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Infrastructure, Economic Growth, and Poverty

A Review

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Abstract

How much an economy should invest in its physical infrastructure is a crucial question being asked by policy makers from developing countries where financial resources for economic development are limited. This paper aims to address this question by bringing insights from the literature that investigates the relationship between infrastructure investment, economic growth, and poverty alleviation. The study shows that there is no consensus among the existing studies, which are mostly focused on industrialized economies, on the relationship between public investment and economic growth. Studies that investigate the relationship between physical infrastructure and economic growth mostly conclude that there exists a positive relationship. This is also true between physical infrastructure and income inequality, as reported by a few studies. This study also identifies many gaps in the literature and highlights the need for further studies to narrow them.

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Infrastructure, Economic Growth, and Poverty: A Review[1]

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Infrastructure, Economic Growth, and Poverty: A Review

1. Introduction

Policy makers, particularly in developing countries, often face a critical question: how much they should invest in physical infrastructure from their scarce financial resources, both resources generated domestically and provided by foreign sources (e.g., bilateral donors, direct foreign investment, multi-lateral donors). The same question is vital for international development financial institutions (e.g., World Bank Group, regional development banks) so that there is not just maximized finance, but also maximum impact on economic development and social welfare in the recipient economies.

Many efforts have been made in the literature to measure the economic growth and social welfare impacts of infrastructure development, both physical capital and human capital (see e.g., Calderón et al. 2015; Chakamera and Alagidede, 2018; Kodongo and Ojah, 2016; German-Soto and Bustillos, 2014; Sahoo and Dash, 2012; Calderón and Servén, 2010). However, there does not exist a consensus in the literature on the relationship between infrastructure investment and economic growth. Many studies, such as Chakamera and Alagidede (2018), Kodongo and Ojah (2016), Sasmal and Sasmal (2016), Sahoo and Dash (2012), Calderón and Servén (2010), Fan and Zhang (2004) and Démurger (2001), find that infrastructure development is significantly associated with economic growth, especially in low- and middle- income countries (China, South Asia, Sub-Saharan Africa). Some studies, such as Lall (1999), Roy et al. (2014) and Shi et al. (2017), however, find either no relationship or a negative relationship between infrastructure investment and economic growth.

Economic historians also debate the role of public investment in economic growth. For example, using 60 years of data (1853-1913) for the Netherlands, Groote et al. (1999) find that investments in new infrastructure (mainly railways and waterways) contributed to economic growth. On the other hand, Herranz-Loncán (2004) finds, using 90 years (1845-1935) of data for Spain, no relationship between infrastructure investment and economic growth. One can wonder if the findings of Groote et al. (1999) or Herranz-Loncán (2004) hold for other developed countries and developing countries.

One of the key challenges to analyze the relationship between infrastructure and economic growth is the measurement challenge – how to measure infrastructure provision. In general, infrastructure provision is measured in physical units, such as length of roads and railway tracks, the capacity of electricity generation plants, length of telecommunication, and electricity transmission lines. However, aggregating these heterogeneous units and service provisions is a challenge. One usual indicator of the flow measurement that is readily available is the infrastructure indices developed by Calderón and Chong (2004) using the principal component technique. Most studies that investigate the relationship between physical infrastructure and economic growth follow this method.

Besides the literature that examines the relationship between physical infrastructure and economic growth, there exists another set of literature that investigates the relationship between public investment (or expenditure) and economic growth. Irrespective of how the infrastructure is represented, the history of research addressing this issue is not that long (Gramlich 1994). David Aschauer is perhaps the first economist who highlighted this issue (Aschauer 1989a, b, c). Others who researched the topic in the 1990s include Garcia-Mila and McGuire (1992), Lynde and Richmond (1992), Evans and Karras (1994), Holtz-Eakin (1994), Holz-Eakin and Schwartz (1995), Sturm and De Haan (1995), Morrison and Schwartz (1996a, b), Wylie (1996), Dalenberg and Partridge (1997), and Fernald (1999).

