable, showed that moderate levels of KOFGI were associated with the highest GDP growth (14.47 %), while higher levels failed to sustain this trend. This suggests that the positive effects of globalization on growth are not uniform across time and may lack long-term sustainability. *Model 2*, incorporating KOFGI and macroeconomic variables, offered limited additional insights but highlighted low domestic investment as a stronger predictor of growth compared to KOFGI.

Model 3, based on the KOF subindices (KOFEcGI, KOFSoGI, KOFPoGI), aligned with the results of Model 1, with moderate levels of the subindices driving growth (12.64 %). However, further increases in the subindices did not correlate with higher growth. Model 4, which combined the subindices with macroeconomic variables, shared similar results with Model 3, while emphasizing the positive influence of domestic investment and the negative impact of government consumption on growth.

Tukey HSD tests revealed that, in all models except Model 1, some clusters were not significantly different from each other, indicating overlap in the underlying economic dynamics (Table 2).

Detailed IF-THEN rules are as follows:

Model 1: KOFGI

– Cluster 1: If KOFGI≈49.36, then GDP growth≈14.47 %.

– Cluster 2: If KOFGI≈32.13, then GDP growth≈-10.91 %.

– Cluster 3: If KOFGI≈62.52, then GDP growth≈1.29 %.

Model 2: KOFGI + Macroeconomic variables

– Cluster 1: If KOFGI≈32.00, inflation≈10.14, rule_of_law≈5.28, ferility_rate≈2.55, government_consumption_aze_percent_of_gdp≈20.33, domestic_inv_aze_percent_of_gdp≈15.59, net_barter_terms_of_trade_index_(2015=100)≈118.56, Life_Expectancy≈62.03 then GDP growth≈-13.82 %.

– Cluster 2: If KOFGI≈50.71, inflation≈3.55, rule_of_law≈9.62, ferility_rate≈1.92, government_consumption_aze_percent_of_gdp≈13.41, domestic_inv_aze_percent_of_gdp≈34.38, net_barter_terms_of_trade_index_(2015=100)≈90.27, Life_Expectancy≈66.93 then GDP growth≈4.83 %.

Table 2

Clustering Results for Fuzzy C-Means Analysis of GDP Growth in Azerbaijan and Error Metrics

Metric	Model 1 (KOFGI)	Model 2 (KOFGI + macroeconomic variables)	Model 3 (subindices)	Model 4 (Subindices + macroeconomic variables)
FPC	0.850	0.605	0.841	0.636
Cluster 1 (target variable avg.)	14.47	–13.82	12.64	6.2
Cluster 2 (target variable avg.)	–10.91	4.82	3.32	–13.82
Cluster 3 (target variable avg.)	1.29	7.24	–10.91	6.33
ANOVA F-statistic	14.22	10.41	9.53	10.13
ANOVA p-value	<0.001	<0.001	0.001	0.001
MSE (Test data)	2.55	6.78	3.94	6.36
RMSE (Test data)	3.39	7.15	4.63	7.07

– Cluster 3: If KOFGI≈58.90, inflation≈5.68, rule_of_law≈13.92, ferility_rate≈1.94, government_consumption_aze_percent_of_gdp≈10.45, domestic_inv_aze_percent_of_gdp≈23.95, net_barter_terms_of_trade_index_(2015=100)≈139.78, Life_Expectancy≈70.01 then GDP growth≈7.24 %.

Model 3: Subindices

– Cluster 1: If KOFEcGI≈57.66, KOFSoGI≈42.72, KOFPoGI≈45.94, then GDP growth≈12.64 %.

– Cluster 2: If KOFEcGI≈66.31, KOFSoGI≈56.72, KOFPoGI≈62.70, then GDP growth≈3.32 %.

– Cluster 3: If KOFEcGI≈37.62, KOFSoGI≈33.06, KOFPoGI≈26.85, then GDP growth≈-10.91 %.

Model 4: Subindices + macroeconomic variables

– Cluster 1: If KOFEcGI≈64.49, KOFSoGI≈55.41, KOFPoGI≈59.88, inflation≈5.76, rule_of_law≈13.54, ferility_rate≈1.91, government_consumption_aze_percent_of_gdp≈10.80, domestic_inv_aze_percent_of_gdp≈23.84, net_barter_terms_of_trade_index_(2015=100)≈133.58, Life_Expectancy≈70.28 then GDP growth≈6.20 %.

– Cluster 2: If KOFEcGI≈37.56, KOFSoGI≈32.72, KOFPoGI≈26.30, inflation≈9.83, rule_of_law≈5.28, ferility_rate≈2.53, government_consumption_aze_percent_of_gdp≈19.93, domestic_inv_aze_percent_of_gdp≈15.86, net_barter_terms_of_trade_index_(2015=100)≈118.65, Life_Expectancy≈62.01 then GDP growth≈-13.82 %.

