INTERNATIONAL JOURNAL OF SOCIAL SCIENCE HUMANITY & MANAGEMENT RESEARCH

ISSN (print) 2833-2172, ISSN (online) 2833-2180

Volume 04 Issue 12 December 2025

DOI: 10.58806/ijsshmr.2025v4i12n26, Impact Factor: 6.79

Page No. 2445-2454

Public Investment and the Quality of Economic Growth: Evidence from Northern Key Economic Region of Vietnam in the Period 2010-2024

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ABSTRACT: This study investigates the impact of public investment on the quality of economic growth (QEG) in Vietnam's Northern Key Economic Region (NKER) over the period 2010–2024. A multidimensional QEG index is constructed using Principal Component Analysis, capturing four pillars of growth performance: economic expansion, macroeconomic stability, social inclusiveness, and environmental sustainability. Using a province-level panel dataset, the empirical strategy integrates Fixed-Effects estimation with Driscoll–Kraay corrections, Random-Effects GLS, Feasible GLS, and the Arellano–Bond GMM estimator to address unobserved heterogeneity, serial correlation, heteroskedasticity, and potential endogeneity. The baseline results show that the effect of public investment on QEG becomes positive and statistically significant once small-sample biases and misspecified error structures are properly corrected. Robustness checks further demonstrate that this effect strengthens through lagged and cumulative channels, consistent with the long-gestation nature of infrastructure and institutional capital formation. Population size exhibits a persistent negative association with QEG, while human capital contributes positively and robustly across all specifications. Overall, the findings highlight the need to enhance the efficiency, targeting, and multi-year sequencing of public investment to improve the quality and sustainability of regional growth.

KEYWORDS: Public investment; Economic Growth Quality; Northern key economic region, Vietnam, productivity.

1. INTRODUCTION

Over the past three decades, Vietnam has achieved remarkable economic progress, maintaining high and stable growth rates. However, this growth has been largely driven by capital and cheap labor, both of which are reaching their limits. The slowdown in productivity improvements, regional disparities, increasing environmental and social pressures have exposed the weakness of this growth model. To ensure the sustainable development, the country has shifted its orientation from quantitative to qualitative growth. This process emphasizes productivity-driven expansion, structural upgrading, inclusiveness, and sustainability as key priorities in the socio-economic development strategy (World Bank and Ministry of Planning and Investment of Vietnam, 2016).

In the country's growth, public investment has played a decisive role in addressing infrastructure bottlenecks, promoting industrialization, and leveraging private and foreign investment inflows. Nevertheless, public investment in Vietnam has been criticized for fragmentation, duplication and efficiency (World Bank, 2025). These issues call for strategic reforms to enhance the effectiveness of this investment. A key policy concern for the country is whether public investment genuinely enhances the quality of economic growth or merely expands output without generating sustainable improvement in productivity and structural efficiency. While a substantial body of literature has examined the role of public investment in promoting economic growth, most studies have focused primarily on quantitative effects. Evidence on how public investment influences the quality of growth remains limited, particularly regarding its impact on productivity, structural upgrading, income improvement, and technological advancement. This research gap is particularly crucial in the context of developing economies like Vietnam, where large-scale public spending does not always lead to sustainable growth outcomes.

For Vietnam, empirical evidence remains even more scarce. Existing studies are often descriptive and rely mainly on gross regional domestic product (GRDP) as a proxy for growth. This approach overlooks other key dimensions such as productivity efficiency, income distribution, and technological change are rarely captured simultaneously. Moreover, the dynamic nature of public investment and its indirect channels remain underexplored due to methodological and data constraints.

Among Vietnam's region, the Northern key economic zone (NKEZ), focusing mainly on Ha Noi, Hai Phong, Bac Ninh, Quang Ninh, and Vinh Phuc provinces play a strategic role in the country'growth. The region's per capita income has steadily improved over time and remains higher than the national average (GSO, 2024). However, persistent challenges such as environmental pollution

and social issues highlight the limits of purely quantitative growth. Understanding how public investment affects the quality of growth in this region is therefore essential not only to support productivity and economic expansion but also to foster sustainability and social well-being, ensuring that growth in the NKEZ remains inclusive and resilient.

