“Impacts of capital, education, and income inequality on economic growth: Evidence from Germany”

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ARTICLE INFO	Zeynab Giyasova, Jeyhun Hajiyev, Gunay Panahova, Asli Kazimova and Mustafa Kemal Oktem (2026). Impacts of capital, education, and income inequality on economic growth: Evidence from Germany. *Problems and Perspectives in Management*, *24*(3), 161-173. doi:10.21511/ppm.24(3).2026.12
DOI	http://dx.doi.org/10.21511/ppm.24(3).2026.12
RELEASED ON	Friday, 31 July 2026
RECEIVED ON	Thursday, 02 April 2026
ACCEPTED ON	Thursday, 09 July 2026

JOURNAL	"Problems and Perspectives in Management"
ISSN PRINT	1727-7051
ISSN ONLINE	1810-5467
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
38	4	6

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine

www.businessperspectives.org

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IMPACTS OF CAPITAL, EDUCATION, AND INCOME INEQUALITY ON ECONOMIC GROWTH: EVIDENCE FROM GERMANY

Abstract

Against the backdrop of economic stagnation, weak external demand, and rising social disparities, this study examines the determinants of economic growth in Germany. Specifically, it investigates the long- and short-run effects of gross capital formation (GCF), government expenditure on education (GEE), and income inequality (GINI) on GDP per capita (GDPPC) over the period 1996–2022. The empirical analysis applies the Autoregressive Distributed Lag (ARDL) bounds testing approach, supported by unit root tests, an error correction model (ECM), and Fully Modified Ordinary Least Squares (FMOLS) estimation. The results confirm the existence of a long-run cointegration relationship among the variables, as the F-statistic of 5.67 surpasses the upper bound critical value at the 1% significance level. The ECM results show that approximately 51.8% of short-run deviations are corrected within one year, indicating a moderate speed of adjustment toward long-run equilibrium. FMOLS estimates suggest that gross capital formation and government expenditure on education are positively associated with GDP per capita in the long run, with coefficients of 0.475 and 0.088, respectively. Income inequality also exhibits a statistically significant but relatively small positive association with economic growth (0.024). In addition, external shocks show asymmetric effects, where financial crises are associated with a 0.055 increase in GDP per capita, while pandemic-related shocks are associated with a 0.089 decrease. Overall, the findings indicate that capital formation and public education expenditure are key long-run correlates of economic growth in Germany, while inequality and external shocks play supplementary but comparatively smaller roles in shaping growth dynamics.

Keywords economic growth, sustainability, capital, education, GINI index, ARDL, FMOLS, Germany

JEL Classification E20, E24, I25, O40, C22

Type of the article: Research Article

Received on: 2nd of April, 2026
Accepted on: 9th of July, 2026
Published on: 31st of July, 2026

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Conflict of interest statement:
Author(s) reported no conflict of interest

INTRODUCTION

Germany has long been regarded as one of the most influential and resilient economies in Europe and the global economy. Over recent decades, sustained industrial strength, export orientation, and technological leadership have positioned the country among the world's leading economic powers. With an estimated gross domestic product exceeding USD 5 trillion in 2025, Germany ranks as the third-largest economy worldwide after the United States and China, and remains the largest economy in Europe (KPMG, 2026). This scale underscores Germany's central role in global production networks, trade flows, and economic stability within the European Union.

Despite this strong structural position, Germany's growth trajectory has weakened in recent years. Following the COVID-19 pandemic, its economy recorded one of the slowest recoveries among advanced economies, with real GDP in 2024 remaining close to its 2019 level. Economic activity stagnated during the first half of 2025, reflecting

a combination of weak external demand, declining export competitiveness, and elevated uncertainty. While a mild improvement emerged toward the end of 2025 (supported by rising private and public consumption, inventory accumulation, and a rebound in capital goods production), overall growth remained constrained by subdued investment, weak export performance, and a negative contribution from net foreign trade (BMWK, 2026; EC, 2025). These developments highlight growing structural challenges facing the German growth model.

In this study, the term "economic growth" is used in place of "sustainable economic growth" to ensure conceptual precision, as the dependent variable is real GDP per capita, which captures economic performance but does not directly measure environmental or broader sustainability dimensions. Accordingly, the analysis focuses on the macroeconomic determinants of long-run economic growth rather than multidimensional sustainability outcomes.

From a regional and structural perspective, existing empirical evidence suggests that Germany's economic growth is shaped by conditional income convergence, strong human capital endowments, and pronounced agglomeration effects. Regions containing major urban and capital centers tend to exhibit higher growth rates, benefiting from productivity spillovers, dense labor markets, and innovation clustering. At the same time, spatial spillovers, domestic investment in capital goods, and interregional linkages play a critical role in shaping growth outcomes, while persistent regional disparities reflect heterogeneous economic structures rather than a uniform growth path (Cuaresma et al., 2014). These findings emphasize the importance of structural and socio-economic factors beyond aggregate demand dynamics.

Against this background, understanding the drivers of Germany's economic growth has become increasingly relevant. While traditional explanations emphasize production capacity, exports, technological innovation, and industrial investment, recent stagnation episodes suggest that broader socio-economic determinants warrant closer examination. In particular, fixed capital accumulation, educational expenditure, and income inequality may exert significant and interrelated effects on long-term growth performance.

1. LITERATURE REVIEW AND HYPOTHESES

The relationship between economic growth, human capital formation, capital accumulation, and income distribution has been extensively examined in the economic development and sustainability literature. In recent years, the conceptualization of growth has shifted from a purely output-centered perspective toward a multidimensional framework in which institutional quality, social inequality, and structural transformation jointly determine long-run development outcomes. Sustainability-oriented studies emphasize that sustainable economic performance depends on the interaction between human capital, governance quality, innovation capacity, and environmental constraints rather than on isolated macroeconomic determinants (Prasetyo & Kistanti, 2020; Hasanov et al., 2024; Hasanov & Azizli, 2025; Mammadov et al., 2024; Niftiyev, 2025). Within this systemic framework, economic growth is increasingly understood as a process shaped by both productive capacity and distributive dynamics.