There is a fundamental difference between the earlier literature that discusses the relationship between public expenditure and economic growth, and the relatively recent literature that establishes the relationship between physical infrastructure and economic growth. The former literature finds the relationship between public expenditure and factors that drive economic growth, especially productivity improvement. On the other hand, the latter literature directly relates the stock of physical infrastructure to economic growth. Moreover, public expenditure includes expenditures on all types of infrastructure services (i.e., physical infrastructure and human capital), whereas infrastructure in the latter literature includes stock of physical infrastructure specifically. Like in the latter literature, the findings of the former literature are mixed. For example, while Aschauer (1989a), Morrison and Schwartz (1996b), and Wylie (1996) find a robust positive relationship between public expenditure and private sector productivity, Holz-Eakin (1994) and Holz-Eakin and Schwartz (1995) find contradictory results depending upon the investigation methodology: no relationship if the estimation of production functions uses the standard techniques to control for unobserved (i.e., state-specific) characteristics, but a strong relationship when such controls are not included. Evans and Karras (1994) find strong evidence of public investment in the education sector being productive, but no evidence in other sectors. Morrison and Schwartz (1996b) find a significant return to manufacturing firms and increased productivity from infrastructure investment. However, the net social benefits of infrastructure investment may be positive or negative depending on the costs of infrastructure investment and the relative growth rates of output and infrastructure. Dalenberg and Partridge (1997) find no role of public investment in the productivity gain of the private sector. Fernald (1999) finds a positive correlation between infrastructure and productivity but does not confirm the causation. Overall, there are no converging results from the early literature (1990s) on the relationship between public sector infrastructure investment and productivity growth in the private sector.

Various analytical approaches have been used to examine the relationship between infrastructure investment and economic growth or drivers of growth, such as productivity. Early studies have used growth models. One example is Holtz-Eakin and Schwartz (1995), who tried to better understand the effect of public investments on private sector productivity while focusing on the long-run steady-state solution. Those authors developed a neoclassical growth model where infrastructure is explicitly introduced into the aggregate production function. Another example is Glomm and Ravikumar (1994), who used a general equilibrium growth model to show that when production exhibits constant returns to augmentable factors, the equilibrium shows constant growth.

While most of the studies are focused on the relationship between infrastructure development and economic growth, only a few studies have examined the linkage between infrastructure development and poverty reduction, or income inequality. The first of these topics is addressed in Chotia and Rao (2017a, b) and Sasmal and Sasmal (2016); while the second is addressed by Calderón and Chong (2004), Calderón and Servén (2004, 2010, 2014), Sasmal and Sasmal (2016), and Chotia and Rao (2017b).

Our study is not the first study reviewing the literature on infrastructure, economic growth and income inequality. There exist others, such as Munnell (1992), Gramlich (1992), Button

(1998), Calderón and Servén (2014), Elburz et al. (2017). The early studies by Munnell (1992) and Gramlich (1992) did not have an opportunity to review most of the literature because the literature was at its infancy level at that time. Those reviews highlighted the importance of the study and provided a framework (especially Gramlich, 1992) for further research on the topic. Button (1998) reviewed the studies linking public investment in general and economic growth. It did not include studies conducted after 1997. Calderón and Servén (2014) conceptually identified the various channels through which infrastructure can affect economic activities and then documented whether the empirical literature supports or refutes the hypothesis.

Our review contributes to the literature by systematically surveying the effect of public investments and physical infrastructure on economic growth and income inequality. Our review is different from Elburz et al. (2017) as we cover all types of physical infrastructure (electricity, transportation, telecommunication) in addition to public investment in general, whereas Elburz et al. focus only on transportation infrastructure.

Our study also identifies research gaps from developing country perspectives. For example, while some countries or regions show a strong relationship between infrastructure investment and economic growth, others do not. One hypothesis could be: in developing countries, especially least-developed countries (or poorest countries measured in terms of per capita GDP), where lack of physical infrastructure (e.g., road and railway networks, electricity generation capacity and transmission/distribution networks) creates severe bottlenecks for economic prosperity, infrastructure investment that reduces or relaxes the infrastructure constraints could boost economic growth. In developed countries where infrastructure is not the barrier to economic growth, investment in infrastructure may not spur further economic growth. Existing literature has not tested this hypothesis, although it is not difficult to do if detailed country-level data on infrastructure are available. This hypothesis boils down to the access vs. stock debate, where the role of access is assumed to be much stronger in developing countries than that of increasing stock in countries where basic infrastructure is already adequately available.