– Cluster 3: If KOFEcGI≈56.60, KOFSoGI≈42.68, KOFPoGI≈45.97, inflation≈3.12, rule_of_law≈9.59, ferility_rate≈1.94, government_consumption_aze_percent_of_gdp≈13.24, domestic_inv_aze_percent_of_gdp≈37.21, net_barter_terms_of_trade_index_(2015=100)≈90.08, Life_Expectancy≈66.47 then GDP growth≈6.33 %.

Full Tukey test results, for detailed review, are as follows:

Model 1: significant differences between all clusters:

– Cluster 1 vs. 2: $p<0.001$, significant.

– Cluster 1 vs. 3: $p=0.019$, significant.

– Cluster 2 vs. 3: $p=0.023$, significant.

Model 2: some clusters not significantly different:

– Cluster 1 vs. 2: $p=0.005$, significant.

– Cluster 1 vs. 3: $p<0.001$, significant.

– Cluster 2 vs. 3: $p=0.860$, not significant.

Model 3: some clusters not significantly different:

– Cluster 1 vs. 2: $p=0.191$, not significant.

– Cluster 1 vs. 3: $p=0.001$, significant.

– Cluster 2 vs. 3: $p=0.015$, significant.

Model 4: some clusters not significantly different:

– Cluster 1 vs. 2: $p=0.001$, significant.

– Cluster 1 vs. 3: $p=1.000$, not significant.

– Cluster 2 vs. 3: $p=0.004$, significant.

The findings of this study diverge from previous research on globalization and economic growth. While studies such as [3, 4] generally report a positive correlation between globalization and GDP growth, this study identifies a nonlinear relationship, where excessive globalization correlates with stagnation or decline.

This study has several limitations. First, data availability constraints limited the timeframe and scope of analysis. Second, while FCM clustering capture nonlinear patterns, endogeneity concerns remain a potential issue. Third, the clustering approach is sensitive to hyperparameter selection, which may affect the grouping of observations. Future studies could address these issues by incorporating a broader dataset and alternative econometric approaches. Additionally, future research should explore sector-specific impacts of globalization on Azerbaijan's economy, particularly in manufacturing and services.

The findings of this study diverge from previous research on globalization and economic growth. While studies [3, 4] generally report a positive correlation between globalization and GDP growth, this study identifies a nonlinear relationship, where excessive globalization correlates with stagnation or decline. These results support the export-oriented industrialization framework, indicating that strategic export policies can be more beneficial for economic growth than unregulated globalization. Conversely, adopting neoliberal globalization policies may negatively affect domestic industrial strategies, as illustrated by the experiences of East Asian countries [12].

This study has several limitations. First, data availability constraints limited the timeframe and scope of analysis. Second, while FCM clustering capture nonlinear patterns, endogeneity concerns remain a potential issue. Third, the clustering approach is sensitive to hyperparameter selection, which may affect the grouping of observations. Future studies could address these issues by incorporating a broader dataset and alternative econometric approaches. Additionally, future research should explore sector-specific impacts of globalization on Azerbaijan's economy, particularly in manufacturing and services.

4. Conclusions

The analysis presented in this study reveals that globalization does not produce uniformly positive impacts on economic growth in Azerbaijan. According to the regression results, increased globalization – particularly in its social and political dimensions – is negatively associated with GDP per capita growth. Among these, social globalization exerts the strongest negative effect, while economic globalization also has a negative, yet comparatively smaller, influence. On the other hand, institutional quality, specifically the rule of law, consistently demonstrates a robust positive relationship with economic growth.

The findings from the Fuzzy C-Means clustering further enrich the understanding of these relationships, clearly illustrating nonlinear, threshold-dependent patterns. Specifically, the results indicate that moderate globalization (as measured by a KOF Globalization Index around 49.36) corresponds with optimal economic growth outcomes, while significantly lower (around 32.13) and higher (around 62.52)

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globalization levels are associated with substantially weaker or negative GDP growth rates.

These results align with the export-oriented industrialization framework, suggesting that strategic export policies may be more effective for growth than globalization alone. In some cases, neoliberal globalization policies disrupt domestic industrial strategies, as seen in East Asian economies. Policymakers should balance globalization with institutional strength and domestic investment to maximize economic benefits.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Manuscript has associated data in a data repository [13].

Use of artificial intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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Latafat Gardashova, *Professor, Department of Computer Engineering, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, ORCID: https://orcid.org/0000-0003-3227-2521*

✉ ***Rasim Aliyev,*** *PhD Student, Department of Management, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, e-mail: Aliyev.rasim1997@gmail.com, ORCID: https://orcid.org/0009-0004-2950-8657*

✉ *Corresponding author*