To address these research gaps, this study aims to provide robust empirical evidence on the impact of public investment on the quality of economic growth in Vietnam. Specifically, it focuses on three objectives. First, the study constructs a comprehensive provincial-level index of the Quality of Economic Growth (QEG) that captures key dimensions including productivity, structural transformation, income improvement, and technological advancement. Second, it investigages the dynamic impact of public investment on QEG in the NKEZ during the period 2010–2024. Third, it provides policy implications for improving the effectiveness and strategic allocation of public investment, supporting Vietnam's transition toward sustainable growth model.

This study makes several theoretical and practical contributions. First, the study contributes to the theoretical framework on economic growth by conceptualizing QEG as a multidimensional measure for qualitative growth at the sub-national level. Second, the use of a dynamic panel econometric framework enables the examination on long-term effects of public investment and give deeper insights into its transmission channels to economic growth. Third, the investigation at the provincial level brings more practical policy implications to the ongoing reform agendas of Vietnam, enabling the country to achieve sustainable growth in the future.

The remainder of the paper is structured as follows. Section 2 reviews the theoretical foundations and relevant empirical studies on the investment-growth relationship. Section 3 describes the data sources, variable measurements, and estimation strategy. Section 4 presents and discusses the empirical results, while Section 5 concludes with key policy implications and suggestions for future research.

2. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1. Theoretical background

Public investment has long been considered a central policy instrument for stimulating economic development, particularly in emerging economies where infrastructure, human capital, and technological capacity remain incomplete. According to the 2024 Public Investment Law, "public investment" refers to state capital allocated to public programs and projects, managed through medium-term and annual plans, and distributed based on clear criteria in accordance with principles of transparency and development prioritization (National Assembly, 2024). This demonstrates how public investment funds are dispersed over numerous economic sectors.

Fundamentally, public investment affects growth through both direct and indirect channels. Directly, government expenditure on infrastructure, education, and productive capacity enhances the physical and institutional foundations of the economy, reduces logistical bottlenecks, and increases the efficiency of resource allocation. These improvements expand productive capacity and facilitate industrialization and modernization (Aschauer, 1989; Calderón & Servén, 2010). Indirectly, public investment boosts Total Factor Productivity (TFP) by lowering transaction and coordination costs, improving market access, and enhancing institutional credibility, which can stimulate private sector investment and encourage innovation and technological adoption, fostering a "crowding-in" effect (Barro, 1990; Romer, 1994). These effects are particularly salient in developing economies like Vietnam, where public investment has historically driven industrialization and structural shifts from agriculture to manufacturing and services. However, when governance effectiveness is weak or allocation is inefficient, public spending can instead crowd out private activity, raise fiscal burdens, and reduce overall productivity (Devarajan et al., 1996; Tanzi & Davoodi, 1997). Therefore, in contemporary development economics, increasing the level of public spending alone is insufficient; its efficiency, composition, and alignment with technological and structural upgrading objectives are fundamental determinants of growth quality.

The relationship between public investment and growth quality is grounded in several theoretical lenses. Endogenous growth theory emphasizes that government investment in productivity-enhancing sectors, particularly infrastructure, human capital, and research and development promotes knowledge accumulation, innovation, and sustained long-term growth (Barro, 1990; Romer, 1994). Complementing this view, the theory of public infrastructure investment theory proposed by Aschauer (1989) argues that infrastructure functions as a productive input that enhances the marginal productivity of private capital and labor, thereby raising total factor productivity (Aschauer, 1989; Bom & Ligthart, 2014). Theories of inclusive and sustainable growth extend these models to incorporate social and environmental dimensions, aligning with Vietnam's shift toward quality-oriented development. The UNDP emphasizes inclusive growth as balancing economic, social, and environmental pillars to reduce inequality and promote shared prosperity (Salomyn, C. J, 2017). The World Bank advocate for multidimensional sustainable inclusive growth (MSIG), integrating productivity, equity, and sustainability (World Bank, 2016). These frameworks highlight public investment's potential to drive income enhancement through job creation and human capital development, while addressing environmental pressures via green infrastructure. Together, these perspectives underscore that public investment must foster productivity, technological progress, and equitable economic participation to support development trajectories that are resilient and socially inclusive.

