Journal of Infrastructure, Policy and Development (2022) Volume 6 Issue 1.
DOI: 10.24294/jipd.v6i1.1419

ORIGINAL ARTICLE

Infrastructure and economic growth: Evidence from the United States

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ABSTRACT

Developing countries have witnessed a rise in infrastructure spending over the past decades; however, infrastructure spending in most developed countries, particularly the US, continues to decline. As a result, in 2021, the US Congress passed a Bipartisan Infrastructure Bill, which invests $1 trillion in the country's infrastructure every year. Using the principal component analysis and VAR estimation, we analyzed the impact of infrastructure (transportation and water, railway networks, aviation, energy, and fixed telephone lines) on economic growth in the US. Our findings show that infrastructure spending positively and significantly impacted economic growth. Additionally, the impulse response analysis shows that shocks to infrastructure spending had positive and persistent effects on economic growth. Our results suggest that infrastructure investment spurs economic growth. Based on our findings, sustained public spending on transport and water, railway networks, aviation, energy, and fixed telephone lines infrastructure by the US government will positively impact economic growth in the country. The study also suggests that policies that promote infrastructure spending, such as the Bipartisan Infrastructure Law (Infrastructure Investment and Jobs Act) passed by the US Congress, should be enhanced to boost economic growth in the US.

Keywords: *economic growth; infrastructure; vector autoregression; United States*

1. Introduction

Infrastructure is the backbone of every economy's growth and prosperity and is critical for households' social and economic welfare. Infrastructure availability and quality are economic growth determinants in both developed and developing countries (Canning and Pedroni, 2004; Holtz-Eakin and Schwartz, 1995). Infrastructure investment increases job creation, improves labor efficiency, lowers production costs, and increases the economy's competitiveness and productivity. A study by the University of Maryland found that every $1 in infrastructure spending in the US contributes about $3 to GDP growth, with a more significant effect during a recession (Business Roundtable, 2015). In contrast, poor infrastructure imposes high costs on the economy, leading to high unemployment, decreased personal income, and a decrease in the country's international competitiveness. A study by Petroski (2016) indicated that delays caused by traffic congestion alone cost the US

ARTICLE INFO
Received: February 1, 2022
Accepted: July 25, 2022
Available online: August 3, 2022

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CITATION
Fosu P and Ankrah Twumasi M (2022). "Infrastructure and economic growth: Evidence from the United States". *Journal of Infrastructure, Policy and Development*, 6(1): 1419. doi: 10.24294/jipd.v6i1.1419

economy over $120 billion yearly.

While the global community has made significant progress in infrastructure spending, there is still a huge infrastructure gap. Globally, public expenditure on infrastructure such as transport, power, water, and telecommunication currently amounts to $2.7 trillion yearly, which should be $3.7 trillion (World Economic Forum, 2016). For instance, China and Vietnam invest around 10% of their GDP on infrastructure; however, these countries are struggling to keep pace with the growing demand for electricity, telephone, and transport (Straub et al., 2008).

In the US, the infrastructure gap is largely seen in almost all sectors of the economy. Public infrastructure spending in the US is at a 20-year low; as a result, most of America's roads, bridges, and dams are rated D+ (American Society of Civil Engineers (ASCE), 2021). The overall infrastructure spending as a share of GDP has declined from 3.0% in 1959 to 2.3% in 2017 (Congressional Budget Office, 2021). For example, public spending on highways as a percentage of GDP dropped from 1.58% in 1958 to 0.92% in 2017 (Congressional Budget Office, 2020). An ASCE report (2021) also indicated that drinking water, wastewater, and irrigational systems will need an extra investment of $632 billion over the next decade. Between 2010 to 2015, China spent about 8.3% of its GDP on public infrastructure compared with 2.3% of GDP in the US (Congressional Budget Office, 2021). In 2019, the US ranked 13th in the world, down from the 5th position in 2002 regarding infrastructure quality (Congressional Budget Office, 2021). The declining trend in infrastructure spending in the US, coupled with the economic crisis caused by the coronavirus pandemic, call for the need to critically examine the impact of infrastructure on economic growth in the US empirically.

