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Unveiling the Impact of Public Capital on Economic Growth: A Global Perspective

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ABSTRACT

This study investigates the impact of public capital on economic growth, alongside the contributions of human capital and international trade, using panel data from 81 high, low, and middle-income countries from 1980 to 2020. Utilizing advanced panel data methodologies, including Pooled OLS and Fixed Effects models, the study constructs a public capital index through Principal Component Analysis, incorporating six physical capital components of infrastructure. The results demonstrate a positive and significant relationship between public capital and economic growth, with human capital, international trade, financial development, domestic investment, and government expenditure also showing positive effects. In contrast, population growth hinders economic growth, while inflation exhibits a negative yet statistically insignificant relationship. These findings highlight the critical role of public capital, human capital, and international trade in driving long-term economic development, offering vital insights for policymakers aiming to foster sustainable economic growth. The study provides a comprehensive framework for understanding key economic growth drivers and provides policy recommendations to prioritize infrastructure investment, education, and trade. Future research could explore the dynamic interactions between public capital and other economic variables, investigate the sectoral impacts of public capital, and examine its role in mitigating income inequality and poverty.

Keywords: Public capital, economic growth, principal component analysis
JEL Classification: H54, O40, C38,

INTRODUCTION

Developing economies face numerous challenges, including stagnant economic growth, low savings and investment rates, poverty, inflation, unemployment, and significant trade and budget deficits. These challenges result in lower living standards compared to developed economies. Achieving sustainable economic growth is essential for improving these standards. According to Morgan (2004), long-term economic growth can be realized either through exogenous growth, by increasing factors of production (Easterly & Levine, 2001; Solow, 1956), or through endogenous growth, which focuses on enhancing productive capacity via human capital and innovation (Aghion & Howitt, 1992; Uzawa, 1965). The seminal works of Lucas (1988) and Romer (1986) underscore the critical role of human capital and innovation in fostering endogenous growth. Similarly, public capital facilitates economic development by boosting productivity and promoting growth (Barro, 1991).

Public capital, encompassing the aggregate assets of the public sector, is a key driver of productivity and development (Agenor & Neanidis, 2015). It includes infrastructure components such as roads, railways, airports, telecommunication networks, energy systems, and public services like education, healthcare, law enforcement, and utility (Romp & Haan, 2007). Public capital is often conceptualized as government investment in physical infrastructure and related services, and its importance in economic development cannot be overstated.

Despite its importance, the link between public capital and economic growth has not received attention in the literature. Existing studies, while valuable, have primarily focused on specific components of public capital, such as telecommunications (internet usage) and transportation (roads), often overlooking their broader cumulative effects. For instance, Schiffbauer (2007) highlighted the impact of telecommunication infrastructure on reducing intermediate goods' transportation costs, while Roller and Waverman (2001) and Belaîd (2004) identified a positive relationship between telecommunications and economic growth in OECD and developing countries, respectively. Similarly, Calderon and Serven (2005) confirmed the positive impact of telecommunication infrastructure on growth using an instrumental variable approach. However, these studies often exclude other critical components, such as energy infrastructure, and fail to address the trade-offs among public capital investments.

Recognizing this gap, the present study explores the broader effects of public capital on economic growth, incorporating major infrastructure components such as road, rail, air transportation, telecommunications, and energy systems. These components collectively influence the pace of production, distribution, and overall economic activity (Yu et al., 2012). For instance, transport infrastructure reduces travel time and costs, facilitates access to larger markets, and attracts foreign direct investment (Gunasekera et al., 2008; Shirley & Winston, 2004). Telecommunication infrastructure enhances information flow, technology adoption, and productivity, enabling new business models and economic efficiency (Czernich et al., 2011; Romer, 1990). Similarly, energy infrastructure plays a critical role, with debates on whether energy consumption drives economic growth or vice versa (Narayan & Singh, 2007; Khan et al., 2020; Paul & Bhattacharya, 2004). The practical implications of this study will empower policymakers and stakeholders to make informed decisions that can drive economic growth and improve infrastructure.

This study addresses the interconnectedness and trade-offs among these components by constructing a comprehensive index of public capital. It also incorporates the roles of international trade, financial development, and the labor force to provide an understanding of how public capital drives economic growth. Unlike previous studies, this paper examines the combined effects of transport, telecommunications, and energy infrastructure on economic growth, thus providing a more integrated perspective.

The rest of the paper is organized as follows: Section 2 reviews the literature on public capital and economic growth. Section 3 outlines the methodology, data description, and sources. Section 4 presents the study's results, while Section 5 concludes the study.

LITERATURE REVIEW

The current section highlights the critical role of public capital (PC) in driving economic growth (EG). Public capital, including infrastructure such as roads, railways, and the electric system, holds a pivotal position in production functions alongside traditional factors like labor and capital. Investment in PC enhances a nation's productive capacity by fostering development projects and increasing investment in plants and machinery (Aschauer, 1993). Barro (1991) emphasized the significant impact of public expenditure on EG, highlighting its role in improving the productivity of factors, enhancing marginal returns on capital, and promoting growth-maximizing investment policies. Given the importance of PC, countries are urged to increase investments in infrastructure components such as transport (roads and railways) and telecommunications to boost productivity and achieve sustainable development (Atolia et al., 2021).

Public capital provides the foundational networks necessary for delivering public services, enhancing living standards, and driving economic progress (Nannan & Jianing, 2012). Easterly and Rebelo (1993) found a strong correlation between public infrastructure investment and EG, particularly in telecommunications and transportation. Infrastructure facilitates market access, reduces inequality, and elevates living standards (Baum-Snow et al., 2017). Telecommunications infrastructure, in particular, plays a transformative role by reducing costs and expanding online markets (Thoyibah & Sugiharti, 2022). It acts as a conduit for information transfer across societies, industries, and institutions, significantly enhancing production, distribution, and consumption. Over time, improvements in the telecommunication sector contribute to higher labor productivity and efficiency, as well as reduced economic disparities between high- and low-income nations

(Farhadi & Ismail, 2011; Kumar et al., 2015).

