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Article

Determinants of economic growth and the externalities of infrastructure investment, Peruvian case 2000–2022

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Abstract: The objective is to determine the impact of economic growth on the externalities of infrastructure investments for the Peruvian case for the periods from 2000 to 2022. The methodologies used are descriptive, explanatory and correlational, analyzing qualitative and mainly quantitative methods. Econometric software was used, and correlations of variables were created for each proposed hypothesis. The estimated model shows that all the independent variables have a significant t-statistic greater than 2 and a probability of less than 5%, which indicates that they are significant and explains the model. The R^2 is 98.02% which indicates that there is a high level of explanation by the independent variables to the LOG(RGDP). The results of the estimated models demonstrate the existence of a positive and significant relationship of investments in infrastructure and externalities on the growth of the non-deterministic component of real GDP, therefore, in a practical way, private and public investment has a positive effect on the non-deterministic growth of real GDP.

Keywords: gross domestic product; private investment; public investment; externalities; economic growth

1. Introduction

The construction of the "Mega Port of Chancay" located just 80 km north of Lima, Peru, on the Pacific coast is one of the most important changes in South American logistics. With financing from Chinese corporations (US $3 billion), the project aims to become a logistics hub in South America (Onandia Osores, 2023) and, therefore, it is a priority to analyze infrastructure investments in the Peruvian case over the last twenty years.

Public infrastructure investment is considered a critical component of economic growth (Alexandro and Basrowi, 2024; Kapustina et al., 2023), primarily because of its impact on capital productivity growth, which is higher the more it complements business investment support (Ibrahimov et al., 2023).

Increases and improvements in infrastructure create externalities that increase the usual effectiveness of the economy. It also has a similar effect to the reduction of tariffs in that it allows for an increase in market size, which produces economies of scale, higher specialty and an increase in the labor market (Prud'homme, 2005).

It also contains important network effects that occur, for example, with the quality of the power supply when more advanced machinery is used (Hulten et al., 2006).

Aschauer (1990) estimates that the infrastructure gap will be $68.8 billion from 2016 to 2020 and $90.734 billion from 2021 to 2025. Overall, the infrastructure gap from 2016 to 2025 is estimated to be approximately $160 billion, a share of GDP in 2013. dollars). The sector that will require the most investment in the medium term (2016–2020) is transportation (30.9% of total investment), mainly roads (16.3%) and rail (11.1%), ports and airports, the group lags behind 1.5% and 2.1% overall. It is followed by the telecommunications sector (18.3% of the total), with the largest share in broadband access (14.6% of the total). From 2016 to 2025, inequality in transport infrastructure will increase again (39.9% of total inequality). Mainly roads (22.8%) and railroads (10.3%). Energy (21.9%) is the second largest investment need in this period, but infrastructure gaps in telecommunications (15.9%) and especially broadband (11.1%) are also important. Between 2016 and 2025, transportation will be the largest infrastructure investment need, accounting for more than a third (36%) of the total, highlighting the gap between road (20%) and rail (10.6%). At the same time, the telecommunications infrastructure deficit is expected to represent 16.9% of the total, a deficit particularly related to broadband access (12.6%). In particular, the projected deficits for ports and airports are not surprising, at approximately US $6.3 billion and US $2.4 billion (at constant 2015 prices) over the 10 years between 2016 and 2025. For example, the "Jorge Chávez" airport in Peru only requires the second runway $1.2 billion of investment, half of the projected investment for the entire period.

Urrunaga and Aparicio (2012); Vásquez and Bendezú Medina (2008) provide the most important studies on the impact of infrastructure on growth in Peru. The first is a comprehensive analysis of the infrastructure-growth relationship using different perspectives and econometric techniques. Its results, in the context of time series and cointegration analysis, show that the overall impact of road infrastructure expansion on overall growth is initially positive, but decreases over time. This is consistent with the interpretation of the results of the Calderón and Servén (2014).

Aschauer (1990) was the first to measure the impact of domestic investment in engineering and infrastructure development on domestic output using the U.S. production function between 1945 and 1985. Among the main results obtained are the estimated output elasticities. In one case it is 0.39 and in the other it is 0.24. Two studies have found that investments in infrastructure such as railroads, airports, highways, energy and water have the greatest impact on U.S. economic growth.

Munnell (1990) indicates that increasing public capital had a positive effect on production and in turn, labor productivity is significantly affected. The approximate elasticity of output in relation to the stock of public capital is 0.34. In other words, a 1% increase in the stock of public capital increases output by 0.34%. Likewise, the marginal productivity of public capital is about 60% and that of private capital is about 30%. Based on the results obtained, Munnell (1990) suggested that, even with a fiscal deficit, New York State must increase current levels of public investment to lock in higher levels of output and growth in labor productivity.

From a fiscal perspective, a study of Randolph et al. (1996) empirically examines the factors that influence investment in transport and communications infrastructure. To do so, the authors use time series and cross-sectional data for the economies of 27 low- and middle-income countries between 1980 and 1986. The purpose of this study

is to determine the impact of public infrastructure spending on economic or sectoral growth and other policy objectives such as poverty reduction. More recent studies confirm a positive and statistically significant impact of infrastructure investment in the transportation sector on economic growth, but with diminishing returns (Butkus et al., 2023), and even infrastructure investments in the energy sector (Meka'a et al., 2024). It is recommended that sustained public spending on transportation and water infrastructure, railways, aviation, energy and fixed telephone lines should be implemented to ensure a country's economic growth (Fosu and Ankrah Twumasi, 2022).