While previous studies have analyzed the effects of infrastructure on economic growth, most of these employed one infrastructure measurement. For example, Fosu (2021) used railway lines (total route, km) to measure infrastructure, Donaldson and Hornbeck (2016) used railroads to measure infrastructure, Banerjee, Duflo and Qian (2020) used access to transportation, Czernich et al. (2011) used broadband, Cronin et al. (1991) used telecommunication, Boopen (2006) used transport capital, Sridhar and Sridhar (2007) used telephone penetration, and Pradhan and Bagchi (2013) used road transportation. Infrastructure is broad, so using one indicator to proxy for infrastructure does not capture the more general definition. This study differs from these previous studies because it included several measures of infrastructure (i.e., transportation and water, railway, aviation, energy technology and efficiency, and fixed telephone lines) and analyzed their effects on economic growth. Thus, the objectives of this study were to examine the impact of infrastructure on economic growth and how temporal and permanent infrastructure shocks affected economic growth in the US using the principal component analysis (PCA) and the VAR estimation. The paper contributes to empirical literature and policy by including several variables in measuring infrastructure using the PCA. That is, the paper focused on a broader measurement of infrastructure. Another contribution of this paper is that it decomposed infrastructure spending into temporary and permanent and examined their effects on economic growth. In addition, the literature on infrastructure and growth nexus has focused mainly on developing and emerging countries with limited studies on developed economies. Thus, this study contributes to the literature by focusing on the US. Lastly, policymakers in both developed and developing countries could rely on the outcome of this study to design appropriate policies to boost infrastructure spending and hence increase output. The rest of the paper is structured as follows. The second section presents the literature review, while the third section gives the methodology. The fourth section presents the results and discussion, and the last section presents the conclusion and recommendations.

2. Literature review

This section of the paper reviews the literature on the relationship between infrastructure and economic growth. The work of Donaldson and Hornbeck (2016) examined the impact of railroads on market access in the US. Their study found a significant effect of railroads on the agricultural sector in 1890. They also found that the agricultural land declined by 63.5% in the absence of railroads, leading to a loss of 3.4% in GNP. Also, Banerjee et al. (2020) sought to estimate the effects of access to transportation networks on regional economic outcomes in China. The authors found that access to transportation networks have a moderate and positive impact on the level of real GDP per capita across sectors; however, it does not affect the growth of real GDP per capita in China. In a similar study, Esfahani and Ramírez (2003) employed a cross-country analysis and found that the contribution of infrastructure services to GDP far outweighs the cost associated with providing those services.

Employing the panel analysis, Czernich et al. (2011) examined the effects of broadband infrastructure on economic growth in OECD countries from 1996 to 2007. Their work found that a 10% increase in broadband infrastructure increased annual GDP per capita growth by 0.9%–1.5%. In addition, employing the difference-in-difference approach, Yoshino and Abidhadjaev (2017) analyzed the impact of a high-speed rail line on tax revenues and the economy of affected regions in Japan. They found a significant positive impact on the region's tax revenue following the connection of the Kyushu rapid train with large cities, such as Osaka and Tokyo.

Cronin et al. (1991) also employed the time series data from 1958–1988 and found a bi-directional causality between telecommunications infrastructure and economic growth in the US. In a similar study, Nadiri and Mamuneas (1991) found a positive impact of public infrastructure and R&D spending on US manufacturing industries' cost structure and performance. They also found a significant variation in the effect on cost structure across sectors and the contribution to labor productivity growth over time. Again, in East Asia, Straub, Vellutini, and Warlters (2008) employed both the growth accounting model and cross-country regressions and found an insignificant relationship between infrastructure, productivity, and growth. Also, using the dynamic panel model, Boopen (2006) found that transport capital contributed significantly to the economic growth of Sub-Saharan African countries and Small Island Developing States. Employing the World Bank's Long-Term Growth Model (LTGM), Devadas and Pennings (2019) analyzed the effects of an increase in the quantity or quality of public investment on growth. They found that a permanent 1% GDP increase in public investment increases growth by around 0.1 to 0.2 percentage points. In their study, Canning and Pedroni (2004) investigated the long-run effects of telephones, electricity generation, and paved roads on per capita income in a panel of countries from 1950 to 1992. They found that infrastructure did induce long-run growth effects; however, they found a significant variation in the results across individual countries. Additionally, using panel data for 48 contiguous US states from 1970 to 1983, Garcia-Milà et al. (1996) estimated the Cobb-Douglas production function with three types of public capital as inputs. After controlling for fixed effects, they found that highways and water and sewers contributed 0.127% and 0.064%, respectively, to the production function, while other capital spending contributed –0.071% to the production function. Also, Sridhar and Sridhar (2007) employed the 3SLS estimation and empirically investigated the relationship between telephone penetration and economic growth in developing countries. They found a positive impact of mobile and landline phones on national output. Zhou (2022) analyzed the effect of digital infrastructure construction on economic growth and found that digital infrastructure reduced search costs, encouraged big data usage, and controlled inflation. Fosu (2019) found a positive and significant impact of infrastructure on economic growth in the long run; however, the effect was insignificant in the short run in the United States. In addition, the author found a one-way causality from growth to infrastructure. In a similar study, Fosu and Twumasi (2022) found a significant positive impact of the US state and local governments' spending on transport and water infrastructures on economic growth; however, federal government spending also had a positive and insignificant effect on economic growth.