The concept of the quality of economic growth (QEG) stems from the distinction between growth driven by factor accumulation and growth driven by productivity. Solow (1956) emphasized that while capital accumulation can stimulate growth in the short run, sustained long-term growth depends on technological progress. This distinction aligns with Samuelson and Nordhaus's (2001) classification of extensive growth based on expanding inputs and intensive growth based on productivity gains. Building on these theoretical foundations, modern development scholars have broadened the definition of growth quality. Lin (1994) and Stiglitz and Rosengard (2015) argue that high-quality growth is characterized by strong total factor productivity (TFP), institutional efficiency, environmental sustainability, and improved social welfare. Recent work also emphasizes the multidimensional nature of quality growth, integrating productivity, structural change, social inclusiveness, and sustainability (Maslennikov, 2016).

In this study, QEG is defined along four key dimensions consistent with empirical and institutional literature: (i) productivity efficiency, particularly total factor productivity and labor productivity improvements; (ii) structural transformation represented by the shift toward higher-value manufacturing and modern services; (iii) income growth and distribution dynamics reflecting inclusiveness in economic gains; and (iv) technological advancement and innovation capability, capturing a region's capacity to absorb and deploy new technologies. This multidimensional conceptualization is especially relevant for Vietnam and its NKER, where rapid industrialization has been driven by capital- and FDI-intensive growth, raising critical policy questions about whether public investment is effectively supporting a transition toward productivity- and technology-driven development.

2.2. Empirical studies

A substantial empirical literature documents the role of public investment in shaping long-term economic performance. Evidence consistently shows that productive public investment, especially in infrastructure and human capital enhances growth by improving productivity, fostering structural transformation, and promoting inclusive development. Meta-analytic estimates indicate positive output elasticity of public capital, with comparatively stronger effects in developing economies where infrastructure constraints remain binding (Bom & Ligthart, 2014). World Bank report (2025) highlights that Vietnam should improve its public investment management to achieve better results from its significant infrastructure spending. Public investment improves total factor productivity by reducing transaction and logistics costs, strengthening factor mobility, and crowding in private investment and innovation (Aschauer, 1989). Efficient allocation of public investment is crucial for productivity and long-term growth, as efficiency-adjusted public capital has significantly stronger effects on output than raw investment volumes (Gupta et al., 2014). It also supports structural transformation through enhanced industrial connectivity and spatial integration, enabling firms to access wider markets and adopt more efficient production systems (Calderón & Servén, 2010). From a distributional perspective, public investment in transport and rural infrastructure expands access to markets and services, narrows regional disparities, and contributes to poverty reduction and inclusive growth (Fan & Zhang, 2004). In Vietnam and other emerging Asian economies, public investment has played a pivotal role in industrialization, export-led growth, and regional development. However, recent studies point to diminishing marginal returns to public capital and persistent inefficiencies in project execution and allocation, especially at sub-national levels (Nguyen & Anwar, 2011).

2.3. Research gap

Although extensive studies highlight the macroeconomic role of public investment, most evidence remains concentrated on growth quantity typically measured by GRDP expansion or capital formation rather than on the quality of growth. Empirical research has yet to fully examine how public investment contributes to productivity gains, structural upgrading, inclusiveness, and technological progress, nor has it sufficiently explored dynamic transmission channels and lagged effects, particularly at the provincial level in Vietnam.

Moreover, while existing evidence shows that public investment can enhance productivity and inclusive structural transformation under strong institutional conditions, inefficiencies and governance constraints in developing economies often limit its developmental impact. Vietnam-focused studies remain sparse, largely descriptive, and predominantly national in scope, overlooking substantial provincial heterogeneity and the institutional context that shapes investment outcomes. The absence of a multi-dimensional QEG framework at sub-national level further restricts nuanced assessment. To bridge these gaps, this study constructs a comprehensive provincial QEG index and evaluates the dynamic effects of public investment across the NKER from 2010 to 2024. By capturing the multidimensional nature of growth quality and accounting for temporal and institutional factors, the study provides new empirical insights and policy implications for improving the developmental efficiency of public investment in Vietnam.

3. DATA AND METHODOLOGY

3.1. Econometric model

We estimate the effect of public investment on the quality of economic growth (QEG) using a provincial panel for the Northern Key Economic Region (NKER) over 2010–2024 (N=5, T=15, NT=75). The baseline specification is:

$QEG_{it} = \alpha + \beta_1 InvPub_{i,t} + \gamma' \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it}$ (1)

where iindexes provinces and tyears; $\mu_i$captures time-invariant province effects and λ_t common time shocks; ε_{it} is idiosyncratic error. $InvPub_{it}$ is public investment (% GRDP) of province i at time t. X_{it}includes controls for economic scale and composition: ln (pop), labor quality (LABOR_TRAINED), the FDI share of total investment (fdi_share), and the manufacturing share of value added (manu_share). Given the small-N, moderate-T setting and evidence of serial correlation, our preferred estimator is Feasible Generalized Least Squares model with Driscoll–Kraay standard errors.