Several studies underscore the positive association between telecommunications and EG. For instance, Tripathi and Inani (2020) established this relationship using data from SAARC countries, while Pradhan et al. (2016a) confirmed causality between telecommunications and EG across 21 Asian economies. However, recent studies, such as Gomez-Barroso and Marban-Flores (2020), suggested that the relationship may be nonlinear, influenced by outdated technologies and varying national policies.

Beyond telecommunications, transportation infrastructure is a vital determinant of EG. Roads, railways, and air transport ensure the efficient movement of goods and people, enhance economic efficiency, and support regional integration (Beyazit, 2015; Sun & Cui, 2018). The benefits of updated transportation infrastructure are significant, as it reduces production costs, fosters technological spillovers, and attracts external investments (Beyzatlar et al., 2014; Jiang et al., 2017). Skorobogatova and Kuzmina-Merlino (2017) emphasized the critical role of transport infrastructure in boosting financial transparency and business performance, while advancements in transportation have been shown to improve productivity and worker health (Quinn et al., 2021). Similarly, air transportation is closely linked to EG. It facilitates foreign investment, global trade, and tourism, enhancing connectivity between producers, consumers, and markets (Ozcan, 2018; Huang et al., 2023). Zhang and Graham (2020) highlighted air transport's dual role in driving EG through labor and goods markets while addressing infrastructure demand.

Energy infrastructure, a significant influencer of EG, impacts production capacity and efficiency. Various studies reveal a complex and dynamic interplay between electricity consumption and EG, with outcomes varying across regions and income levels (Chen et al., 2020; Ferguson et al., 2000; Rafindadi & Usman, 2021). While some studies highlighted a positive two-way causality between electricity use and EG (Apergis & Payne, 2011), others suggest minimal impact in specific contexts, like Mohsin et al. (2021). The research focusing on electricity distribution losses (Adabor et al., 2023) and spatial spillovers (Salahuddin et al., 2018) further underscores the intricate and nuanced relationship between energy infrastructure and economic performance, presenting a stimulating challenge for further exploration.

Despite extensive research, most studies focus on individual components of public capital, such as telecommunications or road transportation, rather than examining their combined effects on EG. Understanding these combined effects is crucial, as it could provide valuable insights into the potential trade-offs in government expenditures, distinguishing between productive and non-productive spending. For instance, while some research establishes the positive impacts of transportation on productivity and spillover effects (Fan & Chan-kang, 2008; Gunasekera et al., 2008), others, like Devarajan et al. (1996), highlight potential trade-offs in government expenditures.

Considering the mixed findings, this study aims to analyze the role of public capital in promoting economic growth. Public capital includes key infrastructure such as transportation networks, telecommunication systems, and energy facilities. To measure its impact, the study develops an index that captures the availability and quality of these infrastructure components. In addition to public capital, the study considers critical factors like financial development, human capital, and international trade. Financial development supports efficient resource allocation, while human capital enhances productivity through education and skills. International trade facilitates market expansion and resource exchange, further influencing growth.

METHODOLOGY AND DATA

This section explains the model used in the study, data, and its sources. It also discusses the estimation methods used to analyze the data. The purpose is to give a clear understanding of the model, data, and analysis techniques used to meet the objective of the study.

Background

The foundational growth model was introduced by Cassel (1924), with subsequent contributions from Harrod (1936) and Domar (1946), who proposed a growth model rooted in labor and capital. The production function is expressed as:

$$Y = f(K, L) \tag{1}$$

where Y represents output, K denotes capital, and L signifies labor. Dividing both sides by L, the intensive form illustrates that output per worker depends on capital per worker:

$$\frac{Y}{L} = f\left(\frac{K}{L}\right)$$
$$y = f(k) \tag{2}$$

Equation 2 assumes a constant marginal product of capital and posits that savings determine output levels. However, it has been criticized for assuming exogenous savings and ignoring diminishing marginal returns to capital.

For instance, Solow (1956) pointed out that the marginal product of capital is diminishing, and the rise in savings has a level effect on the output and does not prevail over a longer period because of the diminishing marginal product of capital. Instead of physical capital accumulation, the economy's long-run growth depends on the technology level, which is considered exogenous.

Diminishing marginal product is crucial in limiting the economy's growth in the presence of technology and labor. However, there is a class of models in which growth is directly proportional to capital growth. The diminishing marginal product of capital neutralizes with the growth of another innovation, for instance. These models are based on the growth framework of Frankel (1962). According to this framework, per capita growth rises continuously in the equilibrium, and there is a constant marginal product of capital. In that sense, saving poses a permanent impact on economic growth. Equation 3 is converted into a simple linear Hicks neutral, Cobb-Douglas production function as follows:

$$Y = A.K^{\alpha}.L^{1-\alpha} \qquad A > 0 \tag{3}$$

$$A = (A_0)e^{g}$$

$$\dot{K} = s.Y$$

where, A represents technological progress, growing at a constant rate (g), and with s is the saving rate.