Furthermore, Sahoo and Dash (2009) investigated the role of infrastructure in economic growth in India from 1970 to 2006 and found that infrastructure stocks played an essential role in economic growth in India. They also found that infrastructure development impacted growth more than infrastructure investments. Additionally, they found a unidirectional causality running from infrastructure development to output growth. More so, the work of Aschauer (1989) considered the relationship of aggregate productivity and stock with flowed government-spending variables. The empirical results revealed that a "core" infrastructure of streets, highways, airports, mass transit, sewers, water systems, etc., has the most explanatory power for productivity. Furthermore, the work of Pradhan and Bagchi (2013) used the Vector Error Correction Model (VECM) and found a bidirectional causality from road transportation to economic growth and capital formation; however, a unidirectional causality was found from rail transportation to economic growth and capital formation.

3. Materials and methods

3.1. Data

The study used historical data covering the period from 1980 to 2016. We obtained data on fixed telephone lines, economic growth, capital stock, and labor from the World Bank (i.e., World Development Indicators).[1] The data on transport and water, railway, aviation, and energy were obtained from the Congressional Budget Office.[2] The choice of this sample period was influenced by data availability. Economic growth was measured as a log of real GDP per capita (current US$), capital stock was measured as a log of gross fixed capital formation (current US$), and labor was measured as tertiary school enrollment (% gross). Transport and water infrastructure, railway, and aviation infrastructure were measured as public spending (billions of 2017 dollars). Energy was measured as public spending on energy technologies and efficiency (billions of 2015 dollars), and telephone lines were measured as fixed telephone subscriptions (per 100 people).

1. Data from the World Bank were gleaned from worldbank.org (World Bank, 2020).

2. Data from the Congressional Budget Office were obtained specifically from these websites: www.cbo.gov/publication/54539 and www.cbo.gov/publication/50980.

Table 1. Correlation analysis

	Transport & Water	Rail	Aviation	Energy	Telephone lines
Transport & Water	1				
Railway	0.876***	1			
Aviation	0.967***	0.759***	1		
Energy	0.371**	0.218	0.424***	1	
Telephone lines	0.341**	–0.079	0.513***	0.196	1

Source: Authors' construct

3.2. Principal component analysis (PCA)

The main objective of this study was to examine the impact of different kinds of infrastructure on economic growth. Specifically, the infrastructure measures we included in this study were transportation and water, railway, aviation, energy, and fixed telephone lines. Analyzing the empirical link between different kinds of infrastructure and economic performance is also associated with a high degree of correlation (Calderón, 2009). The high degree of co-movement among the different infrastructure measures may prevent us from identifying their estimated impact on economic growth. In **Table 1**, we tested the correlation among these infrastructure measures to check if this problem was present in our dataset. Our correlation analysis shows a strong correlation among these infrastructure variables (see Table 1). Thus, to address this problem, we followed the strategy adopted by Calderón and Servén (2004) and constructed an aggregate index that captured the stock of the different types of infrastructure measures.[3] We aggregated these infrastructure measures using the principal component analysis (PCA) (Calderón, 2009). Alesina and Perotti (1996) used the PCA to construct a measure of political instability, while Sanchez-Robles (1998) used this approach to build an aggregate index of infrastructure stocks. The PCA also can reduce dimensionality in the data (Zeng et al., 2017).