Through the work of Cecil Pigou (1920) and de Coase (1960), the study of externalities includes additional modern elements and thus provides important insights into the role of governments in the internationalization of externalities and market failures. Examples include costs that affect third parties and are shared or internalized by consumer agents, producers or third parties that do not participate in industrial or service markets. On the one hand, Coase (1960) presents a new and interesting argument that any pricing system has costs that allow an economic analysis of the rules, organizational forms and means of payment. The case study shows that a key element in effectively allocating the costs is to clarify these three aspects of the transaction to absorb externalities.

In the Peruvian case, it is necessary to establish that practices that promote fiscal stability, such as greater efficiency in public spending and effective tax collection (Chávez-Díaz et al., 2023), contribute positively to economic stability and sustained growth (Flores-Sotelo et al., 2024).

Finally, to provide an additional element for analyzing how externalities are incorporated into the profitability performance of urban megaprojects, the overall "urban system equilibrium" is examined as a condition for maintaining the urban system and externalities are placed as a focal point. This leads to consider as a focal point the relationship between the components of the urban and regional system and urban externalities. In this way, natural, environmental, social and economic factors are addressed.

The study of the impact of economic growth on the externalities of infrastructure investments is crucial because it allows us to understand how these investments, both public and private, influence a country's economic and social development. Positive externalities, such as the improvement in capital productivity or the expansion of the labor market, can enhance economic growth in the long term. However, it is also important to analyze negative externalities, such as adverse environmental or social effects, which could offset the economic benefits. Thus, the assessment of these externalities is essential for designing investment policies that promote sustainable and equitable growth.

The main objective of the research is to determine the relationship between the impact of economic growth and the externalities of infrastructure investment, Peruvian case 2000–2022. The specific objectives are: To determine the relationship between the impact of economic growth and the externalities of public and private investment in infrastructure, Peruvian case 2000–2022.

2. Literature review

Rozas (2010) analyzes the extent to which investment in economic infrastructure boosted growth in Latin America and the Caribbean by improving productivity, competitiveness and quality of life. Survey responses from a set of countries (Argentina, Brazil, Chile, Colombia, Mexico, Peru and Bolivia) show that investment in infrastructure has gradually declined during the period 1980–2006, which could become a serious constraint for growth and development in the main countries of the region.

The model developed by Barro and Sala-i-Martin (1995) establishes that expansions in public spending and investment produce favorable increases in economic growth rates if these in turn have a positive effect on the productivity of private enterprises. More importantly, such effects can occur in public spending and investment in roads or in institutions that secure and secure private property rights, thus tending to secure and improve the profitability of private sector investment. The same would happen with public investment in health and education, which would improve the quality of labor supply and increase private sector productivity.

One of the first economists to use the term externalities was Marshall (1890), who used his study of industrial organization to describe the circumstances of a company's external advantages. For example, labor market, communication services, technology diffusion, etc. Jacobs (1969) offers a second perspective on urban externalities. He argues that the relationship between the dynamics of cities and the development of external influences is typically urban in nature, as cities function as a set of elements. Innovation and continuous innovation. Constant flow of information. Therefore, companies can benefit from sharing information and knowledge with other companies in different sectors, allowing them to improve their production processes and generate growth. This is called Jacob's cross. The source of growth is diversity, not specialization. The validity of the approach proposed by Jacobs is since the flow of information and knowledge is a key element of economic growth in a technological economy. These externalities are called dynamic externalities, while static externalities refer to the benefits of location and urbanization. The latter describes regional specialization, particularly associated with access to specialized suppliers and specialized labor markets.

Recent studies highlight that the goal of economic growth generates a negative externality in the form of pollution, and this pressure may conflict with environmental conservation efforts (Pang and Xie, 2024). On the other hand, in addition to natural externalities, those of the geographical environment are relevant issues to be considered (Ushakov et al., 2023).

Calderón and Servén (2010) also describe the progress of infrastructure in Latin America from a macroeconomic perspective in a chapter of the World Bank's Latin America Economic Handbook. There, they analyze 3 main areas: a) the propensity of infrastructure, evidencing its qualitative and quantitative aspects, and examining the prevalence of its access; b) the contribution of infrastructure to growth, including observations of the costs of infrastructure gaps (in terms of economic growth), and c) the permutation of the roles of the public and private sectors.

Some authors, such as Perrotti and Sánchez (2011), also consider the maintenance costs of different infrastructures as part of the infrastructure gap. These authors consider a certain proportion of the investment required in each sector's infrastructure to be earmarked for maintenance. Similarly, it is thought that the percentages used by these authors are used to estimate the additional maintenance expenditure required to plug the infrastructure gap in Peru.

A study of Hurlin (2005) evaluated the economic impact of public investment in 22 OECD countries over the period 1961–2001. The researchers will use a VAR model to appreciate the dynamic impact of public investment. productive capital. The relevance of this study is that, in accordance with the structure of the public capital data, the analysis is conducted on a larger sample of countries to be able to compare the results across these countries. Regression models that emphasize statistical significance use variables: public capital stock, private capital stock, employment and output levels. It turns out that public capital has a significant positive effect on output in the long run.

From the literature review described above, the following hypotheses are obtained to guide the research.

H0: The impact of economic growth is significantly related to the externalities of infrastructure investment, Peruvian case 2000–2022.

H1: The impact of economic growth is significantly related to the externalities of public investment in infrastructure, Peruvian case 2000–2022.