Subsequent advancements in growth theory, including contributions from Lucas (1988) and Romer (1986), emphasized human capital's pivotal role in amplifying the returns to capital and labor. The augmented production function incorporating human capital (HC) is written as:

$$Y = K^{\alpha}.HC^{\beta}(AL)^{1-\alpha-\beta} \tag{4}$$

Building on earlier models, the current study incorporates public capital (PC) and international trade (TR), which are crucial for fostering economic growth. Public capital, encompassing infrastructure components such as roads, telecommunications, and energy, expands productive capacity and facilitates economic activity (Rinne, 2004; Lee et al., 2016). International trade acts as a conduit for technology transfer and productivity enhancements, with its impact varying across open and closed economies (Coe & Helpman, 1995). The extended production function is thus formulated as:

$$Y = f(PC, HC, TR, K, L) \tag{5}$$

where PC is the public capital, HC is human capital, TR is trade, and K and L are the traditional inputs of capital and labor, respectively.

The study explicitly integrates public capital and trade into the analysis. Public infrastructure, such as roads and telecommunications, is critical for reducing transaction costs, improving market accessibility, and fostering regional integration (Baum-Snow et al., 2017). Similarly, trade facilitates technology diffusion and productivity growth, as emphasized by Grossman & Helpman (1990) and Barro & Sala-i-Martin (1995).

Econometric Model

Given a panel sample of N countries over T periods, the traditional panel data model followed by Balestra (1992) can be written as,

$$Y_{it} = \alpha_{it} + \beta_{it}X_{it} + u_{it} \tag{6}$$

$$i = 1, 2, 3, 4, \ldots\ldots\ldots. N \; and \; t = 1, 2, 3, 4, \ldots\ldots\ldots. T$$

where Y_{it} indicates the observation of the dependent variable, X_{it} is the observation of the vector of independent variables, β_{it} is the vector of slope coefficients of independent variables, α_{it} is the constant term and indicates the consistency and efficiency of slope coefficients, and u_{it} is the vector of error terms, and it is uncorrelated with the intercept and set of independent variables (X_{it}). The intercept (α_{it}) in equation 6 can be varied among countries and over time. Hence, we can write it as

$$\alpha_{it} = \alpha + \delta_i + \gamma_t$$

where δ_i indicates the individual-specific effects and γ_t represents the time-specific effects. Both effects may be fixed and may be random. The incorporation intercept term in equation 3.6 is,

$$Y_{it} = \alpha + \delta_i + \gamma_t + \beta_{it}X_{it} + u_{it} \quad (7)$$

the above equation is the standard model wherein Y_{it} is the dependent variable, α is a constant term, δ_i and γ_t indicates the individual-specific and time-specific effects, respectively. Similarly, X_{it} is the independent variable, β_{it} and u_{it} is the coefficient of the independent variable and error term, respectively.

Empirical Model

The objective of the study is to analyze the impact of public capital on EG. To achieve this objective, the study uses the following empirical model:

$$EG_{it} = \beta_0 + \beta_1 PC_{it} + \beta_2 HC_{it} + \beta_3 TR_{it} + \beta_4^{'} Z_1 + u_{it} \quad (8)$$

where EG represents economic growth, which is the dependent variable, while PC stands for public capital, capturing investments in infrastructure and public goods. HC denotes human capital, reflecting education and skill levels in the population, and TR measures international trade, representing trade openness and its impact on economic growth. The variable Z represents a vector of control variables, which includes financial development, domestic investment, government consumption expenditures, population growth rate (serving as a proxy for the labor force), and inflation.

The term u refers to the econometric error component, capturing unobserved factors affecting economic growth. The subscript i represents individual countries, and t refers to time, indicating the panel data of the analysis. All variables are transformed into their natural logarithmic forms to ensure elasticity interpretation, allowing for the analysis of proportional relationships. Detailed descriptions and measurements of these variables are provided in the appendix (Table A-1).

Estimation Method

The current study uses different indicators of public capital, including road, railways, airfreight, telecommunication, internet, and energy infrastructure. Since there are numerous public capital variables, the dispersion matrix might be too large to analyze and interpret accurately. There are also too many pairwise correlations between the public capital variables to consider. To address the challenge of dealing with multiple public capital variables and their large dispersion matrix, which may be difficult to interpret effectively and to interpret the data in a more meaningful form, the study developed an index for public capital by employing Principal Component Analysis (PCA), as followed by Pradhan et al. (2016b) and Hashmi and Bhatti (2019), the study employs Principal Component Analysis (PCA). In this way, the representation of public capital is manageable and meaningful. PCA is a dimensionality reduction technique that transforms a large number of correlated variables into a smaller set of uncorrelated components while retaining as much of the original variance in the data as possible. This method is commonly used in analyzing complex datasets with multiple variables, enabling researchers to simplify the data and identify key underlying patterns.

Following the report of the Joint Research Centre-European Commission (2008) constructing the index for public capital for different (M) countries, for example, the procedure we follow: different components of public capital selected

(M), a small number of variables (principal components) will capture the maximum variations of the M selected components of public capital. Further, the Q number of principal components can retain a high amount of the variability of the original variables even when Q<M. However, the maximum number of principal components can be M.

$Z_1 = \alpha_{11}I_1 + \alpha_{22}I_2 + \dots + \alpha_{1M}I_M$
$Z_2 = \alpha_{21}I_1 + \alpha_{22}I_2 + \dots + \alpha_{2M}I_M$
.
.
$Z_M = \alpha_{M1}I_1 + \alpha_{M2}I_2 + \dots + \alpha_{MM}I_M$

where M_i is the public capital of country i, Z_i is the i^{th} principal component and α_{ij} is weight assigned to the public capital component of country j and principal component i. α_{ij} labeled as components or factor loading and these factor loadings must satisfy the following two conditions.

1. The principal components are uncorrelated (orthogonal).
2. The first principal component accounts maximum range of variation of the variance of variables. The second accounts for the maximum proportion of the remaining variance and so on. The last principal component will explain all the remaining variations of the variance.