3.2.1. Principal components and eigenvectors/loadings

Panel A of **Table 2** presents the result of the principal component analysis. The result shows that the first component (Comp1) had the largest eigenvalue and thus explains most of the variations in the data. In proportion, Comp1 accounts for about 60.9% of the total variability of the observed variables. Thus, Comp1 entered our growth model in Equation 1. Panel B of Table 2 shows that aviation contributed 56.3% to Comp1, followed by the contributions of transport and water (56.2%), railway (47.1%), energy (29.2%), and then telephone lines (24.5%). This suggests that aviation, transport and water, railway networks, energy, and telephone lines were variables loaded into Comp1.

3.3. Empirical model

Following Garcia-Milà et al. (1996), we specified our basic empirical model to show the impact

[3] Calderón and Servén (2004) found that when infrastructure measures, such as telecommunications, power, and roads, were included together in a growth-regression equation, the estimated coefficient of power was negative and statistically insignificant, while neither the infrastructure measure of main lines nor that of road networks was statistically insignificant in some regressions.

Table 2. Principal components and eigenvectors/loadings

Panel A

Components	Eigenvalue	Difference	Proportion	Cumulative
Comp1	3.044	1.933	0.609	0.609
Comp2	1.111	0.317	0.222	0.831
Comp3	0.793	0.753	0.159	0.99
Comp4	0.041	0.029	0.008	0.998
Comp5	0.011		0.002	1

Panel B

Variable	Comp1	Comp2	Comp3	Comp4	Comp5
Transport & Water	0.562	–0.123	–0.127	–0.266	–0.763
Railway	0.471	–0.52	–0.073	0.678	0.207
Aviation	0.563	0.074	–0.133	–0.536	0.611
Energy	0.292	0.263	0.914	0.101	–0.015
Telephone lines	0.245	0.800	–0.355	0.416	–0.035

Source: Authors' construct

of the aggregate infrastructure index (Comp1) on economic growth, as follows:

$$lnGrowth_t = \beta_0 + \beta_1 lncapital_t + \beta_2 Labor_t + \beta_3 comp1_t + \varepsilon_t \quad (1)$$

where $Growth_t$ denotes economic growth, where capital stock and labor were the control variables in this study. Variable $comp1_t$ is the main explanatory variable in this study. It is the first principal component that included different types of infrastructure, namely transport and water, railway networks, aviation, energy, and telephone lines. Variable β_0 is the intercept parameter, while β_1, β_2 and β_3 are the elasticities. The abbreviation *ln* denotes natural logarithm, while ε is the error term assumed to be normally distributed (i.e., $\varepsilon \sim N(0, \sigma^2)$) and t is time. Labor supply was proxied by tertiary education because labor with tertiary education is more likely to be productive than those with secondary or primary education and can contribute more to productivity. Physical capital is expected to increase or improve production facilities and boost operational efficiency. The study, therefore, expected the capital stock to be positively related to economic growth ($\beta_1 > 0$). Thus, labor or human capital was expected to positively impact economic growth ($\beta_2 > 0$). In addition, available infrastructure was expected to not only reduce the cost of doing business but also increase the marginal product of labor and, thus, increase economic growth ($\beta_3 > 0$).

We also assumed that shock to infrastructure might have a significant impact on growth. We decomposed this shock into temporary and permanent shocks using the Hodrick-Prescott (HP) filter (see **Figure 1**). Variable measured the permanent shock while measured the temporary shock. Thus, we analyzed how these shocks affected growth. The empirical model with temporary and permanent shocks is specified as:

$$lnGrowth_t = \delta_0 + \delta_1 lncapital_t + \delta_2 labor_t + \delta_3 trend_{comp1_t} + \delta_4 cycle_{comp1_t} + \varepsilon_t \quad (2)$$

3.4. Estimation strategy

We employed the vector autoregression (VAR) analysis to examine the dynamic interactions among the variables. The VAR addressed the endogeneity bias that existed in the model. The mathematical representation of the VAR model is specified below:

$$Y_t = \emptyset + \varsigma t + \eta_1 Y_{t-1} + \cdots + \eta_p Y_{t-p} + \mu_1 X_{t-1} + \cdots + \mu_p X_{t-p} + \epsilon_t \quad (3)$$

where η_1, η_p, μ_1, and μ_p are unknown parameters to be estimated, and ϵ is the error term. The optimal lag length is determined by using either the minimum of AIC or SIC. The first step in the VAR estimation is to estimate Equation 3 by OLS. The study employed the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test to examine the stationarity properties of the variables to come up with statistically reliable estimates and avoid spurious regression. Also, the Impulse Response Function (IRF) was performed to observe the reaction of the dynamic model in response to temporary and permanent shocks.