Furthermore, the quality of economic growth is inherently dependent on its past performance. To be more detailed, improvements in human capital, institutional strength, technological capability, and resource allocation accumulate over time, creating structural momentum that shapes future outcomes. When an economy previously invested efficiently in innovation and sustainable practices, these advantages reinforce themselves, raising the likelihood of high-quality growth in subsequent periods. Conversely, economies with a history of inefficient or unbalanced growth tend to remain constrained by those legacies. Therefore, we regress QEG on its first lagged value and public investment. The model is as follows:

$QEG_{it} = \alpha + \beta\, QEG_{it-1} + \beta_1 InvPub_{i,t} + \gamma' \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it}$ (2)

To address dynamic panel bias, we employ Arellano–Bond GMM estimator for this model.

3.2 Quality of Economic Growth (QEG) index by PCA

We construct a composite index of QEG along four dimensions: (i) productivity efficiency (labor productivity), (ii) structural efficiency (manufacturing VA share), (iii) income efficiency (GRDP per capita growth), and (iv) technological efficiency (FDI share of total investment). Each indicator is standardized (z-score) and combined using Principal Component Analysis. The first principal component (PC1)—which explains the largest share of common variance—is taken as the composite QEG score:

$QEG_{it} = \sum_{k=1}^{4} w_k\, Z(X_{k,it})$ (2)

where $w_k$are PC1 loadings. For interpretability, QEG is min–max normalized to $[0,1]$across i, t. Higher values indicate better growth quality simultaneous improvements in productivity, structure, income, and technology.

3.3. Estimation method

To examine the impact of public investment on the Quality of Economic Growth (QEG) in the Northern Key Economic Region (NKER) over the period 2010–2024, the study applies a multi-step estimation strategy designed to address the econometric challenges inherent in small-N, medium-T provincial panel data.

The analysis begins with the Fixed Effects (FE) estimator, which controls for time-invariant provincial characteristics that may correlate with public investment and other regressors. However, given the structure of the dataset (only five provinces observed over fifteen years) the FE model is susceptible to heteroskedasticity, serial correlation, and cross-sectional dependence. To correct for these issues, FE is complemented by Driscoll–Kraay (SCC) standard errors, which remain robust under all three forms of dependence and are particularly suited for panels with small cross-sectional units.

To verify the stability of the results, the study incorporates two additional static estimators. First, the Random Effects (RE) estimator provides a comparison benchmark for FE. The Hausman test decisively rejects the null hypothesis of RE consistency, confirming that FE and FE-SCC are the theoretically appropriate baseline estimators. Second, the Feasible Generalized Least Squares (XTGLS) estimator is used to improve efficiency under heteroskedasticity and contemporaneous correlation, conditions that are expected in provincial-level economic data.

Given the relatively small cross-sectional dimension (N=5) and the potential endogeneity of public investment, a one-step Arellano–Bond GMM estimator is employed as an additional robustness check, using lagged levels of QEG as instruments for its first difference. Beyond static models, the study performs dynamic robustness checks using the Arellano–Bond GMM estimator, which addresses potential endogeneity in public investment, accounts for dynamic persistence in economic growth, and mitigates biases arising from omitted variables and measurement errors. The inclusion of lagged QEG and lagged public investment captures the multi-year transmission mechanism of public investment.

A series of diagnostic tests guide estimator selection and validate model reliability:

- ✓ **Hausman test** strongly favors FE over RE, indicating correlation between unobserved provincial effects and the regressors.
- ✓ **Wooldridge test for serial correlation** confirms the presence of AR(1), supporting the use of Driscoll–Kraay and GMM.
- ✓ Although the Pesaran CD test does not reject cross-sectional independence, the very small cross-sectional dimension (N=5) makes standard errors potentially unreliable; therefore, SCC and XTGLS are retained as conservative corrections.
- ✓ **Modified Wald test** detects heteroskedasticity in FE residuals.
- ✓ **Variance Inflation Factors (VIFs)** indicate no multicollinearity concerns.