$\alpha_{i1}^2 + \alpha_{i2}^2 + \dots + \alpha_{i3}^2 = 1 \; and \; i = 1,2,3, \dots, N.$

The principal component analysis (PCA) includes the tracing the eigenvalues which involve the covariance matrix. The covariance matrix CM is simply expressed as,

$$CM = \begin{bmatrix} cm_{11} & \cdots & cm_{1M} \\ \vdots & \ddots & \vdots \\ cm_{N1} & \cdots & cm_{NM} \end{bmatrix}$$

Where the cm_{11} is the variance of public capital components of country i and cm_{ij} is the covariance of different public capital variables of country i and j and $i \neq j$. The eigenvalues of the above CM matrix of PCA and can be obtained by solving the following equation with identity matrix I and λ vector of eigenvalues with the same order as that of CM matrix.

$|CM - I\lambda| = 0$

An important property of the eigenvalues is that it adds up the sum of diagonal elements of CM. That is, the sum of the variances of the principal components is equal to the sum of the variances of the original variables as,

$$\lambda_1 + \lambda_2 + \dots + \lambda_M = cm_{11} + cm_{22} + \dots + cm_{MM} \quad (9)$$

It is common to standardize the variables to have zero means and unit variance to prevent one variable from influencing the principal components. The correlation matrix of the public capital components is presented in Appendix Table A-2. The highest correlation was observed between road length (RL) and goods transported by railway (RTG) with a coefficient of 0.80, followed by the correlation between RL and goods transported by air (ATG) at 0.77. Additionally, the correlation between RTG and ATG was 0.72. Comparatively, the correlation between fixed broadband subscriptions (FBS) and RL was 0.12, with ATG at 0.15 and an insignificant correlation with RTG at -0.008. Mobile cellular subscriptions (MCS) showed weak correlations with RL (-0.04), ATG (0.19), and RTG (0.07). However, the moderate correlations between electricity consumption per capita (ECPC) and communication metrics (RL: 0.09, ATG: 0.23, RTG: 0.14). A relatively stronger correlation was found between ECPC and FBS (0.64), while its correlation with MCS was moderate at 0.26.

The eigenvalues of the six different indicators of public capital are presented in Appendix Table A-3. The sum of eigenvalues must be equal to the total number of indicators in our case; the study uses six indicators of public capital, and the sum of eigenvalues is equal to six. The first component of the tables explains the maximum variance (44.9%) in all the public capital indicators (the eigenvalue of the first component is 2.694). The second component explains the maximum variance (27.9%) of remaining with an eigenvalue of 1.67. The third component has an eigenvalue close to one, explaining 15% of the variance. The last three components explain 12% of the variance with an eigenvalue less than one for each component. The graphical representation of eigenvalues is presented in Appendix Figure B-1.

The correlation coefficient between the principal component Z and public capital indicators I is known as component loading, $r(Z_j, I_i)$. Component loadings are equal α_{ij} with uncorrelated public capital indicators. Table A-4 in the Appendix presents the component loadings of each public capital indicator. The public capital index is computed by multiplying the values of each indicator by the corresponding factor loading of the variable for the given principal component and then summing these products.

Furthermore, the study employs the panel data of eighty-one (81) countries as it has several advantages over cross-sectional or time-series data since it incorporates both intra-individual dynamics and inter-individual variations. First, it makes it possible to infer model parameters with greater accuracy. Panel data typically has more freedom than time-series data (a panel with only one individual, N = 1) or cross-sectional data (like a panel with only one time, T = 1). The effectiveness of econometric estimations is improved by the degrees of freedom and decreased multicollinearity, offering more accurate insights into the relationships within the data.

A common argument in empirical research is that the presence or absence of certain effects can be attributed to overlooking the impact of specific variables in the model specification that may be correlated with the included explanatory variables. This is especially crucial when doing cross-sectional or time-series studies because it might lead to biased conclusions if significant elements are left out. However, panel data provides a solution to this problem. Researchers can more effectively account for the effects of missing or unobserved factors by using panel data, which includes information on both the individual features of entities over time and the intertemporal dynamics. Similarly, at least two dimensions are present in panel data: a cross-sectional dimension and a time series dimension. The computation of panel data estimators and inference, in general, is more difficult than that of cross-sectional or time series data.

It is preferable to combine the data for N cross-sections and T periods using panel data analysis. Every cross-sectional member in the sample data set has a time series included in this integrated panel data matrix set. Three primary aspects that contribute to the geometric expansion of panel data studies were noted in the literature. The availability of data, the ability to represent human behavior more complexly than with a single cross-section or time series, and the demanding technique are some of these aspects. Panel data models are often estimated using two common methods: the random effect and the fixed effect.

These models assume that differences among cross-sectional units are represented by an intercept term specific to each country. In Random Effects (RE) models, this intercept is treated as random, whereas in Fixed Effects (FE) models, it is considered fixed. To choose between RE and FE models, this study employs the Hausman (1978) test. This method offers several advantages. For instance, it allows control for country-level heterogeneity, reducing the risk of biased estimates. Additionally, the inclusion of both time and cross-country dimensions provides more information, reduces collinearity, and enhances the efficiency of the estimates (Biørn, 2004; Baltagi, 2008).

Data and Sources

This study utilizes a panel dataset comprising 81 countries from 1980 to 2020. The list of countries categorized as middle-income, upper-middle-income, and high-income groups per the World Bank definition is in Appendix Table A-5. The data for the variables of interest is collected from the World Development Indicators (WDI, 2019) and Penn World Table (PWT-9).