4. Results and discussion

We carried out the unit root tests (i.e., ADF and PP) to analyze the stationarity properties of our data. The results from the ADF and PP unit root tests are reported in **Table 3**. The results show that all the variables were nonstationary at a level; however, the variables became stationary after their first-differenced.

Table 4 presents the OLS and VAR estimates from the regression analysis. Although both the OLS and VAR results appear to have the same sign, we discussed the VAR estimates because VAR can address the possible endogeneity issues between growth and infrastructure. We found a positive

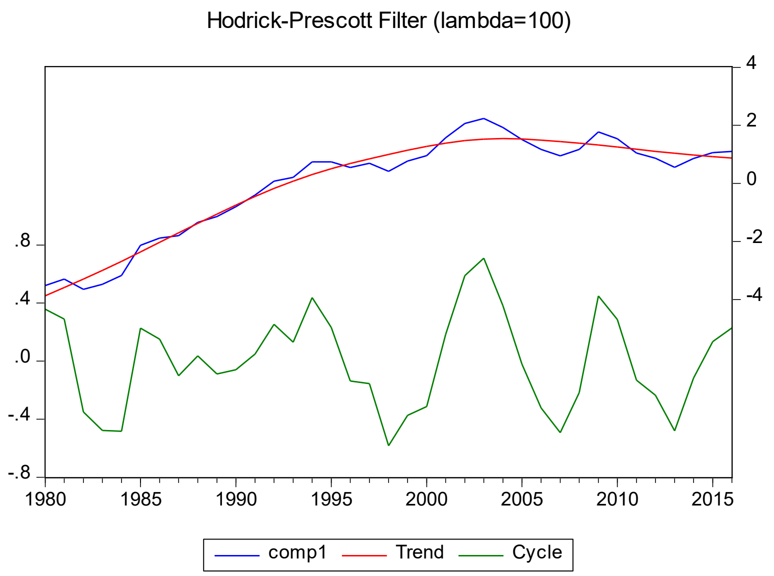

Figure 1. Trend and cycle of the principal component (comp1)
Source: Authors' construct

Table 3. Unit Root Test-Augmented Dickey-Fuller (levels)

Variable	ADF		PP		OI
	Statistic (L)	Statistic(D)	Statistic (L)	Statistic(D)	
GDP	–1.575	–4.072***	–1.731	–3.981***	I(1)
Capital	–2.089	–3.836***	–1.834	–3.323**	I(1)
Labor	–1.797	–4.646***	–1.761	–4.638***	I(1)
Comp1	–2.037	–4.009***	–2.261	–4.002***	I(1)

Note: L denotes level and D denotes first differenced. OI indicates the order of integration.
Source: Authors' construct

Table 4. Effect of infrastructure on growth

Variable	OLS (1)	OLS (2)	Variable	VAR (1)	VAR (2)
	RGDP	RGDP		RGDP	RGDP
Capital	0.326***	0.338***	capital(-1)	0.221***	0.221***
	(38.36)	(22.42)		(2.397)	(2.397)
Labor	0.016	0.024	labor(-1)	0.015	0.015
	(0.64)	(0.89)		(0.383)	(0.383)
Comp1	0.012***		comp1(-1)	0.011***	
	(5.40)			(2.106)	
Cycle_comp1		0.017***	cycle_comp1(-1)		0.003
		(3.23)			(0.248)
Trend_comp1		0.008	trend_comp1(-1)		0.013***
		(1.42)			(2.376)
			RGDP(-1)	0.274	0.315
				(0.986)	(1.115)
Constant	1.330***	0.969**	constant	1.425***	1.694***
	(6.41)	(2.21)		(2.822)	(2.874)
R-Square	0.997	0.997	*R*-Square	0.993	0.993
F-Statistic	3912.48	2922.89			