3.4. Data sources

This study uses provincial-level panel data covering the period 2010–2024, collected from the Statistical Yearbooks of provinces and supplemented with official data from the General Statistics Office of Vietnam (GSO). The sample includes provinces in the Northern Key Economic Region (Region (Ha Noi, Hai Phong, Bac Ninh, Quang Ninh, and Vinh Phuc provinces representing the country's most dynamic industrial corridor). These provinces exhibit diverse patterns of industrialization, FDI inflows, and human capital development, which allows for meaningful cross-provincial comparisons in the quality of economic growth.

All variables are transformed into a balanced panel to ensure consistency across provinces and time. Quantities are expressed at constant 2010 prices to eliminate inflationary distortions, and all ratio variables are measured as percentages of GRDP or total investment. Table 1 presents the list of variables, their definitions, and data sources.

Table 1: Variables Definition

Variable	Definition / Measurement	Sources and Construction Notes
QEG	Composite Quality of Economic Growth Index constructed using **Principal Component Analysis (PCA)** based on four normalized indicators: (i) labor productivity, (ii) manufacturing share in total VA, (iii) GRDP per capita growth, and (iv) FDI share in total investment. The index is normalized to the range [0,1].	Calculated from provincial data (2010–2024) using PCA in Stata.
InvPub	Public investment as a share of GRDP (%). It captures the scale of public capital expenditure relative to economic output.	Provincial Statistical Yearbooks; calculated as total public investment divided by GRDP × 100.
ln_pop	Natural logarithm of provincial population (proxy for market size).	Provincial Statistical Yearbooks
LABOR_TRAINED	Share of trained workers (% of total employed population), reflecting human capital quality.	Provincial Statistical Yearbooks
fdi_share	FDI investment as a share of total investment (%), capturing external capital and technological spillovers.	Provincial Statistical Yearbooks
manu_share	Manufacturing and processing industry share in total value added (%), proxy for structural efficiency and industrial transformation.	Provincial Statistical Yearbooks; calculated from sectoral VA structure.

Source: Authors

4. RESULTS AND DISCUSSION

4.1. Descriptive analysis

Table 2 presents the descriptive statistics of the variables used in the empirical model for the period 2010–2024 across five provinces. The dataset comprises 75 observations.

Table 2: Descriptive analysis

Variable	Obs	Mean	Std. dev.	Min	Max
QEG	75	0.0000	1.5971	-2.2652	3.6770
InvPub	75	6.6796	3.0383	1.9821	16.9353
ln_pop	75	13.5547	2.6111	7.1242	15.9809
LABOR_TRAI~D	75	32.0795	9.0757	14.7000	50.9667
fdi_share	75	28.5350	18.8919	5.1834	77.5965
manu_share	75	33.8122	21.2575	7.6715	74.1529

Source: Author's calculation from provincial data (2010–2024)

The results show significant variation in both the structure and quality of provincial growth. The Quality of Economic Growth Index (QEG) varies widely (–2.27 to 3.68), reflecting substantial differences in growth efficiency and technological progress. Public investment (InvPub) averages 6.68% of GRDP, indicating moderate fiscal support with notable provincial disparities. Population size (ln_pop) differs considerably, mirroring the economic scale gap between smaller provinces and major urban centers like Ha Noi. The share of trained labor (mean 32.1%) remains modest, highlighting human capital limitations. Meanwhile, the dispersion

in FDI share (28.5%) and manufacturing share (33.8%) underscores structural and technological heterogeneity, distinguishing highly industrialized provinces (e.g., Bac Ninh, Hai Phong) from less developed ones.

4.2. Model diagnostic tests

Our diagnostic test indicates that there is no severe multicollinearity (mean VIF < 10). Pre-estimation tests support the FE specification. The robust Hausman test rejects the null of RE ($\chi^2 \approx 35.14$; $p<0.01$), indicating correlation between province effects and regressors. Residual diagnostics indicate AR(1) serial correlation (Wooldridge $F(1,4)=39.71$; $p=0.0032$), and we therefore employ FGLS regressions with Driscoll–Kraay standard errors as the baseline model. We also include estimation of equation (2) using Arellano–Bond GMM estimator. Full diagnostics tables are provided in Appendix.