A first strand of the literature focuses on inequality as a multidimensional phenomenon operating through both economic and social mechanisms. At the micro level, Consiglio and Sologon (2022) showed that individuals from non-academic family backgrounds in Germany face persistent wage disadvantages driven not only by lower educational attainment but also by weaker access to instrumental social capital. Their findings, based on Oaxaca–Blinder decomposition and quantile regression, further indicated that weak-tie career support is both quantitatively and qualitatively inferior for individuals from less educated families, thereby reinforcing inequality beyond formal education systems. At the macro level, Ciaschini and

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Salvati (2026) documented that although per-capita income growth across countries has generally improved living standards over time, it has simultaneously intensified regional and spatial inequalities due to heterogeneous development trajectories. These findings suggest that inequality operates simultaneously at individual, structural, and spatial levels, reinforcing persistent disparities in economic outcomes. Moreover, previous studies have demonstrated that inequality of opportunity and income distribution influence long-run economic growth through multiple transmission channels, including human capital accumulation, labor market outcomes, and investment incentives (Aiyar & Ebeke, 2020). In the German context, rising income inequality has also been identified as an emerging structural challenge with important implications for long-term economic performance (Albig et al., 2017).

A second strand of the literature examines the role of education in shaping both growth and inequality. Rehme (2007) demonstrated that educational expansion initially increases both growth and income inequality, with distributional improvements emerging only in later stages of development, highlighting the nonlinear nature of education effects. Similarly, Hanushek and Woessmann (2020) emphasized that cognitive skills, rather than years of schooling alone, represent the primary driver of long-term economic performance, indicating that the quality of education is more important than its quantity. Extending this argument, Makhlouf and Lalley (2023) showed that educational expansion policies in OECD countries from 1870 to 2016 increased income inequality in the long run while having no significant short-run effects. They further argued that education-driven structural transformation toward the service sector reduces agricultural employment and increases wage dispersion, thereby reinforcing inequality despite supporting overall economic development. These results collectively suggest that education plays a dual role, simultaneously fostering growth while potentially amplifying inequality through structural change mechanisms. Recent evidence further suggests that the growth-enhancing effects of education are strengthened through research and development (R&D), with educational expenditure contributing to economic performance by fostering innovation and technological progress (Diakodimitriou et al., 2025). Similarly, Gulaliyev et al. (2024), in a comparative analysis of Israel and the South Caucasus countries, found that R&D expenditure generates significant positive macroeconomic effects, highlighting the complementary role of innovation investment in promoting sustainable economic growth.

A third strand of the literature focuses on capital formation and investment as key drivers of economic growth. Egger et al. (2010) showed that capital market integration enhances human capital accumulation through capital–skill complementarities, thereby linking financial development with education outcomes. Oliveira et al. (2025) further confirmed that gross capital formation and intermediate education significantly contribute to economic expansion, while structural instability and certain consumption patterns may weaken these effects. Beyond traditional investment channels, Castilho and Fuinhas (2025) demonstrated that tourism-related capital investment reduces inequality and poverty in EU economies, while Roszko-Wójtowicz et al. (2025) highlighted the importance of social capital and trust networks in fostering digital economic participation and innovation diffusion. These findings collectively indicate that capital formation operates through both physical and socio-institutional mechanisms. Using a machine learning framework, Motahar and Mamipour (2025) further demonstrated that wealth inequality exerts a significant influence on economic growth, highlighting the value of advanced analytical approaches in uncovering complex nonlinear relationships between inequality and macroeconomic performance.

A further important dimension of the literature highlights the role of institutions and governance in mediating the relationship between growth, education, and inequality. Ismeti and Hameli (2026), in a comparative analysis of Germany and Kosovo, found that education spending supports economic growth but does not automatically translate into improved labor market outcomes due to structural mismatches. Similarly, Nunoo et al. (2024) showed that corruption control and government effectiveness mitigate the inequality-enhancing effects of human capital accumulation, emphasizing the importance of institutional quality in ensuring inclusive growth outcomes. In addition, composite

indicators such as the Index of Distributive and Developmental Outlook (IDDO) introduced by N. Mitu and G. Mitu (2025) integrate growth and inequality dimensions, reinforcing the need for combined efficiency–equity frameworks in development analysis.

Overall, the literature converges on the view that economic growth is determined by an interconnected system of human capital, physical capital, institutional quality, and income distribution. However, existing studies provide mixed and sometimes contradictory evidence regarding the direction, magnitude, and transmission channels of these relationships, particularly in advanced economies. Moreover, limited attention has been given to the joint long-run interaction of education expenditure, capital formation, and income inequality within a unified econometric framework. In summary, the literature highlights three key insights:

(i) inequality is multidimensional, operating through labor markets, social capital, and spatial divergence;

(ii) education influences both growth and inequality through nonlinear and structural transformation channels; and

(iii) capital formation interacts with human capital and institutions in shaping long-run development trajectories.

Despite these insights, a clear gap remains regarding the integrated long-run and short-run effects of these determinants within a single empirical framework.

Accordingly, the objective of this study is to examine the long-run and short-run effects of gross capital formation, government expenditure on education, and income inequality on economic growth in Germany. Based on the reviewed literature and the empirical structure of I (1) variables with confirmed cointegration, the following hypotheses are formulated:

H1: Gross capital formation has a positive and statistically significant effect on economic growth in both the long run and short run.

H2: Government expenditure on education positively influences economic growth through human capital accumulation in both the long run and short run.

H3: Income inequality has a statistically significant effect on economic growth, although the direction and magnitude of this effect are empirically determined and may vary depending on structural conditions.