RESULTS AND DISCUSSION

In the first step of the analysis, the study checks the stationarity of the variables. To do this, the Fisher-type panel unit root test, as proposed by Maddala and Wu (1999), is employed, which is based on the Augmented Dickey-Fuller (ADF) test. The results of the unit root tests are presented in Appendix Table A-6. The findings indicate that all the variables are stationary at the level, meaning they do not exhibit a unit root and are suitable for further analysis.

A statistical description of the selected variables is also provided in the following Table 1. The mean value of economic growth (EG) is 9.151 with a standard deviation of 1.217. The mean value of public capital (PC) is -0.607 with a standard deviation of 1.151. Human capital (HC) and trade (TR) have mean values of 2.639 and 79.224, respectively, with standard deviations of 0.614 and 53.146. Inflation shows the highest variation from its mean, with a standard deviation of 69.746. On the other hand, human capital exhibits the lowest variation, with a standard deviation of 0.614. These descriptive statistics provide a basic understanding of the data's central tendencies and dispersion, allowing for better interpretation of the results in subsequent analyses.

Table 1: Statistical Description

Variable	Mean	Std. Dev.	Min	Max
EG	9.151	1.217	5.96	11.623
PC	-0.607	1.541	-6.567	2.414
HC	2.639	0.614	1.169	3.892
TR	79.224	53.146	9.136	442.62
CPI	75.509	69.746	0	2740.2
FD	57.429	43.317	0	304.575
GCF	4.333	27.450	-164.509	887.575
GFCE	16.649	5.531	0.911	76.222
POP	1.119	1.314	-3.848	15.177

Note: EG represents the log of GDP per capita as a measure of economic growth, PC represents public capital, HC represents human capital, TR represents trade% of GDP, CPI represents inflation, FD represents financial development, GCF represents domestic investment, GFCE represents government expenditure, and POP represents population growth.

The values of the correlation matrix are presented in Table A-7 in the appendix. The correlation between public capital (PC) and economic growth (EG) is 0.12, suggesting a weak positive relationship between these variables. The correlation between human capital (HC) and economic growth is 0.22, indicating a moderate positive relationship. The correlation between trade (TR) and economic growth is 0.35, showing a moderate to strong positive association. The correlation between inflation and economic growth is 0.24, which indicates a weak to moderate positive relationship. Other control variables, such as financial development (0.097), domestic investment (0.36), government expenditure (0.49), and population growth (-0.34), also exhibit varying degrees of correlation with economic growth. Notably, the highest correlation is found between government expenditure and economic growth (0.49), while the lowest is between trade and growth (0.03). All correlation values are statistically significant at the 5% level, except the correlation between trade and growth, which is significant at the 10% level.

The following Table 2 depicts the regression result of equation (3.8), which explains the empirical relationship between PC and EG along with other determinants, including human capital and trade, and some control variables like inflation, financial development, domestic investment, government expenditures, and population growth. The study follows the panel rules to investigate the link between the above variables. This study employs the pooled OLS (POLS) and fixed effect (FE) methodology under the assumption of no heterogeneity and cross-section dependence. Following Alsaleh and Abdul-Rahim (2022) and Skare and Porada-Rochon (2022) , this study chooses the FE model by comparing it with a random effect (RE) based on the Hausman result (as depicted below), which suggests that FE is more suitable.

The second column of Table 2 indicates the regression results of POLS, and the third column contains the regression results of the robust FE model. The direction and strength of the relationship between PC and EG, along with all other control variables, are almost similar to both POLS and FE models, so the study just explains the slope coefficient values of the FE model here. The coefficient value of PC is 0.031, which means that a one percent increase in public capital will increase the EG by 0.031%. The relationship is positive (Romp & Haan, 2007; Shioji, 2001), and statistically significant at a 10% level of significance. Public capital acts as a major input in determining long-run sustained economic growth because it reduces the allocative inefficiencies and boosts economic activity (Agenor & Neanidis, 2015; Dessus & Herrera, 2000).

Table 2: Public Capital Impacts on Economic Growth

Variable	POLS-Model	FE-Model
PC	0.024* (0.093)	0.031* (0.071)
HC	0.148*** (0.000)	0.293** (0.018)
FD	0.038*** (0.000)	0.061*** (0.004)
GCF	0.162*** (0.000)	0.119*** (0.005)
GFCE	0.383*** (0.000)	0.222*** (0.001)
POP	-0.621*** (0.000)	-0.372*** (0.038)
TR	0.090*** (0.000)	0.062 (0.151)
CPI	-0.007 (0.401)	0.003 (0.870)
Constant	5.486*** (0.000)	5.848*** (0.003)
R-square	0.929	0.812
F-stat (p-value)	0.000	0.000
Hausman (p-value)		0.000

*Note: ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.*
This estimation uses a robust standard error model, as suggested by Newey and West (1987).

Similarly, the coefficient value between human capital (HC) and EG is 0.293, which indicates that a 1% per cent increase in human capital will lead to an increase in EF by 0.29%. The relationship is positive (Claude & Hippe, 2022; Jahanger et al., 2022) and significant at a 5% level of significance.

Furthermore, the coefficient value of financial development (FD) is 0.061, which means that a 1% increase in FD will increase the EG by 0.06%. The relationship is positive and statistically significant at a 1% significance level. These results align with Jahanger et al. (2022) and Makuyana and Odhiambo (2019) . FD affects EG in many ways; it surges saving and technological change and connects investors to suitable investment projects without any discrepancy. It further enables advanced capital instruments, e.g., machinery, for production, increasing productivity and ultimately becoming a source of sustainable economic growth (Li et al., 2020).