H2: The impact of economic growth is significantly related to the externalities of private investment in infrastructure, Peruvian case 2000–2022.

3. Methodology

The study is of a correlational-causal type and is developed based on a hypothetico-deductive scientific approach, using a linear regression econometric model. The empirical evidence obtained is used to test or reject hypotheses. Inferences on the relationships between variables are made without direct intervention, considering the fundamentals of economic theory and based on the relationship between the independent variable (X) and the dependent variable (Y) based on the proposed modeling.

The research carried out is descriptive, explanatory and relational, analyzing qualitative and mainly quantitative methods, providing me with the necessary analysis, as well as other experiences that provide me with the results and allow me to confront the proposals made.

The present study is non-experimental, of longitudinal trend type, and seeks to establish correlations and/or causal relationships of independent variables with dependent variables during a specific period. Time series information or historical trends of specific populations were used to make inferences about change. For this project, the period of the variable involved in the analysis is part of a non-experimental longitudinal design.

As a technique for data collection from tertiary and secondary sources are Ministry of Economy and Finance (MEF), Central Reserve Bank of Peru (BCRP),

National Institute of Statistics and Informatics (INEI) and other institutions such as IMF and World Bank.

The frame of reference of the absolute data information is in millions of soles, the observation period is 2000–2022, and each variable is the observation period of 12 data (considering that although the work period is 2000–2022, the values of the product variables are in millions of soles at 2007 real prices).

Tables 1 and **2** show the reference framework of the information considered for the growth and analysis of the research.

Table 1. Gross domestic product by type of expenditure (Real percentage changes).

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
I. Internal demand	7.7	7.5	7.2	2.2	2.6	1.0	1.5	4.2	2.3	−9.7	14.4
a. Private consumption	7.2	7.4	5.7	3.9	4.0	3.7	2.6	3.8	3.0	−8.7	11.7
b. Public consumption	4.8	8.1	6.7	6.0	9.8	−0.6	0.7	0.4	2.2	7.4	10.7
c. Gross domestic investment	10.2	7.3	10.9	−3.1	−4.0	−5.3	−1.2	7.5	0.5	−21.5	25.9
Gross fixed investment	6.0	16.3	7.9	−2.3	−4.7	−4.1	−0.3	4.4	3.3	−16.4	34.9
i. Private	11.0	15.6	7.1	−2.2	−4.2	−5.2	0.1	4.1	4.5	−16.6	37.6
ii. Public	−11.2	19.5	11.1	−2.7	−6.9	0.3	−1.8	5.4	−1.5	−15.5	23.7
Change in inventories (Contribution to GDP)	1.0	−2.3	0.7	−0.2	0.3	−0.2	−0.2	0.6	−0.6	−0.9	−2.2
II. Exports of goods and non-financial services	6.1	6.5	−0.7	−0.8	4.7	9.1	7.4	2.4	0.7	−20.1	14.0
Minus:											
III. Imports of goods and non-financial services	11.4	11.4	4.2	−1.3	2.2	−2.3	3.9	3.2	1.2	−15.7	18.8
IV. GDP	6.3	6.1	5.9	2.4	3.3	4.0	2.5	4.0	2.2	−11.1	13.3
Note: Domestic demand without inventories											
Note: Domestic demand without inventories	6.6	9.8	6.4	2.4	2.3	1.2	1.7	3.6	3.0	−8.7	16.6

Source: INEI and BCRP.

Table 2. Gross domestic product by type of expenditure (Millions of soles at 2007 prices).

	2011	**2012**	**2013**	**2014**	**2015**	**2016**
I. Internal demand	401,875	431,931	462,985	473,274	485,616	490,557
a. Private consumption	252,507	271,305	286,857	298,045	309,917	321,383
b. Public consumption	44,063	47,634	50,802	53,845	59,148	58,793
c. Gross domestic investment	105,306	112,992	125,326	121,385	116,550	110,380
Gross fixed investment	104,027	121,028	130,548	127,530	121,515	116,497
i. Private	84,518	97,722	104,660	102,337	98,062	92,983
ii. Public	19,509	23,307	25,887	25,192	23,452	23,514
Change in inventories (Contribution to GDP)	1279	−8036	−5222	−6145	−4965	−6117
II. Exports of goods and non-financial services	112,676	119,948	119,167	118,174	123,730	134,957
Minus:						
III. Imports of goods and non-financial services	108,296	120,680	125,718	124,141	126,839	123,933
IV. GDP	406,255	431,199	456,435	467,308	482,506	501,581

Table 2. (*Continued*).

	2017	2018	2019	2020	2021
I. Internal demand	498,082	519,108	531,145	479,503	549,315
a. Private consumption	329,870	342,541	352,747	321,946	356,364
b. Public consumption	59,183	59,409	60,695	65,187	72,308
c. Gross domestic investment	109,028	117,158	117,702	92,370	120,643
Gross fixed investment	116,165	121,258	125,268	104,717	141,440
i. Private	93,077	96,911	101,290	84,450	116,364
ii. Public	23,088	24,347	23,978	20,268	25,076
Change in inventories (Contribution to GDP)	−7,137	−4,100	−7,565	−12,347	−24,036
II. Exports of goods and non-financial services	144,887	148,402	149,402	119,324	136,008
Minus:					
III. Imports of goods and non-financial services	128,754	132,845	134,386	113,353	134,712
IV. GDP	514,215	534,665	546,161	485,474	550,611

Source: INEI and BCRP.