The linkages among infrastructure, economic growth and income inequality remain vague. This review does not attempt to capture many issues, such as the mechanisms through which infrastructure affects economic growth and inequality. It has a narrow focus – reviewing the empirical studies that have investigated the relationship between infrastructure and economic growth, and between infrastructure and income inequality. It covers either public expenditure or major physical infrastructure sectors (transportation, electricity, telecommunication) jointly. It does not discuss in detail the studies that investigate the role of single infrastructures, such as roads or power, to drive economic growth or poverty reduction. However, we lightly touch on it in Section 3.2 to indicate this type of study also exists in the literature. Many other issues, such as the institutional aspect of infrastructure, local economic or welfare impacts of individual infrastructure projects or programs, have not been included. These topics have rich literatures that warrant separate reviews.

The paper is organized as follows. Section 2 presents the critical review of methodologies used to investigate the relationships between infrastructure investment and economic growth as well as income inequality. This is followed by the discussion of findings of studies that investigate the relationship between infrastructure investment and economic growth (Section 3). Section 4 discusses the findings from studies that investigate the direct linkage between physical infrastructure and income inequality, followed by some critical issues related to the literature (Section 5). Section 6 highlights the research gaps, and finally, Section 7 draws key conclusions.

2. Empirical Approaches of the Existing Literature

This review study begins with surveying the empirical approaches presented in the literature. First, in section 2.1, the measurement of public infrastructure variables is discussed. Next, in section 2.2, empirical identification strategies and approaches used to evaluate public infrastructure's effect on economic performance and poverty alleviation are presented together with a discussion of their strengths and weaknesses.

2.1 Measurement of Variables

The literature measures infrastructure in different forms, from public expenditure to stock of physical infrastructure. Most of the earlier studies use public expenditure to represent infrastructure (Aschuer, 1989a; Munnell,1990; Munnell and Cook,1990; Duffy-Deno and Eberts, 1991; Hulten and Schwab, 1991; Evans and Karras, 1994; Holz-Eakin,1994; Holtz-Eakin and

Schwartz, 1995; Sturm and De Haan, 1995; Nourzad and Vrieze, 1995; Morrison and Schwartz, 1996a &1996b; Wylie, 1996; Dalenberg and Partridge, 1997; Sturm, 1997; Seitz, 2000; Demetriades and Mamuneas, 2000; Wang, 2002; Paul, Sahni, and Biswal, 2004). Table 1 presents these studies. There are several challenges when using public expenditure. First, public expenditure could cover, in addition to infrastructure, education, health care, internal security, defense, and physical infrastructure. Second, even if data on public expenditure allocated for physical infrastructure are available, the breakdown between new physical infrastructure vs. maintenance of existing physical infrastructure may not be available. Third, the impacts of human capital occur at a significantly different time lag than physical infrastructure; however, public expenditure usually does not distinguish between the two. Fourth, it is not possible to distinguish the quantity vs. quality of infrastructure when public expenditures are used to represent infrastructure investment.