2. METHOD

This study employs annual macroeconomic data for Germany to examine the impacts of capital formation, education expenditure, and income inequality on economic growth. Economic growth is measured by real gross domestic product per capita (GDPPC), which serves as the dependent variable. The explanatory variables include gross capital formation (GCF), government expenditure on education (GEE), and income inequality, proxied by the Gini index (GINI). Together, these variables capture key economic, human capital, and distributional dimensions of growth.

The data are compiled from internationally recognized and harmonized sources to ensure consistency and reliability. Specifically, GDP per capita and gross capital formation are obtained from the World Bank (n.d.) and the International Monetary Fund (IMF, n.d.), while complementary national data, particularly for education expenditure and inequality indicators, are sourced from the Federal Statistical Office of Germany (DESTATIS, 2026). The datasets are integrated to construct a coherent time series, with careful cross-validation to address definitional consistency across sources. It improves the methodological transparency of the study by clearly defining all variables, their measurement units, and data sources. It also resolves previous inconsistencies by correctly distinguishing government expenditure on education from enrollment indicators. In addition, it ensures comparability by standardizing all data to consistent annual macroeconomic series for Germany over 1996–2022.

To stabilize variance and allow for elasticity-based interpretation of estimated coefficients, GDP per capita (GDPPC) and gross capital formation (GCF)

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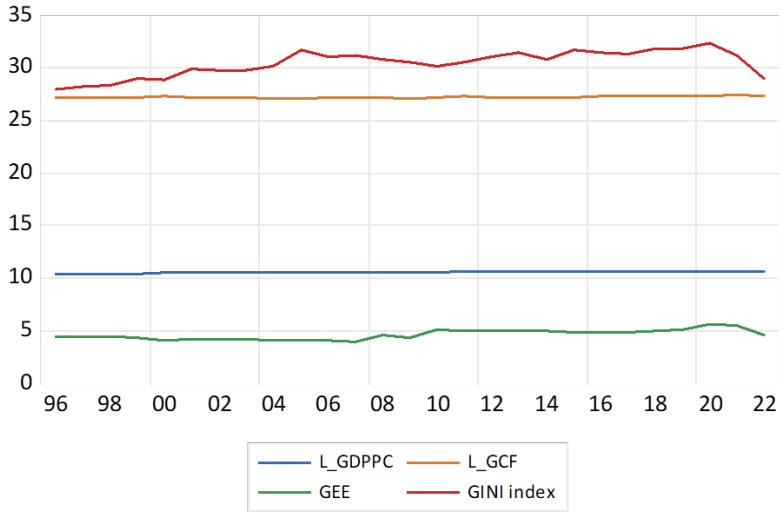

Figure 1. Trends in GDP per capita, capital formation, education expenditure, and income inequality (1996–2022)

are transformed into their natural logarithmic forms. This transformation also helps to mitigate potential heteroskedasticity and scale effects commonly observed in macroeconomic time-series data. Government education expenditure (GEE) and the Gini index (GINI) are retained in their original levels, as they are expressed in percentage and index form, respectively. They are widely interpreted in levels within the empirical growth literature. All variables are expressed on an annual basis from 1996 to 2022 and are aligned temporally to ensure comparability across observations. The resulting dataset provides a suitable empirical foundation for econometric analysis of the long-run and short-run relationships between economic growth, capital accumulation, educational investment, and income inequality in Germany.

GDP per capita (GDPPC) and gross capital formation (GCF) are transformed into natural logarithmic form in order to stabilize variance, reduce potential heteroskedasticity, and allow for elasticity-based interpretation of estimated coefficients. In contrast, government expenditure on education (GEE) and the Gini index (GINI) are retained in their original levels because both variables are expressed as percentage/index measures, where logarithmic transformation is neither necessary nor standard practice in the empirical growth literature. This mixed transformation approach is consistent with previous macroeconomic studies that combine log-transformed scale variables with level-based institutional and distributional indicators.

Figure 1 illustrates the time-series dynamics of L_GDPPC, L_GCF, government expenditure on education (GEE), and the Gini index over the period 1996–2022. While the logarithms of GDP per capita and gross capital formation remain largely stable with only modest variation, income inequality exhibits pronounced fluctuations, peaking around 2020 before declining markedly in subsequent years. In contrast to these relatively stagnant patterns, government expenditure on education shows a clear and sustained upward trend from the post-2008 period onward, indicating a gradual strengthening of public investment in education.

The time-series data in Table 1 indicate that L_GDPPC and L_GCF remain highly stable, with very low standard deviations (less than 0.11), reflecting consistent but relatively flat economic growth and investment over the 27 years. In contrast, the GINI index displays pronounced volatility, peaking around 2020 before declining sharply, whereas government expenditure on education (GEE) demonstrates a gradual upward trend beginning after 2008. Overall, the Jarque–Bera test probabilities, all exceeding 0.05, indicate that the distributions of all four variables do not significantly deviate from normality. These patterns highlight the stability of core economic indicators alongside the greater variability in income distribution and gradual policy-driven changes in educational investment.

Table 1. Descriptive statistics of data variables

Statistic	L_GDPPC	L_GCF	GEE	GINI
Mean	10.560	27.228	4.608	30.452
Median	10.560	27.237	4.544	30.800
Maximum	10.697	27.385	5.590	32.400
Minimum	10.381	27.037	3.922	28.000
Std. Dev.	0.101	0.094	0.456	1.229
Skewness	–0.157	0.016	0.325	–0.549
Kurtosis	1.714	2.373	2.163	2.256
Jarque–Bera	1.972	0.443	1.263	1.977

Figure 2 illustrates the dummy variables alongside the key macroeconomic indicators. The evidence shows that L_GDPPC and L_GCF exhibited relative stability over the period 1996–2022, whereas the GINI index experienced marked fluctuations. In particular, income inequality increased significantly during the 2008 global financial crisis and the COVID-19 pandemic, followed by a sharp decline thereafter. These movements in the GINI index coincide with the timing of the dummy variables, as the Crisis dummy peaks in 2009 and the Pandemic dummy remains in effect during 2020–2021. This correspondence indicates that major economic shocks exerted a substantial influence on income distribution, while aggregate economic output and investment levels were comparatively resilient over the same period.