The model used will be of ordinary least squares (MCO) using the variables of the RGDP, private investment and public investment in logarithmic terms, additionally an autoregressive term called RGDPt-1 will be included, the result will be analyzed by means of the statistical tests *R*, *t*, *F*, *D–W* and in addition to the multicollinearity, normality, heteroscedasticity and autocorrelation tests for each regression used. Then, Dickey Fuller tests will be performed to find the best stationary model for each series and to estimate a VEC model to identify Johansen cointegration, since the latter is the most optimal test for more than 2 variables in the long run.

The variable representation of the research results of the econometric models proposed in Eviews12 are as follows:

$$\text{MODEL 1: } LnRGDPt = c + B1LnI\_PRIt + B2LnI\_PUBt + B3LnI\_RGDPt\text{-}1 + ut$$

$$B1 > 0;\ B2 > 0;\ B3 > 0$$

where:

C = It is the intersection of the regression line when the independent variable is zero.

LnRGDPt = Natural logarithm of Real Gross Domestic Product in the period 2000t1 to 2022t4.

LnI_PRIt = Natural logarithm of Private Investment in the period 2000t1 to 2022t4.

LnI_PUBt = Natural logarithm of Public Investment in the period 2000t1 to 2022t4.

LnI_RGDPt-1 = Natural logarithm of Real Gross Domestic Product in the previous period, from 2000t1 to 2022t4.

Ut = It is the random variable.

$$\text{MODEL 2: } LnRGDPt = c + B1LnI\_PUBt + B2LnI\_RGDPt\text{-}1 + ut$$

$$B1 > 0;\ B2 > 0$$

where:

C = It is the intersection of the regression line when the independent variable is zero.

LnRGDPt = Natural logarithm of Real Gross Domestic Product in the period 2000t1 to 2022t4.

LnI_PUBt = Natural logarithm of Public Investment in the period 2000t1 to 2022t4.

LnI_RGDPt-1 = Natural logarithm of Real Gross Domestic Product in the previous period, from 2000t1 to 2022t4.

Ut = It is the random variable that considers other variables that are not considered in the model.

$$\text{MODEL 3: } LnRGDPt = c + B1LnI\_PRIt + B3LnI\_RGDPt\text{-}1 + ut$$

$$B1 > 0;\ B2 > 0;\ B3 > 0$$

where:

C = It is the intersection of the regression line when the independent variable is zero.

LnRGDPt = Natural logarithm of Real Gross Domestic Product in the period 2000t1 to 2022t4.

LnI_PRIt = Natural logarithm of Private Investment in the period 2000t1 to 2022t4.

LnI_RGDPt-1 = Natural logarithm of Real Gross Domestic Product in the previous period, from 2000t1 to 2022t4.

Ut = It is the random variable.

4. Results

Private investment shows a constant growth with a positive trend, from S/6678 million in 2000 to 48,709 million soles by 2022, **Figure 1** shows that it has maintained a constant variance until the end of 2019. At the beginning of 2020 there is a drop due to the COVID-19 pandemic, thus falling back to levels like 2009, then a rebound effect is observed where there is a recovery in the following periods.

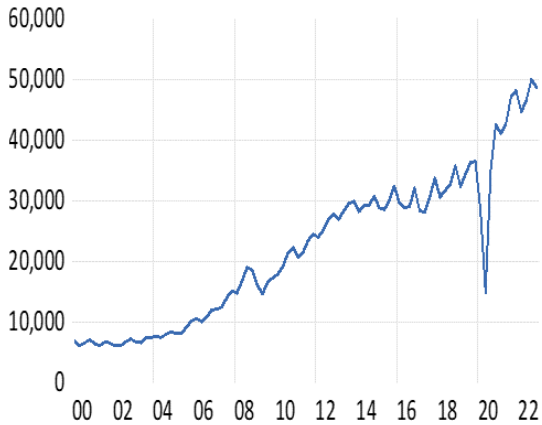

Figure 1. Private investment (millions of soles).

Source: BCRP statistical series.

Public investment, unlike private investment, shows a seasonal cycle, since it has an annual budget to be executed. It is observed that in the fourth quarter of each year it reaches its highest peak of investment for each year.

Likewise, it is observed that starting in 2009, its investment rate grew notably with respect to previous years, going from S/6343 million in the fourth quarter of 2008 to 8956 million soles in 2009, being this year the beginning of the constant growth of public investment.

Furthermore, in the year 2020, during COVID-19, a greater contribution and intervention of the State through public investment is observed. This was necessary given the restrictive policies and confinement that were given to deal with the economic recession. By 2021, when the restrictive policies were withdrawn, the economy had a remarkable recovery thanks to the private sector, which is why there was less State intervention in public investment, as shown in **Figure 2**.

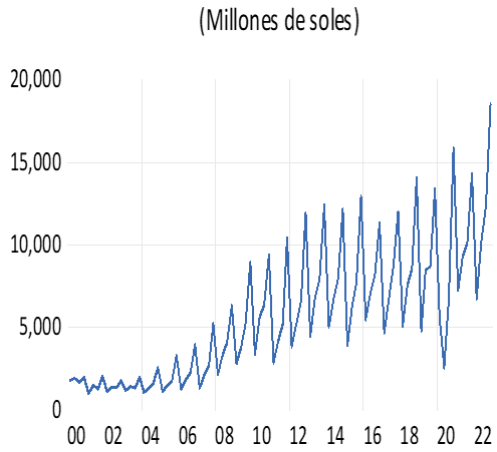

Figure 2. Public investment (millions of soles).