The limitation of the use of public expenditures led to the use of an alternative technique where variables representing economic growth are directly linked with variables representing physical stock of infrastructure, such as length of road, electricity generation capacity, length of telecommunication lines, etc. Studies using physical infrastructure stock include Garcia-Mila and McGuire (1992), Rives and Heaney (1995), Lewis (1998), Lall 1999, Calderón & Chong (2004), Estache et al. (2005), Zou et al. (2008), Calderón & Servén (2010), Herrerias (2010), Czernich et al. (2011), Banerjee et al. (2012), German-Soto & Bustillos (2014) and Shi et al. (2017). These studies are presented in Table 2. One of the key challenges using physical infrastructure is their heterogeneity. Existing studies use two approaches to address this issue. Some studies use a single infrastructure type, such as road (Estache et al. 2005; German-Soto & Bustillos 2014); railway (Herrerias 2010; Banerjee et al. 2012; Mostert & Van Heerden 2015; Shi et al. 2017) or telecommunication (Czernich et al. 2011) to represent infrastructure. However, using a single infrastructure type may not correctly estimate the true state of infrastructure in a region. The second approach is to develop an index that combines different types of infrastructures as well as different measures within a specific type. Studies, such as Sanchez-Robles (1998), Calderón & Chong (2004), Calderón & Servén (2010), Sahoo & Dash (2009, 2010, 2012) and Sahoo et al. (2012), developed infrastructure indices while combining various measures of infrastructure stocks employing the principal component analysis method. The principal component methods involve mathematical procedures that transform a number of correlated variables into a smaller number of uncorrelated variables. Although the effect of alternative infrastructure services (e.g., roads, electricity, water sanitation) and their efficient provisions on economic performance vary, principle component methods enable the econometrician to consolidate the number of equations estimated. However, the effect of the infrastructure index on performance is different than that of total capital. This is because of the varying degrees of economies of scale, network externalities via connecting regions and countries, and its competition enhancing effect through improved market access and the lowering of transportation costs.

Accounting for variables that represent the quality of infrastructure through physical measures allows the econometrician to incorporate quality into the analysis. To this end, Chakamera & Alagidede (2018) use electricity distribution losses, mobile phone quality scores, and fraction of paved road in the total road kilometers, to develop a quality infrastructure index. These variables were used to develop an infrastructure quality index using principal component methods. Calderon and Serven (2010) constructed a synthetic index of infrastructure quality by using waiting time for the installation of main telephone lines for telecommunication, transmission, and distribution losses for electricity and the share of paved roads in total roads for roads. Like in Chakamera & Alagidede (2018) and Calderon and Serven (2010), Kodongo and Ojah (2016) also develop a synthetic index to represent the quality of infrastructure in their analysis.

2.2 Estimation Techniques

The majority of empirical studies use statistical methods to estimate the various effects of interest. A few studies also use structural modeling, particularly computable general equilibrium (CGE) modeling, to assess the impacts of infrastructure on economic growth. We start with discussion of econometric/statistical approaches followed by general equilibrium modeling. Since the focus of this work is on the empirical studies investigating the effect of infrastructure on economic performance, inequality, and poverty, this study did not survey studies conceptualizing the effect of infrastructure on the various parameters (Glomm & Ravikumar 1994; Holtz-Eakin & Schwartz 1995, among others).

While the basic principles of the econometric approach should not be affected by how infrastructure is measured, in practice there are some specific issues in the mathematical techniques that result in the estimates of the relationship depending on how infrastructure is measured. Therefore, we have divided the discussion below between methodologies used in studies that use public expenditure and studies that use physical infrastructures for the same purpose.

2.2.1 Econometric/Statistical techniques

In this section, we discuss the statistical/econometric approach, including key limitations faced by these approaches and how some of these limitations have been addressed over time.

<u>*Studies representing infrastructure through public expenditure:*</u> To establish the relationship between the infrastructure investment and economic output, the early studies mostly expressed the real economic output (e.g., per capita real GDP) as a function of labor input, capital input and public expenditures (or government expenditures on infrastructure) expressed in monetary units. To this end, public expenditures representing infrastructure, in many studies, refer to the flow of capital. The reason is that these values are available in countries' national accounting systems.

The first studies estimating the relationship between economic growth and infrastructure employed a production function approach, where the estimation techniques vary across studies. Many studies use ordinary least squares (OLS) in levels (Aschauer 1989a, 1989b, 1989c; Munnell 1990, Munnell & Cook 1990; Garcia-Mila & McGuire 1992; Lynde & Richmond 1992; Holtz-Eakin & Schwartz 1995; Rives & Heaney 1995; Sturm & De Haan 1995; Wylie 1996; Lewis 1998, among others). However, some studies use cross-sectional and panel data techniques to control for (unobservable) characteristics (Evans & Karras 1994; Holz-Eakin 1994, among others), first differences (Hulten & Schwab 1991; Evans & Karras 1994; Sturm & De Haan 1995, among others), and instrumental variable techniques (Duffy-Deno & Eberts 1991; Esfahani & Ramírez 2003, among others).