To ensure the appropriate specification of econometric models and to avoid spurious regression results, the stationarity properties of the variables were first examined using the Augmented Dickey–Fuller (ADF) test proposed by Dickey and Fuller (1979, 1981) and the Phillips–Perron (PP) test developed by Phillips and Perron (1988). These unit root tests allow for different forms of serial correlation and heteroskedasticity in the error terms and are widely used in applied macroeconomic analysis. The results of the unit root tests determine the order of integration of each variable and guide the selection of a suitable cointegration framework.

Prior to the estimation of the ARDL model, a pairwise correlation matrix among the independent variables – gross capital formation (GCF), government expenditure on education (GEE), and the GINI index (GINI) – was examined to detect potential multicollinearity issues. This step ensures that the estimated coefficients are not distorted by excessive linear dependence among regressors.

To investigate the existence of a long-run equilibrium relationship between economic growth and its determinants, the Autoregressive Distributed Lag (ARDL) bounds testing approach developed by Pesaran et al. (2001) was employed. The ARDL methodology is particularly suitable when variables are integrated of mixed orders, I(0) and I(1), but not I(2). The unrestricted ARDL model is specified as follows:

$$\begin{aligned}\Delta \ln GDPPC_t &= \alpha^0 + \Sigma\left(\alpha_i \Delta \ln GDPPC_{\{t-i\}}\right) \\ &+ \Sigma\left(\beta_j \Delta \ln GCF_{\{t-j\}}\right) + \Sigma\left(\gamma_k \Delta GEE_{\{t-k\}}\right) \\ &+ \Sigma\left(\delta_l \Delta GINI_{\{t-l\}}\right) + \varphi^1 \ln GDPPC_{\{t-1\}} \\ &+ \varphi^2 \ln GCF_{\{t-1\}} + \varphi^3 GEE_{\{t-1\}} + \varphi^4 GINI_{\{t-1\}} + \varepsilon_t,\end{aligned} \quad (1)$$

where Δ denotes the first-difference operator; ln*GDPPC*$_t$ is the natural logarithm of real *GDP* per capita; *lnGCF*$_t$ is the natural logarithm of gross capital formation; *GEE*$_t$ denotes government expenditure on education; *GINI*$_t$ is the Gini index; α^0 is the intercept; α_i, β_j, γ_k, and δ_l are the short-run coefficients; φ^1-φ^4 are the long-run coefficients; *p*, *q*, *r*, and s represent the optimal lag lengths selected using the Akaike Information Criterion (AIC); *t* denotes the time period; and ε_t is the random error term.

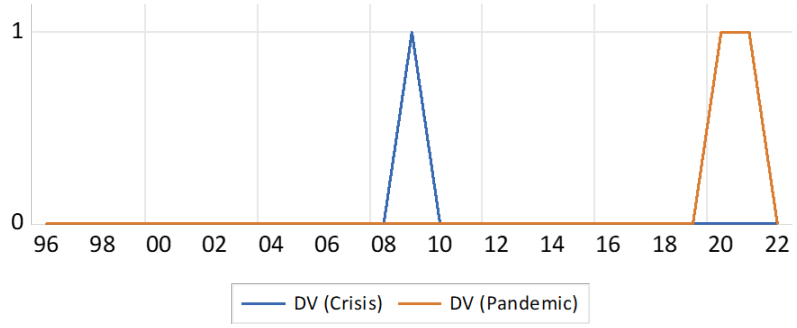

Figure 2. Crisis–pandemic dummy variables

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The Autoregressive Distributed Lag (ARDL) model is particularly suitable for small sample sizes and has been widely applied in empirical macroeconomic studies with limited annual observations. Given the dataset covering the period 1996–2022 (27 observations), the model remains statistically appropriate within this framework. The optimal lag structure for each variable was selected based on the Akaike Information Criterion (AIC) and Schwarz Information Criterion (SIC), ensuring the most efficient specification. The final estimated model uses the lag structure that minimizes information loss while maintaining model parsimony. After lag selection, the effective sample size is reduced accordingly, and all estimations are performed on the adjusted observation range. Robustness checks indicate that the main results remain stable under alternative lag specifications.

The joint significance of the lagged level variables is tested using an *F*-statistic (bounds test) to determine the presence of cointegration. If the computed *F*-statistic exceeds the upper critical bound, a long-run relationship is confirmed. Once cointegration is established, the long-run coefficients are estimated from the ARDL model. Short-run dynamics are then examined using the Error Correction Model (ECM), which captures the speed at which deviations from long-run equilibrium are corrected following short-term shocks.

To validate the robustness of the ARDL model, a set of diagnostic tests was conducted, including tests for serial correlation, heteroskedasticity, normality of residuals, and model specification. In addition, parameter stability was assessed using the CUSUM and CUSUM of Squares (CUSUMSQ) tests, ensuring that the estimated coefficients remain stable over the sample period.

As a robustness check and to quantify the numerical impact of the independent variables on economic growth, the Fully Modified Ordinary Least Squares (FMOLS) estimator developed by Phillips and Hansen (1990) was applied. FMOLS corrects for both endogeneity and serial correlation in cointegrated systems, providing unbiased and efficient long-run estimates. The FMOLS model is specified as:

$$\backslash \ln GDPPC_t = \alpha_0 + \beta_1 \backslash \ln GCF_t + \beta_2 GEE_t + \beta_3 GINI_t + u_t, \quad (2)$$

where $\ln GDPPC_t$ is the natural logarithm of real GDP per capita; $\ln GCF_t$ is the natural logarithm of gross capital formation; GEE_t denotes government expenditure on education; $GINI_t$ represents the Gini index; α_0 is the intercept; β_1, β_2, and β_3 are the long-run regression coefficients; and u_t is the random error term.