Source: BCRP statistical series.

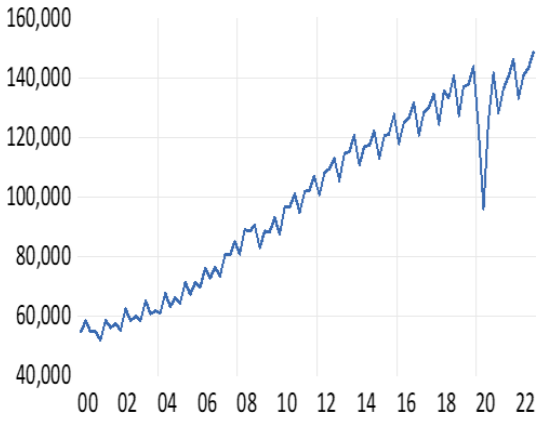

Figure 3. Real GDP (millions of soles).

Source: BCRP statistical series.

With respect to real GDP (**Figure 3**), a positive trend is observed, with constant growth and variance with seasonal patterns. The most relevant in the period analyzed is from 2020 onwards, where a drop of −11% is observed with respect to the previous year. The real GDP is explained by private investment and public investment, in addition to consumption and net exports, in this research the factors of externalities of

public and private investments are highlighted. Therefore, it can be argued that the intervention of both gives as part of the result the behavior of real GDP, obtaining a real GDP in 2022 quarter 4 of 149,000 million soles.

The results obtained for the hypotheses proposed are as follows:

H0: The impact of economic growth is significantly linked to infrastructure investment externalities, Peruvian case 2000–2022.

The estimated model in **Table 3** initially shows that all the independent variables have a significant t-statistic greater than 2 and a probability of less than 5%, which indicates that they are significant and explains the model.

Table 3. Analysis of the estimated model (combined effect of private and public investment).

Dependent variable: LOG(RGDP)				
Method: least squares				
Sample (adjusted): 2000Q2 2022Q4				
Included observations: 91 after adjustments				
Variable	Coefficient	Std. error	*t*-statistic	Prob.
C	4.609.389	0.440242	1.047.011	0.0000
LOG (I_PRI)	0.247938	0.039121	6.337.761	0.0000
LOG (I_PUB)	0.058834	0.015326	3.838.913	0.0002
LOG (RGDP(-1))	0.342752	0.064724	5.295.612	0.0000
R-squared	0.980212	Mean dependent var		1.145972
Adjusted *R*-squared	0.979529	S.D. dependent var		0.317185
S.E. of regression	0.045382	Akaike info criterion		−3.304464
Sum squared resid	0.179175	Schwarz criterion		−3.194096
Log likelihood	1.543531	Hannan-Quinn criter.		−3.259937
F-statistic	1.436507	Durbin-Watson stat		1.778430
Prob(*F*-statistic)	0.000000			

Source: BCRP statistical series.

The R^2 is 98.02%, which indicates that there is a high level of explanation by the independent variables to the LOG (RGDP), as well as the *F*-statistic or global significance concludes that being less than 5%, the independent variables have a significant effect on the dependent variable. The Durbin-Watson coefficient presents a value of 1.7784 close to 2, so it does not present a serial correlation.

The coefficient of the LOG(I_PRI) is 0.2479, which indicates a direct correlation with respect to the LOG(RGDP), which means that for each 1% variation of the LOG(I_PRI), the LOG(RGDP) will increase by 0.2479%.

On the other hand, the coefficient of LOG(I_PUB) is 0.0588, which indicates a direct correlation with respect to LOG(RGDP), which means that for every 1% variation of LOG(I_PRI), LOG(RGDP) will increase by 0.0588%.

Finally, the LOG (RGDP (−1)) is an autoregressive term to optimize the model in terms of serial correlation with respect to the previous period, it has a coefficient of 0.3427%, which explains that with 1% changes in the lagged periods, the LOG(RGDP) will increase by 0.3427%.

This analysis is consistent with the hypothesis.

H1: The impact of economic growth is significantly related to the externalities of public investment in infrastructure, Peruvian case 2000–2022.

The estimated model in **Table 4** initially shows that all the independent variables (LOG(I_PUB) and LOG (RGDP (−1)) have a significant *t*-statistic greater than 2 and a probability of less than 5%, which indicates that they are significant and explain the model.

Table 4. Analysis of the estimated model (public investment effect).

Dependent variable: LOG(RGDP)				
Method: least squares				
Sample (adjusted): 2000Q2 2022Q4				
Included observations: 91 after adjustments				
Variable	Coefficient	Std. error	*t*-statistic	Prob.
C	2.361.568	0.313523	7.532.348	0.0000
LOG (I_PUB)	0.120403	0.014249	8.449.839	0.0000
LOG (RGDP (−1))	0.706767	0.035869	1.970.436	0.0000
R-squared	0.971075	Mean dependent var		1.145972
Adjusted *R*-squared	0.970418	S.D. dependent var		0.317185
S.E. of regression	0.054554	Akaike info criterion		−2.946847
Sum squared resid	0.261898	Schwarz criterion		−2.864071
Log likelihood	1.370815	Hannan-Quinn criter.		−2.913452
F-statistic	1.477201	Durbin-Watson stat		2.107496
Prob(*F*-statistic)	0.000000			

Source: BCRP statistical series.