The GCF positively impacts growth; the coefficient value of GCF is 0.11, which means that a 1% increase in GCF will boost EG by 0.11%. It is statistically significant at a 1% level of significance. The results are positive, highly significant and in line with Boamah et al. (2018) and Olaoye et al. (2020). While the strength of this relation may change around the business cycle and differ across the countries (Stupnikova & Sukhadolets, 2019). Along with domestic investment, the GFCE also boosts economic growth. The study indicates that a 1% increase in GFCE will surge the EG by 0.22%, and this strength is statistically significant at a 1% significance level. The positive and significant results are in line with Ariani et al. (2022), Bania et al. (2007), and Glomm and Ravikumar (1997).

The coefficient value of POP is -0.372, which indicates a negative relationship between population and EG. It indicates that the population's growth is unsuitable for economic growth. It is because it creates administrative and distribution issues, which become a hurdle to growth. The study reveals that a 1% increase in POP will reduce the EG by 0.37%. The result is significant at a 5% level of significance and in line with Headey and Hoge (2009), Kelley and Schmidt (1995), and Peterson (2017).

The coefficient value of TR is 0.062, which indicates that a 1% increase in TR will boost the EG by 0.06%. The relationship is positive (Nabi et al., 2022; Qi et al., 2022) and insignificant. However, trade promotes growth because it is a way of transforming knowledge, along with a wider range of other inputs worldwide. It has productive effects on EG because it encourages specialization among industries and increases their efficiency; it also reduces the income gap among countries (Grossman & Helpman, 1990; Singh, 2010).

However, the study indicates that inflation (CPI) harms the economy's growth. the coefficient value of CPI -0.007 indicates the negative relationship between CPI and EG and is in line with Mandeya and Ho (2021) and Olamide et al. (2022) , while it is statistically insignificant, as claimed by Baklouti and Boujelbene (2019) and Nabila and Anwar (2021) Because inflation creates uncertainty in the economy, the fear of loss becomes the main hurdle in the way of investment.

The R-square value is 0.81, which indicates that the selected independent variables explain 81% of the variations in EG. The F-stat p-value depicts that the model is stable. Furthermore, the empirical results that public capital directly impact economic growth according to the countries' income groups are depicted in the Appendix as Table A-8.

CONCLUSION

The current study aims to examine the impact of public capital on economic growth, alongside the effects of human capital and international trade. To achieve these objectives, the study analyzes panel data from 81 high- and low-income countries over the period 1980-2020, employing advanced panel data methods such as Pooled OLS and Fixed Effect models. An index for public capital is constructed using Principal Component Analysis, which combines six different physical capital components. The findings suggest a positive and significant relationship between public capital and economic growth, indicating that increased public investment can substantially contribute to long-term economic growth.

Additionally, the study highlights the positive roles of human capital, international trade, financial development, domestic investment, and government expenditure in fostering economic growth. In contrast, population growth is found to have a negative impact on economic growth, as it introduces challenges related to distribution and administration. While inflation is negatively correlated with growth, its effect is statistically insignificant. These findings underscore the importance of public capital, human capital, and trade in promoting economic development. The results provide valuable insights for policymakers, offering guidance for the formulation of effective economic policies aimed at achieving sustainable economic growth.

This study holds significant importance as it contributes to the existing literature on the relationship between public capital and economic growth, offering valuable empirical evidence for both developed and developing countries. By analyzing the roles of public capital, human capital, and international trade, the study provides comprehensive insights into the key drivers of economic growth. Policymakers can use these findings to prioritize investments in public infrastructure, human capital development, and trade policies, all of which are crucial for fostering economic development. Additionally, the study's findings emphasize the need for a balanced approach to managing population growth and controlling inflation, offering a roadmap for sustainable and inclusive growth.

In terms of future research, it would be beneficial to explore the dynamic interactions between public capital and other key economic variables such as technological innovation, institutional quality, and governance. Additionally, future studies could investigate the long-term effects of public capital on growth in specific sectors, such as education, health, and infrastructure, to better understand the channels through which public capital influences economic performance. Moreover, future research could consider examining the impact of public capital on income inequality and poverty reduction, providing a broader understanding of its role in promoting inclusive growth.

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Appendix

Table A-1: Variable Description

Variable	Measure and description
EG	Real GDP per capita: Proxy for economic growth Source: World Development Indicator (WDI), by World Bank
PC	Public capital index includes the following six components of physical capital (RL) *Length of roads (km)* (ATG) *Goods transported by railway (million ton-km)* (RTG) *Goods transported by air (million ton-km)* (FBS) *Fixed broadband subscriptions (per 100 people)* (MCS) *Mobile cellular subscriptions (per 100 people)* (ECPC) *Per capita electricity consumption (kwh)* Source: World Development Indicator (WDI), by World Bank
HC	Human capital index: based on years of schooling and returns to education. Source: Penn World Table-9 (PWT-9).
TR	Measure for trade openness: Trade (% of GDP) Source: World Development Indicator (WDI), by World Bank
FD	Measure for financial development: Domestic credit to private sector (% of GDP) Source: World Development Indicator (WDI), by World Bank
GCF	Measure for domestic investment: Gross capital formation (constant 2015 US$) Source: World Development Indicator (WDI), by World Bank
GFCE	Measure for government expenditures: General government final consumption expenditure (constant 2015 US$) Source: World Development Indicator (WDI), by World Bank
POP	Measure for labor force: Population, total Source: World Development Indicator (WDI), by World Bank
CPI	Measure for inflation: Consumer price index (2010 = 100) Source: World Development Indicator (WDI), by World Bank

Table A-2: Matrix of correlations (Public Capital components)

Variables	RL	ATG	RTG	FBS	MCS	ECPC
RL	1.000					
ATG	**0.771**	1.000				
RTG	**0.807**	**0.727**	1.000			
FBS	**0.125**	**0.153**	-0.008	1.000		
MCS	**-0.047**	**0.199**	**0.071**	**0.708**	1.000	
ECPC	**0.098**	**0.238**	**0.147**	**0.646**	**0.263**	1.000

Note: bold values indicate the correlation is statistically significant at p < 0.05.