The FMOLS results serve as a complementary estimation technique to the ARDL framework and allow for a consistent assessment of the magnitude and direction of the effects of capital formation, education expenditure, and income inequality on economic growth.

3. RESULTS

The results of the unit root tests presented in Table 2 indicate that all four variables – L_GDPPC, GEE, L_GCF, and GINI – are non-stationary in their levels, as both the ADF and PP tests fail to reject the null hypothesis of a unit root at the 5% significance level. However, after first differencing, all series become stationary, with *p*-values falling below 0.05 in both tests, confirming the absence of unit roots in the differenced data. These findings suggest that the variables are integrated of order one, I(1), requiring appropriate transformation before performing regression or cointegration analyses. Accordingly, although the original series display trending patterns over time, their first differences are stable, allowing for reliable estimation of both short-run and long-run relationships using techniques suitable for I(1) processes.

The correlation matrix presented in Figure 3 shows that GEE (Gross Enrollment Ratio) exhibits a moderate positive correlation with both GINI (0.468) and L_GCF (0.585), indicating that higher levels of educational enrollment are associated with increased income inequality and greater capital formation. Conversely, the correlation between GINI and L_GCF is relatively weak (0.251), suggesting a limited direct relationship between income distribution and investment. Overall, these results imply that education and capital accumulation are more strongly interrelated, while their joint influ-

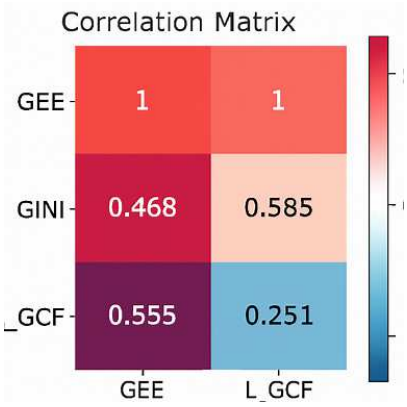

Figure 3. Correlation matrix of the variables

Table 2. Unit root test

Variable	Test	Level (p-value)	1st Difference (p-value)	Order of Integration
L_GDPPC	ADF	–3.169 (0.112)	–5.149 (0.001)	I(1)
	PP	–2.976 (0.157)	–11.374 (0.000)	I(1)
GEE	ADF	–2.381 (0.377)	–4.075 (0.021)	I(1)
	PP	–2.381 (0.377)	–4.067 (0.022)	I(1)
L_GCF	ADF	–2.398 (0.371)	–5.355 (0.001)	I(1)
	PP	–2.324 (0.407)	–10.825 (0.000)	I(1)
GINI	ADF	–0.755 (0.957)	–4.291 (0.012)	I(1)
	PP	–0.722 (0.960)	–4.276 (0.012)	I(1)

ence on income inequality is more significant than the direct link between inequality and investment.

Table 3 shows that the computed *F*-statistic (5.6702) exceeds the upper critical bounds at all conventional significance levels (10%, 5%, 2.5%, and 1%), indicating strong evidence of cointegration among the variables. This result confirms the existence of a stable long-run equilibrium relationship between GDP per capita, gross capital formation, government expenditure on education, and income inequality in Germany. Accordingly, the null hypothesis of no long-run relationship is rejected, justifying the application of ARDL-based long-run and short-run estimation techniques.

The ECM results presented in Table 4 indicate that GEE, L_GCF, and the GINI index exert statistically significant short-run effects on GDP per capita. In contrast, the COVID-19 pandemic dummy shows a significant negative impact. The error correction term (–0.5183) is negative and highly significant, implying that roughly 51.8% of any short-run deviation from the long-run equilibrium is adjusted within one year, thereby confirming the stability of the long-run relationship among the variables.

The diagnostic tests reported in Table 5 confirm the robustness of the ARDL model. Specifically, the Breusch–Godfrey LM test, with a p-value of 0.1385, indicates no evidence of serial correlation in the residuals at lag 1. In contrast, the Breusch–Pagan–Godfrey test, with a p-value of 0.8160, suggests that the error terms are homoskedastic, exhibiting constant variance. Collectively, these results affirm that the model's assumptions are satisfied, supporting the reliability of the estimated

Table 3. F-bound test results

Test Statistic	Value	Significance Level	I(0) Lower Bound	I(1) Upper Bound	Decision
F-statistic	5.6702	10%	2.08	3.00	Cointegration confirmed
		5%	2.39	3.38	Cointegration confirmed
		2.5%	2.70	3.73	Cointegration confirmed
		1%	3.06	4.15	Cointegration confirmed

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Table 4. ECM results

Variable	Coefficient	Std. Error	t-Statistic	Prob. (p-value)	Significance
D(GOVERNMENT_EXP)	0.0213	0.0077	2.7579	0.0186	Significant (5%)
D(L_GCF)	0.2719	0.0247	11.0074	0.0000	Significant (1%)
D(GINI_INDEX)	0.0097	0.0025	3.7517	0.0032	Significant (1%)
D(DV__PANDEMIC_)	–0.0609	0.0089	–6.8490	0.0000	Significant (1%)
CointEq(–1)*	–0.5183	0.0661	–7.8320	0.0000	Highly Significant

Table 5. Model diagnostic test results

Test	Null Hypothesis (H0)	Statistic (Obs*R-squared)	p-value (Chi-Square)	Decision
Breusch–Godfrey Serial Correlation LM	No serial correlation at up to 1 lag	2.194457	0.1385	Fail to reject
Breusch–Pagan–Godfrey Heteroskedasticity	Homoskedasticity	5.991726	0.8160	Fail to reject

coefficients and the validity of subsequent statistical inferences.

The model demonstrates strong statistical robustness, as indicated by the Breusch–Godfrey and Breusch–Pagan–Godfrey tests, which reveal no evidence of serial correlation or heteroskedasticity in the residuals. Additionally, the CUSUM and CUSUM of Squares plots in Figure 4 confirm that the model's parameters remain stable within the 5% significance bounds, collectively validating the reliability of the estimated long-run and short-run coefficients.