The R^2 indicates that the variables explain 97.10% of the dependent variable LOG(RGDP), and the prob(*F*-statistic) or global significance concludes that, being less than 5%, the independent variables have a significant effect on the dependent variable. As for the Durbin-Watson, it presents a value of 2.1075 close to 2, so it does not present serial correlation.

Considering public investment as the only independent variable to explain the dependent variable RGDP, we obtain the following:

The coefficient of LOG (I_PUB) is 0.1204, which indicates a direct correlation with respect to LOG (RGDP), this means that for each 1% variation of LOG(I_PUB), the LOG (RGDP) will increase by 0.1204%.Finally, the LOG (RGDP (−1) is an autoregressive term to optimize the model in terms of serial correlation with respect to the previous period, it has a coefficient of 0.7067, which explains that with 1% changes in the lagged periods, the LOG (RGDP) will increase by 0.7067%.

This analysis is consistent with the hypothesis.

H2: The impact of economic growth is significantly related to the externalities of private investment in infrastructure, Peruvian case 2000–2022.

The estimated model in **Table 5** initially shows that all the independent variables have a significant *t*-statistic greater than 2 and a probability of less than 5%, which indicates that they are significant and explains the model.

Table 5. Analysis of the estimated model (private investment effect).

Sample (adjusted): 2000Q2 2022Q4				
Included observations: 91 after adjustments				
Variable	Coefficient	Std. error	*t*-statistic	Prob.
C	4.890.048	0.466786	1.047.599	0.0000
LOG (I_PRI)	0.343134	0.032533	1.054.718	0.0000
LOG (RGDP (−1))	0.279558	0.067304	4.153.650	0.0001
R-squared	0.976860	Mean dependent var		1.145972
Adjusted R-squared	0.976334	S.D. dependent var		0.317185
S.E. of regression	0.048795	Akaike info criterion		−3.169956
Sum squared resid	0.209526	Schwarz criterion		−3.087181
Log likelihood	1.472330	Hannan-Quinn criter.		−3.136561
F-statistic	1.857436	Durbin-Watson stat		2.107605
Prob(F-statistic)	0.000000			

Source: BCRP statistical series.

The R^2 is 97.68%, which tells us that there is a high level of explanation by the independent variables (LOG(I_PRI) and LOG (RGDP (−1))) to LOG (RGDP), as well as the prob(*F*-statistic) or global significance concludes that being less than 5%, the independent variables have a significant effect on the dependent variable. As for the Durbin-Watson test, it presents a value of 2.1076 close to 2, so it does not present a serial correlation.

Considering private investment as the only independent variable to explain the dependent variable RGDP, the following is obtained:

The coefficient of LOG(I_PUB) is 0.3431, which indicates a direct correlation with respect to LOG(RGDP), this means that for every 1% variation of LOG(I_PUB), LOG(RGDP) will increase by 0.3431%.

Finally, the LOG (RGDP (−1)) is an autoregressive term to optimize the model in terms of serial correlation with respect to the previous period, it has a coefficient of 0.2795, which explains that with 1% changes in the lagged periods, the LOG(RGDP) will increase by 0.2795%.

This analysis is consistent with the hypothesis.

Model VEC

$$\begin{aligned}LnRGDPt = {} & A0 + A1LnRGDPt\text{-}1 + A2LnRGDPt\text{-}2 + A3LnRGDPt\text{-}3 + B1LnI\_PRIt\text{-}1 + B2LnI\_PRIt\text{-}2 + \\ & B3LnI\_PRIt\text{-}3 + C1LnI\_PUBt\text{-}1 + C2LnI\_PUBt\text{-}2 + C3LnI\_PUBt\text{-}3 + ut\end{aligned}$$

where:

LnRGDPt = Natural logarithm of the real GDP, it is a column vector of endogenous variables of dimension 3 × 1.

A0 = It is a matrix of constants of dimension 3 × 1.

A1, A2 and A3 = These are 3 × 3 lag coefficient matrices representing the dynamics of the endogenous variables.

LnI_PRIt = Natural logarithm of private investment, is a column vector of exogenous variables of dimension 3 × 1.

B1, B2 and B3 = These are 3 × 3 lag coefficient matrices representing the influence of the exogenous variables on the endogenous variables.

LnI_PUBt = Natural logarithm of public investment, it is a column vector of exogenous variables of dimension 3 × 1.

C1, C2 and C3 = These are 3 × 3 lag coefficient matrices representing the influence of the exogenous variables on the endogenous variables.

Ut = This is an error column vector of dimension 3 × 1.

The Johansen cointegration test indicates whether 3 or more series are cointegrated in the long run, for this test was used for 2 and 3 lags, giving as optimal and consistent up to 3 lags. Thus, given the table, it indicates that, for no cointegrating vector, it has a probability of 3.03%, so it rejects that there is no cointegrating vector, for a maximum of 1 cointegrating vector, it has a probability of 38.01%, so it accepts that there is a maximum of 1 cointegrating vector, according to **Table 6** and joint analysis using the Granger causality test in **Table 7**.

This test was performed for 4 lags, but it does not show consistency since there is no cointegrating vector. Therefore, the study variables LOG (RGDP), LOG (I_PRI) and LOG (I_PUB) are closely related in the long run and cointegrate with each other.

Table 6. Johansen co-integration.