*Note: OLS (1) and VAR (1) include comp1, while OLS (2) and VAR (2) include cycle_comp1 and trend_cycle1. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0. Variable comp1 is the first principal component or the index of several types of infrastructure, which are transport and water, railway networks, aviation, energy, and telephone lines. Variable cycle_comp1 captures the temporary shock, while trend_comp1 captures the permanent shock.*
Source: Authors' construct

and statistically significant effect of capital stock on economic growth. The estimates show that a 1% increase in capital stock increased economic growth by 0.221% at the 1% significance level. An increase in capital stock enhanced the marginal product of labor and thus increased aggregate supply. This result supports the work of Santiago et al. (2020), who found a positive impact of public and private capital investments on economic growth for 30 Latin American and Caribbean countries. Our results also support the work of Aschauer (1998), who showed a positive impact of public capital on economic growth.

The results indicate that labor proxied by tertiary school enrollment had a positive and insignificant effect on economic growth. The estimates show that a 1% increase in tertiary education increased US economic growth by 0.015%. The intuition is that higher education develops the human capital (i.e., skills and ability) of labor, thus increasing the marginal product and overall productivity of labor. Also, labor with higher education can contribute significantly to research and development, thus leading to growth. In addition, a more educated labor tends to earn more income and can increase spending and investment, thereby increasing aggregate demand or output. This result also supports the endogenous growth theory, which asserts that labor or human capital is an essential factor of production. The positive and significant impact of labor on economic growth supports the findings of Bils and Klenow (2000) and Hanushek and Kimko (2000).

The aggregate infrastructure index (Comp1), the main variable of interest in this study, showed a positive and 1% significant impact on economic growth. Empirically, we found that a 1% increase in infrastructure investment led to a 0.011% increase in economic growth in the US. This finding supports those of several studies, which showed that infrastructure investment stimulates economic growth (Garcia-Milà et al., 1996; Calderón and Servén, 2004; Calderón, 2009; Alesina and Perotti, 1996; Sanchez-Robles, 1998; Donaldson and Hornbeck, 2016; Banerjee et al., 2020; Czernich et al., 2011; Fosu, 2019, 2021; Cronin et al., 1991; Boopen, 2006; Sridhar and Sridhar, 2007; Pradhan and Bagchi, 2013). Infrastructure spending not only reduces the cost of doing business and transaction costs but also increases the marginal product of labor and economic efficiency, thus increasing economic growth. Infrastructure can also serve as an input for different sectors. For example, a well-developed transportation infrastructure leads to faster, affordable, more efficient, and flexible transport facilities that enable more significant manufacturing and production productivity (Meersman and Nazemzadeh, 2017).

Our findings show that temporary and permanent increases in infrastructure spending boosted economic growth; however, the temporary spending effect was insignificant. The results show that a 1% increase in a permanent increase in infrastructure spending boosted US economic growth by 0.013%, an effect that was significant at 1%. A permanent increase in infrastructure investment will imply permanent job creation, leading to an increase in permanent income. With a rise in permanent income, household consumption increases, thus leading to an increase in aggregate demand. The demand for infrastructures such as roads, water, and transportation is growing due to rising population and household income. So, a permanent increase in infrastructure investment will ensure that funds are always available to repair or replace old and worn-out infrastructures, thus increasing productivity and quality of life.

Additionally, our results on Impulse Response Functions (IRF) from the VEC model are shown in **Figure 2**. An IRF shows how a dynamic system responds to external shocks. The results indicate