The FMOLS results presented in Table 6 indicate that government expenditure on education (GEE), gross capital formation (GCF), and the GINI index all have statistically significant and positive long-run effects on GDP per capita (GDPPC), suggesting that investments in human and physical capital, alongside income distribution dynamics, are key drivers of economic growth. Meanwhile, the crisis and pandemic dummy variables exhibit contrasting effects: economic crises show a marginal positive impact on GDPPC, whereas the pandemic exerts a pronounced negative influence, underscoring its disruptive effect on productivity and income. The model's high R^2 of 0.88 and adjusted R^2 of 0.84 demonstrate strong explanatory power and robustness, collectively highlighting the critical roles of structural, policy, and external factors in shaping long-term economic performance.

Based on the FMOLS estimation, a one-unit increase in government expenditure on education (GEE) is associated with an approximate

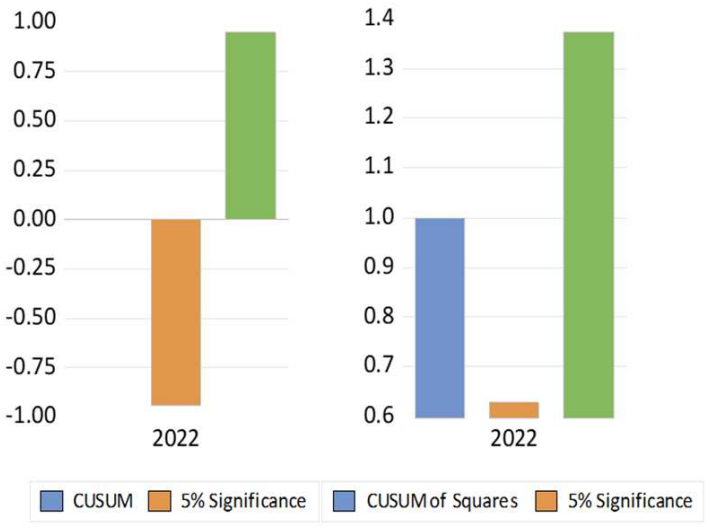

Figure 4. CUSUM test results

Table 6. Regression results: FMOLS estimation

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Govt Expenditure on Education	0.088152	0.013613	6.475735	0.0000
L_GCF (Log of Gross Capital Formation)	0.475060	0.060230	7.887471	0.0000
GINI_INDEX	0.023653	0.005934	3.985862	0.0011
DV__CRISIS_ (Dummy Variable)	0.055146	0.022664	2.433169	0.0271
DV__PANDEMIC_ (Dummy Variable)	–0.088930	0.018099	–4.913491	0.0002
C (Constant)	–3.480521	1.628663	–2.137041	0.0484

0.088-unit rise in GDP per capita (GDPPC), ceteris paribus, highlighting the positive contribution of educational investment to economic growth. Likewise, a 1% increase in gross capital formation (L_GCF) is linked to an increase of about 0.475 units in GDP per capita, underscoring the substantial role of physical capital accumulation in promoting economic performance. Additionally, a one-unit increase in the GINI index results in a 0.024-unit rise in GDP per capita, while economic crises are associated with a 0.055-unit increase and pandemics with a 0.089-unit decline, illustrating the differential effects of external shocks on economic outcomes.

The hypothesis testing results provide empirical support for all three proposed hypotheses. Specifically, *H1*, *H2*, and *H3* are accepted, confirming the statistically significant contributions of gross capital formation, government expenditure on education, and income inequality to economic growth across both estimation approaches.

4. DISCUSSION

The empirical findings confirm the existence of a stable long-run equilibrium relationship among GDP per capita, gross capital formation, government expenditure on education, and income inequality in Germany. The ARDL bounds test and the significant error correction term indicate that these variables move together over time and that short-run disequilibria are corrected at a relatively rapid pace. This adjustment mechanism reflects the structural coherence of the German economy, where capital accumulation and public policy instruments interact within a stable institutional framework.

Gross capital formation emerges as the most influential determinant of economic growth, exerting a strong and positive long-run elasticity with respect to GDP per capita. This result aligns closely with the evidence reported for France, where capital was identified as a long-run determinant of GDP and where bidirectional causality between output and capital formation was established (Ozatac et al., 2017). Although causality analysis is not explicitly examined in the present framework, the magnitude and significance of the capital coefficient suggest a mutually reinforcing relationship between investment and economic expansion in Germany. The findings thus support the broader theoretical consensus that sustained physical capital deepening remains central to long-term productivity growth in advanced economies.

Government expenditure on education also demonstrates a positive and statistically significant long-run effect on economic growth. This outcome corroborates the education-induced growth hypothesis and is consistent with the French case, where public expenditure on education was found to exert a unidirectional long-run causal impact on GDP (Ozatac et al., 2017). In contrast to the inverse relationship observed for Ukraine, where declining real education expenditure was associated with a rising share of highly qualified individuals, a result interpreted as structurally inconsistent and potentially distortionary (Vorhach, 2020), the German evidence indicates a more coherent transmission mechanism from education spending to economic performance. The positive association suggests that public investment in education in Germany effectively contributes to human capital formation, productivity enhancement, and innovation capacity, thereby reinforcing long-term growth.

Furthermore, while Vorhach (2020) finds no pronounced average relationship between higher education expenditure, qualification levels, and GDP across a broad sample of foreign countries, the German case demonstrates a clearer and sta-

http://dx.doi.org/10.21511/ppm.24(3).2026.12

tistically robust linkage between educational investment and economic output. This outcome resembles the more explicit trend identified for individual EU countries in which higher education expenditure corresponds with stronger qualification levels and higher GDP. Germany's results may reflect institutional efficiency, labor market alignment, and the quality of education systems, which together strengthen the growth-enhancing effects of educational spending.