The methodologies used in the early studies had several limitations, thereby questioning the credibility of their findings: ***key issues raised included spurious correlations, endogeneity and reverse causality.*** However, the analyses improved over the years because the data used spanned a long period of time, and the new methodologies addressed many of these concerns.

While limitations of early studies were borne from the measurement of infrastructure, the methodology adopted, and the empirical relationship established, these concerns were addressed with time as the literature evolved.

The key concern in the estimation techniques as well as in the use of production functions to represent the relationship in earlier studies was ***spurious correlations***, where variables exhibit similar correlations even though they are unrelated. For example, Aschauer's (1989a) original aggregate time-series estimates suggested public capital has a large and positive impact on firms' output and productivity (a 1% increase in public to private capital stocks yields a 0.39% increase in total factor productivity), though these estimates are likely too large to be credible due to the flawed methodology. That paper investigated output per unit of capital and total factor productivity, where the independent variables were government services. The structure of the data resulted in aggregate time-series data that are subject to common trends, thus yielding spurious correlation. Realizing these flaws, follow-up studies addressed the aforementioned concerns and improved the methodology used (Table 1). This resulted in scholars abandoning the use of the production function approach and instead adopting the use of first differences (e.g., Hulten & Schwab 1991; Evans & Karras 1994), which addresses the identification problem arising from spurious correlation. Targeting spurious correlation, Hulten and Schwab (1991) applied first-differencing methods to remove potential common trends. Similar to fixed-effects methods, first-differencing controls unobserved time-invariant region-specific fixed effects. Sturm and De Haan (1995) bring up another reason for estimating the model in first differences: nonstationarity of the time-series data used in the early work. Recently, this strand of the literature included updated and further refined empirical techniques. For example, Calderon et al. (2015) used pooled mean group estimators, which unrestrict short-run parameter heterogeneity across countries while imposing (testable) restriction of long-run parameter homogeneity.

Other key concerns raised toward the early literature were ***endogeneity and reverse causality***, which leads to the use of instrumental variables (e.g., Duffy-Deno & Eberts 1991; Holz-Eakin 1994; Esfahani & Ramírez 2003). A pronounced identification issue that involved this type of research was reverse causality; that is, the causation not only runs from the independent variables to the variable of interest but also runs in reverse from the dependent variable to the independent variable. In addition, although the initial literature used Cobb-Douglas production function estimates as a measurement of output, current literature considers this to be inadequate (Lynde and Richmond 1992; Morrison and Schwartz 1996a, 1996b). While studying the effect of public capital investment on the economic performance measured by per capita personal income, Duffy-Deno and Eberts (1991) addressed the problem of reverse causality through simultaneous equations and estimated the reduced form of the system of equations. Additionally, the study uses public capital stock estimates instead of expenditures to improve the measurement of public investment. The endogeneity problem is addressed by using an exogenous variation, though the specific instrument variable used in the paper may not be appropriate. Along with the further understanding of causal inference and the advancement of modern microeconomics research techniques, Fernald (1999) points to the problem associated with the direction of causation.

Physical infrastructure and economic growth/income inequality: Studies that establish the relationship between physical infrastructure and economic growth. These studies express the economic growth variables as a function of variables representing physical infrastructure stock along with other variables. For example, while comparing the impacts of infrastructure on economic growth across African countries over the years 1970 to 2005, Calderón and Servén (2010) use both internal instrumental variables of the lagged dependent variable and external instruments of demographic variables to address the endogeneity problem. And, they apply GMM developed by Arellano and Bond (1991) and Arellano and Bover (1995) to a dynamic panel to address the reverse causality problem. To address some empirical challenges that arise from the lagged dependent variable, the presence of nonlinearity and cointegration among variables, reverse causality and the endogeneity among different forms of capital, Shi et al. (2017) use the vector error correction model (VECM) which emphasizes the long-run relationship.