Series: LOG (RGDP) LOG (I_PRI) LOG (I_PUB)				
Lags interval (in first differences): 1 to 3				
Unrestricted cointegration rank test (trace)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigen value	Statistic	Critical value	Prob.**
None *	0.228199	3.163.756	2.979.707	0.0303
At most 1	0.077656	8.843.040	1.549.471	0.3801
At most 2	0.019460	1.729.351	3.841.465	0.1885
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level				
* Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
Unrestricted cointegration rank test (maximum eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigen value	Statistic	Critical value	Prob.**
None *	0.228199	2.279.452	2.113.162	0.0289
At most 1	0.077656	7.113.690	1.426.460	0.4758
At most 2	0.019460	1.729.351	3.841.465	0.1885
* Denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) *p*-values				

Source: BCRP statistical series.

Table 7. Granger causality.

VEC granger causality/block exogeneity wald tests			
Sample: 2000Q1 2022Q4			
Included observations: 89			
Dependent variable: D(LOG(RGDP))			
Excluded	Chi-sq	df	Prob.
D (LOG (I_PRI))	5.059.392	2	0.0797
D (LOG (I_PUB))	2.988.951	2	0.2244
All	1.098.828	4	0.0267
Dependent variable: D(LOG(I_PRI))			
Excluded	Chi-sq	df	Prob.
D (LOG (RGDP))	0.514584	2	0.7731
D (LOG (I_PUB))	6.843.563	2	0.0327
All	8.152.454	4	0.0862
Dependent variable: D (LOG (I_PUB))			
Excluded	Chi-sq	df	Prob.
D (LOG (RGDP))	3.525.264	2	0.0000
D (LOG (I_PRI))	4.648.801	2	0.0000
All	6.638.981	4	0.0000

Source: BCRP statistical series.

(1) In the first section it indicates that Private and Public investment together (Prob. 2.67%) cause in the Granger sense the RGDP

(2) In the second section it indicates that public investment causes Private investment in the Granger sense, since its probability is less than 5%, while public investment together with RGDP do not cause Private investment.

(3) In the third section, the RGDP and Private Investment cause in the Granger sense individually and jointly public investment, since they all have probabilities less than 5%.

Infrastructure investment in Peru has been a central axis of economic development in recent decades. This allowed for a significant expansion in the coverage of basic services, despite the challenges of a late start and very low-income levels. In the last ten years, the water supply to households has increased from 72.6% to 87.6%. The rate of use of public health services increased from 62.8% to 71.2%, and the rate of electricity use increased from 86.4% to 95.2%. This means that 7.1 million more people have access to water, 4.7 million to sanitation and 8.8 million to electricity in the last ten years.

However, this effort has not reached the desired level that would allow Peru to reach the level of competitiveness and productivity that would allow the income of its residents to increase significantly. The benefits of investments aimed at eliminating deficiencies should be complemented with a series of measures related to improving the quality of access to public services, the development and implementation of management mechanisms that facilitate multi-year resource forecasting. Improving the management of public investment projects and continuous coordination and cooperation between the public sector at three levels: public and private.

In addition, infrastructure investments should be specific to Peru, taking advantage of the opportunities it offers and focusing on adapting and mitigating the risks associated with the specificities of each of Peru's geographic regions. It should be noted that the characteristics of large-scale urban infrastructure projects are comparable to public sector investment initiatives. The project will be implemented using management and financing methods like those of private companies but will focus on investing in public goods. Rationalization of the market for goods and services and factors of production for all subjects of the economy. For example, major urban highways generate savings by reducing travel time, reducing pollution and congestion, and improve the welfare of users by providing better access to services and employment centers. Market demand for goods and services can also increase. Likewise, projects of this type improve companies' access to raw materials and factor markets, which are important factors in internationalization, as well as bring production processes closer to distribution and exchange points in terms of global reach.

However, the social benefits and positive externalities associated with this type of projects require the inclusion of spatial considerations in the analysis, as occurs in most economic profitability studies, which allow decisions to be made on the implementation of investment projects, otherwise it will not change. Since they cannot be quantified, they fall into the realm of "intangible benefits or costs".

Therefore, the result of the research shows a positive and significant relationship between infrastructure investments, both public and private, and the growth of real Gross Domestic Product (GDP) in Peru during the period 2000–2022. The estimated econometric models indicate that these investments generate positive externalities that boost economic growth, with a high explanatory capacity of the independent variables on GDP. Private investment has a stronger impact on economic growth than public investment, although both are fundamental. In addition, it is confirmed that investments in infrastructure, by improving capital productivity and expanding the labor market, have a direct effect on GDP growth, which underlines the importance of continuing to promote these investments for the sustainable development of the country.

5. Discussion

According to Pedroni (2004) the analysis applied demonstrated the probability of cointegration between infrastructure variables and GDP per capita. Since the probability of inverse causality between variables was required, to propose a variation of the method of Pedroni (2004) in which the causality in both directions of the regression of interest is robust. Simplifying this relationship, we obtain $yt = \beta 0 + \beta 1 ft + et$, which is specified in the endogenous growth model group. Here, ft is a vector of infrastructure variables, as defined. yt is per capita income. et embodies the stationary error term. $\beta 0$ is the intercept. This formula uses the residuals to estimate the ADF test for unit roots. Therefore, the values shown above mean that the null hypothesis is rejected for all events. It is then assumed that each 27 of the series is not stationary, but that there is a combination between the infrastructure variables and GDP.