The positive long-run association between income inequality and GDP per capita identified for Germany contributes to the ongoing debate on the inequality–growth nexus. Although a substantial share of empirical studies report a negative relationship between inequality and economic growth, meta-analytical evidence demonstrates that findings remain heterogeneous and context-dependent (Dorofeev, 2022). In particular, it has been argued that the level of inequality determines the direction of its impact, such that increases in relatively egalitarian and high-income countries may coincide with growth-enhancing mechanisms. The German case appears consistent with this conditional interpretation, as moderate inequality within a strong institutional framework may support savings, investment, and labor market flexibility. However, distributional evidence for Germany indicates that total income inequality has risen over recent decades, particularly at the upper tail of the distribution, with increasing persistence among top earners (Drechsel-Grau et al., 2022). These structural dynamics suggest that while inequality may coexist with economic growth at the macro level, its composition and persistence raise concerns regarding social mobility and inclusiveness. Consequently, the findings underscore that the inequality–growth relationship is nonlinear and structurally conditioned rather than universally negative or positive.

Overall, the comparative perspective indicates that Germany's growth dynamics are more closely aligned with the education-induced growth framework observed in France and the EU context than with the structural inconsistencies identified in Ukraine. The results reinforce the view that when institutional quality and policy effectiveness are sufficiently strong, both physical and human capital accumulation operate as complementary long-run determinants of economic growth.

CONCLUSION

The objective of this study was to examine the long-run and short-run effects of gross capital formation, government expenditure on education, and income inequality on economic growth in Germany. The empirical findings indicate that gross capital formation, government expenditure on education, and the GINI index all exert statistically significant positive effects on GDP per capita in the long run. The ARDL-ECM results further confirm a stable long-run equilibrium relationship among the variables, with approximately 51.8% of short-run deviations adjusted within one year. In addition, external shocks such as financial crises and pandemics were found to have significant but asymmetric effects on economic performance, with crises showing a mild positive impact and pandemics exerting a strong negative effect. Overall, the results suggest that sustainable economic growth in Germany is primarily driven by the accumulation of physical and human capital, while also being shaped by income distribution dynamics and external macroeconomic shocks. These findings imply that policy frameworks should prioritize continuous investment in education and capital formation, while ensuring that inequality remains within a developmentally supportive range and that adequate stabilization mechanisms are in place to mitigate the effects of large-scale economic disruptions.

AUTHOR CONTRIBUTIONS

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Writing – review & editing: Gunay Panahova, Asli Kazimova, Mustafa Kemal Oktem.

DECLARATION OF GENERATIVE AI IN THE WRITING PROCESS

In preparing this manuscript, we used AI-based tools exclusively for language editing and stylistic refinement. After use, we reviewed and edited the text and bear full responsibility for its content. All theoretical, analytical, and empirical results were generated using established econometric software programs.

REFERENCES

1. Aiyar, S., & Ebeke, C. (2020). Inequality of opportunity, inequality of income and economic growth. *World Development, 136*, Article 105115. https://doi.org/10.1016/j.worlddev.2020.105115
2. Albig, H., Clemens, M., Fichtner, F., Gebauer, S., Junker, S., & Kholodilin, K. (2017). How rising income inequality influenced economic growth in Germany. *DIW Economic Bulletin, 7*(10), 113-121. Retrieved from https://hdl.handle.net/10419/157336
3. BMWK. (2026). *Economic Situation and Cyclical Development. Federal Ministry for Economic Affairs and Energy.* Retrieved from https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Dossier/economic-development.html
4. Castilho, D., & Fuinhas, J. A. (2025). Exploring the effects of tourism capital investment on income inequality and poverty in the European Union countries. *Journal of Economic Structures, 14*(1), Article 6. https://doi.org/10.1186/s40008-025-00349-2
5. Ciaschini, C., & Salvati, L. (2026). Income growth. In *Sustainable Development: Official Statistics and Thematic Indicators as a Compass to Understand Complexity* (pp. 19-33). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-032-12559-0_2
6. Consiglio, V. S., & Sologon, D. M. (2022). The myth of equal opportunity in Germany? Wage inequality and the role of (non-) academic family background for differences in capital endowments and returns on the labour market. *Social Indicators Research, 159*(2), 455-493. https://doi.org/10.1007/s11205-021-02719-2
7. Cuaresma, J. C., Doppelhofer, G., & Feldkircher, M. (2014). The determinants of economic growth in European regions. *Regional Studies, 48*(1), 44-67. https://doi.org/10.1080/00343404.2012.678824
8. DESTATIS. (2026). *National accounts, domestic product. Economy.* Statistisches Bundesam. Retrieved from https://www.destatis.de/EN/Themes/Economy/National-Accounts-Domestic-Product/_node.html
9. Diakodimitriou, D., Tsioutsios, A., & Papageorgiou, T. (2025). Education expenditures and growth: Is R&D the link? *Journal of Policy Modeling, 47*(2), 322-337. https://doi.org/10.1016/j.jpolmod.2025.01.003
10. Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association, 74*(366), 427-431. https://doi.org/10.1080/01621459.1979.10482531
11. Dickey, D. A., & Fuller, W. A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica, 49*(4), 1057-1072. Retrieved from https://ideas.repec.org/a/ecm/emetrp/v49y1981i4p1057-72.html
12. Dorofeev, M. L. (2022). Interrelations between income inequality and sustainable economic growth: Contradictions of empirical research and new results. *Economies, 10*(2), Article 44. https://doi.org/10.3390/economies10020044
13. Drechsel-Grau, M., Peichl, A., Schmid, K. D., Schmieder, J. F., Walz, H., & Wolter, S. (2022). Inequality and income dynamics in Germany. *Quantitative Economics, 13*(4), 1593-1635. https://doi.org/10.3982/QE1912
14. EC. (2025). *Economic forecast for Germany. Economy and Finance.* European Commission. Retrieved from https://economy-finance.ec.europa.eu/economic-surveillance-eu-member-states/country-pages/germany/economic-forecast-germany_en

http://dx.doi.org/10.21511/ppm.24(3).2026.12

15. Egger, H., Egger, P., Falkinger, J., & Grossmann, V. (2010). The impact of capital market integration on educational choice and the consequences for economic growth. *The World Economy, 33*(10), 1241-1268. Retrieved from https://ideas.repec.org/a/bla/worlde/v33y2010i10p1241-1268.html