The techniques used to establish the relationship between the physical infrastructures and income inequality are not different from those establishing the relationships between the physical infrastructure and economic growth. The only difference is that the dependent variable representing economic output or growth is replaced with that representing income inequality – Gini coefficients. Several studies do both: measure the growth and inequality impacts in the same paper. These studies include Calderon and Chong (2004), Calderon and Serven (2004), Calderon and Serven (2010), Chatterjee and Turnovsky (2012), Sasmal and Sasmal (2016), Chotia and Rao (2017a), Chotia and Rao (2017b) and Hooper et al. (2018). Table 2 presents these studies.

Given the data availability, many studies applied fixed effects and random effects to the panel data set to control for unobservable characteristics (Démurger 2001; Fan & Zhang 2004; Sasmal & Sasmal 2016; Hooper et al. 2018). Although panel data with fixed effects control for the endogeneity, potential problems of simultaneity, and reverse, causation remain. Furthermore, given the idea of strong autocorrelation between past and current inequality, more and more studies add lagged dependent variables into the regression as the explanatory variable, creating the structure of dynamic panels. OLS estimates of the dynamic panel are biased due to the intrinsic autocorrelation problem of the error term. Therefore, Calderón and Chong (2004) use the GMM-IV method to consistently estimate the dynamic panel.

Another potential issue of the panel data, even in the static case, is the existence of cointegration. OLS estimators of the co-integrated vectors are asymptotically biased. Thus, to study and estimate the panel co-integrated relationships among the variables of interest, Chotia and Rao (2017a) employ an autoregressive distributed lag (ARDL) bound testing approach to study the link between infrastructure development and poverty in India. Chotia and Rao (2017b) also use the panel dynamic ordinary least squares (PDOLS) method introduced by Kao and Chiang (1999) to correct for the bias.

2.2.2 Structural modeling approach

Although most of the existing studies use statistical methods to estimate the impacts of infrastructure investment on economic growth, some studies develop structural models, mostly CGE types. This approach employs a large system of equations to describe the behaviors of all economic agents (i.e., productive sectors, households, government, rest of the world) and linkages within the agents (e.g., inter-industry relationship) and between the agents. and the model is capable of assessing the economy-wide effects of various scenarios pertaining to infrastructure and public investment. For instance, using a CGE model, Mostert and Van Heerden (2015) assesses the short- and long-term effects of proposed infrastructure investment on the well-being of the Limpopo Province in South Africa, a province locked into poverty, inequality, and high levels of unemployment. Another example is Sebastian and Steinbuks (2017), who developed a CGE model to study public infrastructure and its effect on structural transformation. Those authors introduced heterogeneity in firms' size and thus entry costs and implemented their model for Brazil. Through the modeling of firm behavior, Sebastian and Steunbuks (2017) were able to show the importance of supply-side explanations of structural change and the implication of public policy in supporting growth. A third example is Chakraborty and Lahiri (2007), who quantified the impact of public capital on income differences across nations while employing an accounting approach.

There are two advantages of the structural model. First, it can measure the interactions of economic agents in response to investment shocks. For example, it can determine the impacts of investment not only on economic growth but also on all variables related to economic output, such as factor income, international trade, public expenditure. Second, it can simulate the impacts of infrastructure quality. For example, Wing and Rose (2020) analyze the economic impacts of investment in infrastructure to backup electric power outages in California's Bay Area economy. Timilsina et al. (2018) estimate the economy-wide costs of scheduled power outages (load shedding) in Nepal.

The key difference between studies using statistical/econometric approaches and the CGE modeling is that while the former assess the relationship based on historical data (i.e., ex-post analysis), the latter simulate the potential impacts of infrastructure investments on economic growth (ex-ante analysis).

3. Infrastructure Investment and Economic Growth

This section presents results from a large number of studies, mostly empirical, that attempt to establish the relationship between infrastructure and economic growth. The results, however, are mixed. Most studies find a positive relationship between infrastructure and economic growth, whereas some studies did not find a relationship between the two. The degree of relationship is highly different across the studies depending on several factors (e.g., stage of economic development) and also the methods used to establish the relationship. We first discuss the studies investigating the impacts of infrastructure as a whole (combining all major infrastructure types) on economic growth followed by some studies that claim a particular infrastructure type (e.g., transport or electricity) alone has a significant impact on economic growth.