According to Urrunaga and Aparicio (2012) The first group of models has output per capita as the dependent variable, estimated at the level of output. It is framed within the neoclassical theory of exogenous growth and evaluates the temporal effects of infrastructure on society. output. Using these models, it was verified that all infrastructure has a positive and significant effect on regional per capita output. Similarly, this relationship holds across the different estimators used, indicating that the results are robust (no sign changes between specifications and magnitudes of similar coefficients).

To Calderón and Servén (2014) there is an average causal link of 3.6% between the level of infrastructure and economic growth, which is much higher than the 0.16% relationship found in this study. However, as explained by Troncoso and Acero (2006), It cannot be ignored that investment in transportation infrastructure is very important, and its promotion or delay is of great importance for economic growth. Mishra et al. (2013) found an increase of 0.46%, which is close to the value found in the concurrent study. While in the work of Vásquez and Medina (2008) found an increase in the economy. According to the findings of this study, the most appropriate option would be to invest in roads that are favorable for agriculture.

Vásquez and Medina (2008) found that a 1% increase in road infrastructure impacts a country's GDP by 0.218 percentage points. In the meantime, Devarajan et al. (1996) points out that a negative result does not indicate that the explanatory variable is negatively related to the economic growth and that the circumstance is not productive, but rather indicates a slow growth or may indicate a high level of investment to achieve higher growth during the mentioned period.

Machado and Hiroshi (2017) estimates that both the direct effect and the time lag of employment adjusted for education and transportation investments have statistically significant and positive coefficients. Thus, a 1% increase in human capital-adjusted employment in region i increases regional output by 0.119% on average. Similarly, a 1% increase in transportation investment in region i increases the region's output by 0.025% on average. In terms of indirect effects, both physical capital and communications investments lead to statistically significant increases in regional output. Specifically, a 1% increase in the capital stock in all regions except region 1 increases their output by 0.776% on average. Similarly, a 1% increase in communications investment in all regions except region i increases regional output by 0.008% on average.

Straub (2008) considers that infrastructure is directly related to production and stimulates economic growth, since it is an important input for private activities. Several studies have summarized the main findings on these relationships.

Limitations of the study include the use of econometric models based on historical data that may not fully capture the future dynamics of infrastructure investment and its impact on economic growth. In addition, the research focuses on aggregate macroeconomic variables, which may limit the detailed analysis of effects at the regional or sectoral level. Another limitation is that mainly positive economic externalities are considered, without a thorough analysis of negative externalities such as adverse environmental or social impacts. Finally, the study relies on data available between 2000 and 2022, which may not adequately reflect the effects of recent events such as the COVID-19 pandemic on investment and growth.

6. Conclusions and recommendations

It was noted that investment in road infrastructure is not only a direct benefit. This is because roads are built solely to reduce vehicle operating costs and save travel time for users. It is well known that roads generate positive externalities, such as increased productive activity in various sectors of the local economy, a corresponding increase in employment and population, and therefore an increase in the domestic market increases the movement of vehicles. In this sense, it is necessary to include indirect benefits when calculating the total benefits of roads.

Private investment shows constant growth with a positive trend, going from 6678 million soles in 2000 to 48,709 million soles by 2022. It can be observed that it has maintained a constant variance until the end of 2019. At the beginning of 2020 there was a drop due to the COVID-19 pandemic, falling back to levels like those of 2009, then a rebound effect was observed, with a recovery in the following periods.

Likewise, it is observed that Public Investment, starting in 2009, its investment index grew notably with respect to previous years, going from 6343 million soles in the fourth quarter of 2008 to 8956 million soles in 2009, this year being the beginning of the constant growth of public investment. In addition, for the COVID-19 pandemic in the year 2020, a greater contribution and intervention of the state is seen through public investment, being necessary given the restrictive policies and the confinement of an economic recession due to the situation in 2020.

From the economic point of view, large infrastructure projects are linked to urban services and mobility, i.e., they are "good" and therefore create a specific market. There is a demand for that good, which reflects the "willingness to pay" for travel or mobility and urban services, as well as the production of that good or service (travel, drinking water, education, etc.). According to the World Bank, "cities account for 55% of gross national product (GDP), 73% of middle-income earners and 85% of high-income earners". Therefore, urban megaprojects are important. Large generators of economic development conditions, but also large generators of urban and environmental externalities.

In this method of evaluating investment decisions, used mainly in the public sector, externalities are expressed only as intangible costs and benefits that cannot be "valued" in a monetary unit (income redistribution effects, landscape impacts, national security, etc.). These intangible effects are only mentioned in the study but are not significant in the cost-effectiveness analysis and the updated assessment of the net benefits of the project.

Policy suggestions for Peru include improving efficiency in public investment, optimizing the management and use of resources allocated to infrastructure projects. It is proposed to establish effective coordination and cooperation mechanisms between the three levels of government and the private sector to maximize the impact of infrastructure investments. In addition, it is recommended that investments be adapted to the country's geographic particularities, prioritizing projects that mitigate specific risks and take advantage of regional opportunities, ensuring that they are carried out with a sustainable and equitable development perspective, with due legal assurances, without corruption and with transparent information.

It is recommended that future studies include the need to deepen the analysis of the impact of negative and positive externalities generated by infrastructure investments in different economic sectors and regions of the country. In other words, studies that evaluate the impact of these investments on sustainable development, particularly in aspects such as environmental conservation and social welfare. Finally, it is suggested to investigate the long-term effects of infrastructure on poverty reduction and the improvement of the quality of life of the population in the most vulnerable areas of the country.

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