16. Gulaliyev, M., Hasanov, R., Sultanova, N., Ibrahimli, L., & Guliyeva, N. (2024). R&D expenditure and its macroeconomic effects: A comparative study of Israel and South Caucasus countries. *Public and Municipal Finance, 13*(2), 44-55. http://dx.doi.org/10.21511/pmf.13(2).2024.05

17. Hanushek, E. A., & Woessmann, L. (2020). Education, knowledge capital, and economic growth. In S. Bradley & C. Green (Eds.), *The Economics of Education* (2nd ed., pp. 171-182). Elsevier. https://doi.org/10.1016/B978-0-12-815391-8.00014-8

18. Hasanov, R. I., & Azizli, N. N. (2025). Doughnut economics: Exploring a new alternative sustainable model. *Economic Alternatives, 2025*(1), 149-165. https://doi.org/10.37075/EA.2025.1.08

19. Hasanov, R. I., Giyasova, Z., Azizova, R., Huseynova, S., & Zemri, B. E. (2024). Long-term dynamics between human development and environmental sustainability: An empirical analysis of CO_2 emissions in Azerbaijan. *Challenges in Sustainability, 12*(4), 273-280. https://doi.org/10.56578/cis120403

20. IMF. (n.d.). *Germany, Datasets.* International Monetary Fund. Retrieved from https://www.imf.org/external/datamapper/profile/DEU

21. Ismeti, E., & Hameli, K. (2026). The effect of education on economic growth and unemployment rate – A comparative analysis between Kosovo and Germany. *International Journal of Comparative Education and Development*, *28*(1), 20-35. https://doi.org/10.1108/IJCED-07-2025-0098

22. KPMG. (2026, July). *Economic Key Facts Germany.* Retrieved from https://kpmg.com/de/en/insights/geopolitics/economic-key-facts-germany.html

23. Makhlouf, Y., & Lalley, C. (2023). Education expansion, income inequality and structural transformation: Evidence from OECD countries. *Social Indicators Research, 169*(1), 255-281. https://doi.org/10.1007/s11205-023-03161-2

24. Mammadov, E., Azimzadeh, A., Valizadeh, F., Ibrahimli, M. B., & Farzullayev, T. (2024). The role of innovations in companies for sustainable economic development. In *International Conference on Smart Environment and Green Technologies* (pp. 449-457). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-81564-5_53

25. Mitu, N. E., & Mitu, G. T. (2025). Measuring equitable prosperity in the EU-27: Introducing the IDDO, a composite index of growth and income inequality (2005–2024). *World, 6*(3), Article 103. https://doi.org/10.3390/world6030103

26. Motahar, S. A., & Mamipour, S. (2025). The impact of wealth inequality on economic growth: A machine learning approach. *Computational Economics, 67,* 1233-1258. https://doi.org/10.1007/s10614-025-10902-7

27. Niftiyev, I. (2025). Artificial intelligence in green management and sustainability: A bibliometric survey. *E3S Web of Conferences, 608*, Article 05019. https://doi.org/10.1051/e3sconf/202560805019

28. Nunoo, J., Taale, F., Ofori, I. K., Mwinlaaru, P. Y., & Adama, A. Y. S. (2024). Human capital and income inequality in Africa: Robust governance synergies and thresholds. *Cogent Economics & Finance, 12*(1), Article 2417757. https://doi.org/10.1080/23322039.2024.2417757

29. Oliveira, H., Moutinho, V. F., & Afonso, O. (2025). Exploring the relationship between technological progress, human capital, political uncertain, energy consumption, and economic growth: Evidence from a panel data analysis. *Journal of the Knowledge Economy, 16*(3), 13482-13515. https://doi.org/10.1007/s13132-024-02431-9

30. Ozatac, N., Taspinar, N., El Rifai, O., & Eren, B. (2017). The relationship between government expenditure on education and economic growth: The case of France. In *The Impact of Globalization on International Finance and Accounting: 18th Annual Conference on Finance and Accounting (ACFA)* (pp. 61-70). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-68762-9_7

31. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289-326. https://doi.org/10.1002/jae.616

32. Phillips, P. C. B., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with I(1) processes. *Review of Economic Studies, 57*(1), 99-125. https://doi.org/10.2307/2297545

33. Phillips, P. C. B., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika, 75*(2), 335-346. https://doi.org/10.1093/biomet/75.2.335

34. Prasetyo, P. E., & Kistanti, N. R. (2020). Human capital, institutional economics and entrepreneurship as a driver for quality & sustainable economic growth. *Entrepreneurship and Sustainability Issues, 7*(4), 2575-2589. http://doi.org/10.9770/jesi.2020.7.4(1)

35. Rehme, G. (2007). Education, economic growth and measured income inequality. *Economica, 74*(295), 493-514. https://doi.org/10.1111/j.1468-0335.2006.00555.x

36. Roszko-Wójtowicz, E., Sharma, G. D., Dańska-Borsiak, B., & Grzelak, M. M. (2025). Social capital as a driver of e-commerce development: Evidence from European panel data analysis. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 20*(2), 681-712. Retrieved from https://www.ceeol.com/search/article-detail?id=1390840

37. Vorhach, O. (2020). Empirical evaluation of the education expenditure impact on economic growth. *Virtual Economics, 3*(4), 48-71. Retrieved from https://www.ceeol.com/search/article-detail?id=914874

38. World Bank. (n.d.). *Data, Germany.* World Bank Database. Retrieved from https://data.worldbank.org/country/germany