Table A-3: Eigenvalues of individual public capital indicators

Component	Eigenvalue	Proportion	Cumulative
Comp1	2.695	0.449	0.449
Comp2	1.678	0.280	0.729
Comp3	0.910	0.152	0.880
Comp4	0.336	0.056	0.936
Comp5	0.224		
Comp6	0.158		

Principal components (eigenvectors)

Figure B-1: Graphical representation of eigenvalues

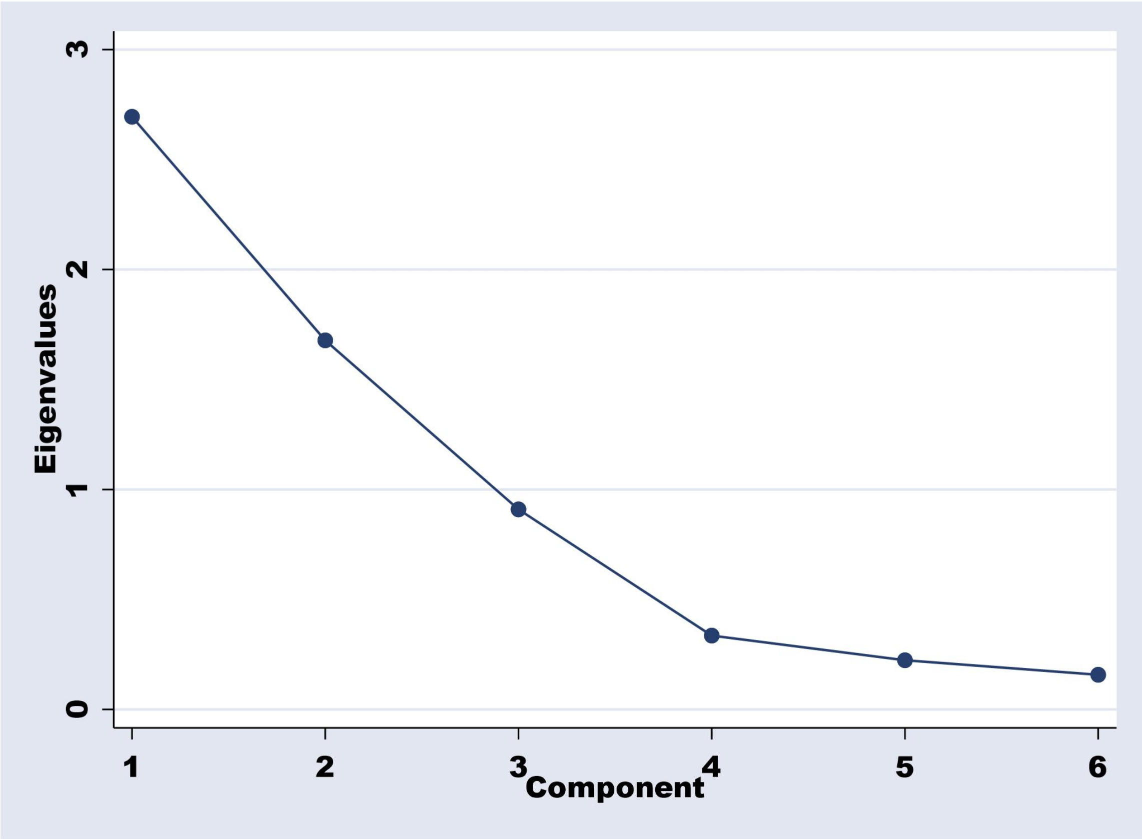

Table A-4: Component loading for individual public capital indicators

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6
RL	0.536	-0.265	-0.034	-0.048	-0.279	0.749
ATG	0.561	-0.085	0.029	-0.341	-0.431	-0.613
RTG	0.509	-0.290	0.080	0.323	0.718	-0.175
FBS	0.237	0.620	-0.253	-0.560	0.399	0.151
MCS	0.089	0.327	0.936	-0.005	-0.010	0.090
ECPC	0.274	0.589	-0.226	0.681	-0.248	-0.046

Table A-5: List of Countries

Lower Middle-Income Countries (LMI)	Upper Middle-Income Countries (UMI)	High Middle-Income Countries (HIC)	
Algeria	Argentina	Australia	Lithuania
Egypt, Arab Rep.	Armenia	Austria	Luxembourg
El Salvador	Belarus	Belgium	Malta
India	Brazil	Canada	Netherlands
Indonesia	Bulgaria	Chile	New Zealand
Iran, Islamic Rep.	China	Croatia	Norway
Kenya	Colombia	Cyprus	Poland
Mongolia	Costa Rica	Czech Republic	Portugal
Morocco	Cuba	Denmark	Saudi Arabia
Nigeria	Ecuador	Estonia	Slovak Republic
Pakistan	Guatemala	Finland	Slovenia
Philippines	Jamica	France	Spain
Sri Lanka	Jordan	Germany	Sweden
Tunisia	Kazakhstan	Greece	Switzerland
Ukraine	Malaysia	Hong Kong SAR, China	United Arab Emirates
Zimbabwe	Mexico	Hungary	United Kingdom
	Panama	Iceland	United States
	Peru	Ireland	Uruguay
	Romania	Israel	Venezuela, RB
	Russian Federation	Italy	
	South Africa	Japan	
	Thailand	Kuwait	
	Turkey	Latvia	