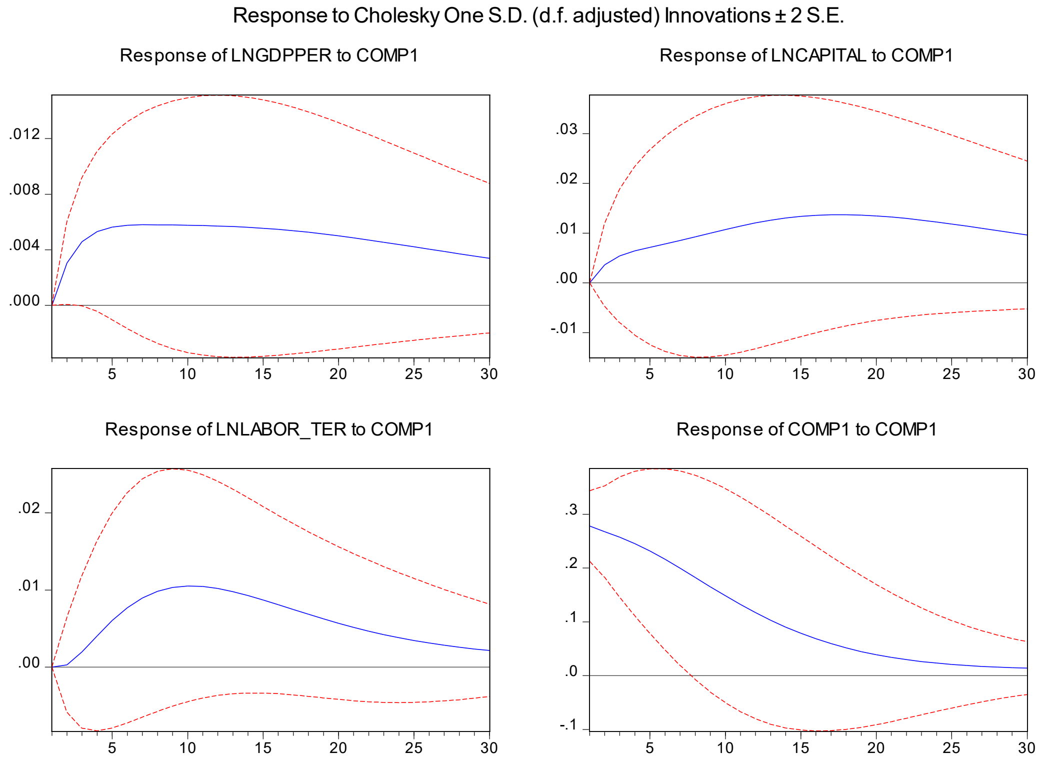

Figure 2. Impulse response function (IRF) analysis

that shocks to infrastructure spending had a positive and persistent increase in economic growth. The results also suggest that a permanent boost in infrastructure spending may have a long-term effect on growth.

5. Conclusion and policy recommendations

The main objective of this study was to examine the impact of infrastructure on economic growth. In addition, we analyzed the impact of temporal and permanent infrastructure spending on economic growth using annual data from 1980 to 2016, the principal component analysis, and VAR estimation. The study included several infrastructure measurements, which were transportation and water, railway networks, aviation, energy, and fixed telephone lines, to capture a broader scope of infrastructure. We used the PCA to construct an index or aggregate infrastructure and reduced the dimensionality and correlation among these infrastructure variables. The eigenvalue from the PCA showed that the first principal component (Comp1) contributed 60.8% of the total variability in the data. We also decomposed the aggregate infrastructure index into temporary and permanent spending using the Hodrick-Prescott (HP) filter. Our result shows that a 1% investment in infrastructure led to a 0.011% increase in economic growth, and this effect was significant at 1%. This result suggests that infrastructure investment spurs economic growth because it reduces the cost of doing business, reduces transaction costs, increases the marginal product of labor, and increases economic efficiency. The impulse response analysis showed that shocks to infrastructure spending had a positive and persistent impact on economic growth. The study suggests that the US government's sustained public spending on transportation and water, railway networks, aviation, energy, and fixed telephone lines infrastructure will positively impact economic growth in the US.

The study also suggests that policies that promote infrastructure spending, such as the Bipartisan Infrastructure Law (Infrastructure Investment and Jobs Act) passed by the US Congress, should be enhanced to boost economic activity and employment.[4] For example, technological innovations in US states such as New York, California, Texas, Illinois, and Maryland could be enhanced since these states concentrate more on technology and security-related jobs. While previous studies have examined the effects of infrastructure on economic growth, this study is different because it examined the effects of several infrastructure measures on economic growth using the PCA and VAR estimation strategy. Additionally, the current study used US national data to analyze the growth effects of infrastructure spending. Future studies can also use data at the level of US states to analyze the impact of infrastructure on growth because state-level panel data provides more significant within-sample variations for the variables compared with aggregate data. Also, as enough data become available, future research could evaluate the impact of the Bipartisan Infrastructure Law on the US economy using causal inference analysis. Future research could also evaluate the impact of the Bipartisan Infrastructure Bill by comparing the economic growth in the US with the growth in another developed country that does not have such an infrastructure investment policy.

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