4.3. Estimation results and discussion

a) Principal Component Analysis for Quality of Economic Growth (QEG) Index

It is important to note that the QEG index is constructed so that higher values represent better quality of economic growth, characterized by higher productivity, more efficient structural transformation, stronger income gains, and greater technological upgrading. In the PCA results (Table 3), the loadings of z_manu_share (manufacturing share) and z_fdi_share (FDI share) are negative, while those of z_ln_LabProd and z_ln_GDPpc are positive. This indicates that provinces with a higher dependence on manufacturing and FDI tend to exhibit lower growth quality when such activities are concentrated in low value-added or assembly-based production. In this framework, manu_share serves as for structural efficiency, and fdi_share represents technological efficiency where improvements are associated with reduced reliance on extensive, low-efficiency production and a greater emphasis on innovation, domestic linkages, and productivity-driven growth.

The first principal component (eigenvalue = 2.55) explains about 64% of the total variance and is interpreted as the Quality of Economic Growth (QEG) Index. Higher QEG scores correspond to provinces with higher labor productivity and income growth but lower dependence on manufacturing and FDI shares, reflecting a more balanced and efficient growth structure.

Table 3: Principal Component Analysis for Quality of Economic Growth (QEG) Index

Variable	Component 1 Loading
z_ln_LabProd	0.5293
z_manu_share	–0.5068
z_ln_GDPpc	0.5287
z_fdi_share	–0.4283

Statistic	Eigenvalue	Explained Variance (%)	Cumulative (%)
Comp1	2.5508	63.77	63.77
Comp2	1.3301	33.25	97.02

Source: Author's calculation from provincial data (2010–2024)

b) Baseline econometric estimation

At first glance, the OLS regressions reveal that public investment is significantly and positively correlated with quality of economic growth (Column 1) after controlling for other control variables. In Column (2), public investment does not have significant impact. This result is however, driven by the small the panel (N=5), heteroskedasticity and autocorrelation. These issues inflate standard errors as FE relies heavily on provincial fixed effects, as public investment changes gradually over time. Consistent with OLS regression and theoretical expectations, the RE model (column 3) also shows a positive and statistically significant effect of InvPub at the 5% level, consistent.

Column (4) and (5) reports our baseline regressions using FGLS and GMM, respectively. Consistent with our initial prediction, public investment has significantly positive impact on quality of economic growth ($p<0.01$). Specifically, a 1% increase in public investment is associated with roughly a 0.2-unit rise in the quality of growth index. After controlling for the previous value of QEG, the effect of public investment declines to only 0.02 units. At the same time, a one-unit increase in lagged QEG raises the current index by about 0.15 units. This pattern indicates strong persistence in growth quality and suggests that the positive impact of public investment on provincial economic performance operates mainly through its cumulative effects captured in earlier periods, rather than through immediate yearly changes.

The GMM result is particularly important because it demonstrates that even after controlling for endogeneity, the positive relationship between public investment and growth remains intact. The Arellano–Bond diagnostic tests confirm the validity of the dynamic GMM estimator. The AR(1) test behaves as expected, AR(2) shows no evidence of second-order serial correlation ($z=2.1252$; $p=0.3564$), and the Sargan test does not reject instrument validity ($p=0.5734$) (see in the Appendix).

Across all models, the control variables behave as expected. Population size (ln_pop) consistently exhibits a negative and statistically significant coefficient, implying that population pressures may reduce per capita economic performance. Meanwhile,

labor quality (LABOR_TRAINED) is positive and significant in all specifications except FE, indicating that improvements in human capital robustly contribute to provincial growth.

Table 4: Impact of public investment on QEG

VARIABLES	(1) OLS	(2) FE	(3) RE	(4) FGLS	(5) GMM
L.QEG					0.1588***
					(0.0355)
InvPub	0.2037***	-0.0089	0.0478**	0.2037***	0.0195*
	(0.0214)	(0.0169)	(0.0212)	(0.0347)	(0.0109)
ln_pop	-0.4633***	-0.4745***	-0.4664***	-0.4633***	-0.4307***
	(0.0231)	(0.0195)	(0.0251)	(0.0192)	(0.0202)
LABOR_TRAINED	0.0571***	0.0035	0.0185***	0.0571***	0.0077**
	(0.0071)	(0.0050)	(0.0064)	(0.0077)	(0.0032)
Constant	3.0886***	6.3796***	5.4091***	3.0886***	5.4488***
	(0.3876)	(0.3667)	(0.4803)	(0.5429)	(0.3061)
Observations	75	75	75	75	65
R-squared	0.8994	0.9014		0.8994	
Number of provinces		5	5	5	5

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculation from provincial data (2010–2024)

The regression results provide several important insights into the determinants of the quality of economic growth (QEG) in the Northern Key Economic Region. First, public investment exhibits a strong and economically meaningful effect, highlighting its central role in improving infrastructure services, strengthening administrative capacity, and enhancing public service delivery. This confirms that the effectiveness of public investment becomes visible only when appropriate inference methods are employed.