Table A-6: Fisher-type panel unit root test result

Variables	At level				Conclusion
	Fisher type (ADF)		**Fisher type (ADF-demean)**		
	Intercept	Intercept & trend	Intercept	Intercept & trend	
EG	0.85	2.20**	-0.34	2.75**	I (0)
PC	51.73***	41.94***	28.61***	33.39***	I (0)
HC	71.63***	5.55***	2.27**	-2.693	I (0)
TR	3.46***	4.58***	3.85***	2.92***	I (0)
CPI	151.47***	76.64***	46.98***	31.16***	I (0)
FD	6.16***	3.06***	5.34***	2.34***	I (0)
GCF	2.91***	8.54***	8.19***	6.81***	I (0)
GFCE	1.64*	1.63*	-0.93	2.64***	I (0)
POP	119.57***	34.46***	12.58***	-2.28	I (0)

*Note: ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.*

Table A-7: Matrix of correlations

	Variables	EG	PC	HC	TR	CPI	FD	GCF	GFCE	POP
All Countries	EG	1.00								
	PC	**0.12**	1.00							
	HC	**0.22**	**0.36**	1.00						
	TR	0.03	**-0.29**	**0.33**	1.00					
	CPI	**0.24**	**0.10**	**0.25**	**0.16**	1.00				
	FD	**0.09**	**0.43**	**0.52**	**0.27**	**0.15**	1.00			
	GCF	**0.36**	-0.01	-0.00	-0.01	**0.12**	0.01	1.00		
	GFCE	**0.49**	**-0.09**	**0.06**	**-0.06**	**0.08**	-0.04	**0.92**	1.00	
	POP	**-0.34**	**-0.23**	**-0.08**	-0.03	**-0.03**	-0.01	**0.71**	**0.60**	1.00
Lower-Income Countries	EG	1.00								
	PC	**0.38**	1.00							
	HC	**0.20**	0.09	1.00						
	TR	**-0.09**	-0.12	**0.56**	1.00					
	CPI	**0.29**	0.11	**0.15**	-0.01	1.00				
	FD	**0.41**	**0.32**	**0.32**	**0.38**	**0.36**	1.00			
	GCF	**0.36**	-0.07	-0.01	**-0.22**	**0.16**	**-0.12**	1.00		
	GFCE	**0.38**	-0.02	0.00	**-0.27**	**0.14**	**-0.15**	**0.98**	1.00	
	POP	**-0.15**	**-0.26**	-0.07	**-0.14**	0.01	**-0.23**	**0.84**	**0.84**	1.00
Middle-Income Countries	EG	1.00								
	PC	0.09	1.00							
	HC	**0.12**	**-0.33**	1.00						
	TR	**-0.18**	**-0.20**	**0.53**	1.00					
	CPI	0.08	**0.25**	**0.49**	**0.21**	1.00				
	FD	**-0.28**	**0.63**	**-0.16**	0.04	-0.01	1.00			
	GCF	**0.35**	**0.81**	**-0.22**	**-0.46**	-0.03	**0.45**	1.00		
	GFCE	**0.56**	**0.51**	**-0.30**	**-0.60**	**-0.28**	0.11	**0.88**	1.00	
	POP	**-0.17**	**0.70**	**-0.27**	**-0.46**	-0.02	**0.52**	**0.89**	**0.89**	1.00
High-Income Countries	EG	1.00								
	PC	**0.14**	1.00							
	HC	**0.29**	**0.41**	1.00						
	TR	0.03	**-0.39**	**010**	1.00					
	CPI	**0.33**	**0.11**	**0.31**	**0.17**	1.00				
	FD	0.03	**0.36**	**0.42**	**0.12**	**0.24**	1.00			
	GCF	**0.36**	**-0.20**	**0.13**	**0.19**	**0.19**	0.05	1.00		
	GFCE	**0.51**	**-0.16**	**0.25**	**0.09**	**0.23**	0.03	**0.91**	1.00	
	POP	**-0.44**	**-0.49**	-0.01	**0.14**	**-0.03**	0.04	**0.61**	**0.46**	1.00

Note: bold values indicate the correlation is statistically significant at a 5% level of significance.

Table A-8: The impact of public capital on economic growth (Income Group wise)

Variable	Low-Income Countries	Middle-Income Countries	High-Income Countries	All countries
(POLS)				
PC	0.071***	0.062	0.013	0.024*
HC	0.038	-0.314***	0.261***	0.148***
TR	0.015	0.107*	-0.018	0.091***
CPI	0.078***	0.145***	0.035***	-0.007
FD	0.025	0.189***	0.025**	0.038***
GCF	0.187***	-0.707***	0.322***	0.162***
GFCE	0.474***	0.575***	0.242***	0.383***
POP	-0.746***	-0.522***	-0.716***	-0.621***

Constant	5.284***	4.549***	6.527***	5.486***
R-square	0.901	0.977	0.918	0.929
F-stat (p-value)	0.000	0.00	0.000	0.000
(FE)				
PC	0.134***	0.065	0.043***	0.031**
HC	0.075	0.386	0.408***	0.293***
TR	0.051*	0.079	-0.045**	0.062***
CPI	0.124***	0.054*	0.041***	0.003
FD	0.022	0.122**	0.024***	0.061***
GCF	0.227***	-0.043*	0.265***	0.119***
GFCE	0.394***	0.245*	0.173***	0.222***
POP	-1.272***	-1.591**	-0.616***	-0.372***
Constant	14.663***	27.219**	7.567***	5.848***
R-square	0.347	0.195	0.816	0.812
F-stat (p-value)	0.000	0.000	0.000	0.000
*Note: ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.*				