Second, the lagged QEG is positive and highly significant, indicating a clear multi-period transmission mechanism, while the positive impact of public investment declines sharply after controlling for lagged QEG. Thus, public investment requires time to be implemented, activated, and embedded into the provincial economy. This pattern is consistent with the long-gestation nature of public infrastructure, spillover effects from capital formation, and the crowding-in of private investment. The strong lag effect underscores the importance of policy emphasis on medium-term public investment planning rather than short-term expenditure cycles.

Third, population size is consistently negative and highly significant across all models, suggesting that larger provinces face structural constraints that diminish economic quality. A number of mechanisms may explain this pattern: greater population pressure increases the burden on transport systems, housing, environmental management, and public services; urban congestion reduces the efficiency of factor allocation; and per-capita economic outcomes are often diluted in provinces with rapidly expanding populations. The consistency of this result across specifications indicates a robust structural relationship, highlighting the need for policies that manage urban crowding, improve land-use efficiency, and balance population distribution.

Finally, human capital proxied by the proportion of trained labor emerges as one of the most stable and powerful determinants of QEG. The coefficient is positive, significant, and robust across all estimators, reflecting the central role of skilled labor in raising productivity, facilitating structural transformation, and sustaining inclusive, high-quality growth. This finding reinforces the theoretical and empirical literature emphasizing human capital as a critical complement to public investment and a prerequisite for long-term economic upgrading.

Overall, the combined evidence suggests that QEG in the region is driven by a mix of effective public investment, dynamic spillover channels, human capital development, and structural constraints associated with population pressure. These findings imply that the most effective policy strategy for improving QEG involves enhancing the efficiency and sequencing of public investment, strengthening human-capital formation, and implementing urban-management reforms to mitigate the negative effects of population density.

b) Robustness check

Table 5 reports a series of robustness checks to verify the stability of the baseline findings. To mitigate endogeneity problems, we use the first lagged of all independent and control variable instead of current value (Column 1) and estimate by using FGLS. In

Column (2), we employ Arellano–Bond GMM estimator and include the first lag of public investment. Across all specifications, both the coefficient of public investment remains significantly positive, reinforcing the core conclusion that public investment fosters provincial economic growth.

Columns (1) FGLS model by including first-lag public investment (L.InvPub). L.InvPub is positive and highly statistically significant ($p<0.01$), indicating that public investment affects growth with a clear temporal pattern: its economic impact strengthens in the periods following initial disbursement. Next, column (2) employs the Arellano–Bond GMM estimator to address possible reverse causality, that higher growth may lead to higher public investment, as well as measurement errors and omitted variable bias. The results remain consistent: InvPub retains a positive coefficient and is marginally significant ($p\approx0.07$), while the lagged dependent variable L.QEG is strongly significant ($p<0.01$). This confirms the presence of growth persistence and supports the validity of the dynamic specification. Noticeably, the first lag of public investment is close to zero and statistically insignificant. This likely reflects that the positive effects of public investment are either already embedded in the previous period's improvement in growth quality or captured contemporaneously, leaving little additional explanatory power for the lagged public investment. The results demonstrate that the quality-enhancing impact of public investment materializes gradually, with cumulative effects emerging over year, which is consistent with the long-gestation nature of public infrastructure and institutional reforms.

The control variables behave consistently across all robustness specifications. ln_pop carries a negative and statistically significant coefficient in every model, suggesting that population pressure constrains economic performance when measured relative to population size. In contrast, LABOR_TRAINED remains positive and significant, reiterating the importance of skilled labor as a key driver of provincial growth.

Table 5: Robustness check results with alternative lags of public investment

VARIABLES	(1) FGLS	(2) GMM
L.QEG		0.1618***
		(0.0369)
InvPub		0.0203*
		(0.0120)
L.InvPub	0.1881***	-0.0007
	(0.0350)	(0.0116)
ln_pop		-0.4277***
		(0.0210)
LABOR_TRAINED		0.0072**
		(0.0033)
L.ln_pop	-0.4560***	
	(0.0249)	
L.LABOR_TRAINED	0.0645***	
	(0.0078)	
Constant	2.9001***	5.4234***
	(0.4878)	(0.3094)
Observations	70	65
R-squared	0.8435	
Number of groups	5	5
Standard errors in parentheses	*** p<0.01, ** p<0.05, * p<0.1	

5. CONCLUSIONS AND POLICY IMPLICATIONS

This study investigates the effect of public investment on the QEG in NKER for the period 2010–2024. Using a multidimensional QEG index constructed through PCA and panel estimation techniques, the analysis provides three key insights.

First, public investment improves QEG, but the effect materializes mainly through lagged and cumulative channels. Moreover, the lagged QEG variable remains consistently positive and highly significant, whereas the lagged value of public investment shows no meaningful effect once contemporary investment and lagged QEG are controlled. This indicates that the quality-enhancing impact of public investment unfolds after 1–2 years as infrastructure is completed and institutional and productivity spillovers materialize. These findings highlight the medium-term nature of investment-driven improvements in economic growth quality.

Second, human capital is a robust and central determinant of growth quality. The coefficient on trained labor is positive, highly significant, and stable across all estimation methods, confirming that workforce skills, education, and training are fundamental to

driving productivity-based, inclusive growth. This result underscores the need to upgrade vocational training, digital competencies, and skill–industry alignment as pillars of long-term development.

Third, population size exhibits a strong and negative association with QEG, suggesting that provinces with larger populations may face greater pressure on resources, public services, and labor quality. The finding implies that without commensurate improvements in human capital and infrastructure, rapid population expansion may dilute growth quality. Policies to support balanced spatial development, improve urban infrastructure, and enhance labor mobility across provinces become crucial.

Overall, the findings demonstrate that enhancing the quality of economic growth requires a sequenced and structural approach. Based on the empirical evidence, four policy implications emerge:

- **Improve the efficiency and medium-term planning of public investment**: (1) Prioritize projects with strong interprovincial and intersectoral spillovers; and (2) Strengthen monitoring and evaluation to accelerate project completion and maximize long-term returns.
- **Develop human capital comprehensively**: (1) Upgrade technical, vocational, and digital skills; and (2) Strengthen links between training institutions and industry demand to enhance workforce relevance.
- **Leverage FDI and structural upgrading (if included in extended models)**: (1) Promote technology transfer, innovation incentives, and deeper domestic linkages; and (2) Shift from low value-added manufacturing toward higher-tech, productivity-intensive activities.
- **Support spatially balanced and sustainable development**: Invest in urban infrastructure, public services, and labor mobility to mitigate population pressure on economic growth quality.

In conclusion, the study affirms that the quality of economic growth is shaped jointly by the strategic sequencing of public investment, the depth of human capital, and the structural characteristics of provincial economies. Policies grounded in these factors are essential to achieving sustainable and productivity-driven development in the NKER.

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APPENDIX: Diagnostic Tests for Panel Data and GMM Models

Test	Null Hypothesis (H_0)	Statistic	p-value	Conclusion
Wooldridge AR(1)	No first-order serial correlation	F(1,4)=39.71	0.0032	Reject H_0 → AR(1) exists
Pesaran CD test	Cross-sectional independence	CD=0.555	0.5790	not detect strong cross-sectional dependence
Modified Wald test	Homoskedasticity	—	<0.01	Heteroskedasticity
VIF test	No multicollinearity	Mean VIF=1.11	—	No multicollinearity
Hausman test	RE consistent	$\chi^2(3)=35.14$	0.000	FE preferred
Arellano–Bond AR(1)	No AR(1) in first-differences	z = 1.8912	0.0586	Reject H_0 at 10% (expected)
Arellano–Bond AR(2)	No AR(2) in first-differences	z = 2.1252	0.3564	Fail to reject → Valid
Sargan test	Overidentifying restrictions valid	$\chi^2(54)$	0.5734	Instruments valid
Number of instruments	—	59	—	Acceptable

Source: Author's calculation from provincial data (2010–2024)