3.1 Public Infrastructure and Economic Growth

In parallel to the increase of political interest in public investments toward the end of the 20th century, scholars began exploring the importance of infrastructure investment, particularly in relation to economic growth (Table 2). Taking advantage of different methodologies and various geographical locations, this strand of literature resulted in a wide range of estimates.

Focusing on North America, the literature offers evidence supporting the hypothesis that public infrastructure positively impacts economic growth (Munnell 1990; Garcia-Mila & McGuire 1992; Rives & Heaney 1995; Wylie 1996). For example, Munnell (1990) looked at the relationship between public capital and measures of economic activity at the state level. Munnell, then, concluded that public capital has a significant, positive impact on output, although the output elasticity was roughly one-half the size of the national estimate (Aschauer 1989a). Similarly, Garcia-Mila and McGuire (1992) used data on 48 contiguous states from 1969 to 1983 to estimate the impact of public infrastructure (captured by education and highways) on gross state product. The estimates were consistent with Munnell's (1990) results, both in terms of the sign and the magnitude. Focusing on the economic performance at the community level, Fox and Smith (1990) and Rives and Heaney (1995) show investments contribute to U.S. local economies positively and significantly. Examining the role infrastructure on economic growth in Canada, Wylie (1996) finds that output elasticities of infrastructure in Canada are comparable and even larger than that in the United States.

The findings should, however, be interpreted carefully as the methodologies used in these studies have several limitations. The estimation techniques used to suffer from the endogeneity of the public capital stock and economic performance, spurious correlation, reverse causality where the causation also runs from the economic measures to the input of public capital, and measurement error due to lack of data.

Some studies have surveyed existing literature analyzing the relationship between infrastructure and economic growth (e.g., Munnell 1992[3]; Gramlich 1994[4]; Button 1998; Elburz et al. 2017). While the survey of Button (1998) examined the links between public capital and the role of endogenous growth processes, Elburz et al. (2017) offer new insights on variation in the empirical results investigating public investment infrastructure and regional growth. Elburz et al. (2017) conduct a meta-analysis of 42 studies published during the 1995-2014 period. The meta-analysis reports the following: (i) studies that employ data from the United States are more likely not to register a positive relationship between public infrastructure and economic growth; (ii) results differ across the studies due to difference in infrastructure measurement used, analytical methods, geographical scale of the study, and (iii) analysis that introduces interregional, interstate and interprovincial public infrastructure is likelier to yield negative effects, suggesting spillovers impact these investments.

Several studies report that whether or not infrastructure investment boosts economic growth depends on the stage of economic development of a country. In developed economies where infrastructure is not a constraint for economic development, infrastructure development may not furnish an economic growth effect. On the other hand, in countries where lack of infrastructure is a barrier to economic growth, the relationship between infrastructure investment and economic growth is strong (Sanchez-Robles 1998; Esfahani and Ramírez 2003). Examining the economic growth effect of public investment through a cross-country data, Sanchez-Robles (1998) shows that the indicator of infrastructure investment is positively and significantly correlated with economic growth in the sample of 19 Latin American countries. With an analysis using a panel of 75 countries around the world, Esfahani and Ramírez (2003) finds that the contribution of infrastructure services to GDP is substantial and, in general, exceeds the cost of provision of those services.

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[3] Munnell (1992) is the earliest review of infrastructure and economic growth issue; since the literature was at its infancy level, the study only highlights the importance of further research in this area.

[4] This paper is also similar to Munnell (1992) but it provides more details on the methodological framework used to analyze the issue.

Table 1: Examples of studies analyzing the relationship between public expenditure and economic variables

Dependent variable	Study	Level of aggregation	Period	Specification	Method	Findings	Limitations in the methodology used
Output (sector output or reginal/national GDP)	Aschuer (1989a)	US National	1949 to 1985	Cobb-Douglas; Log levels	OLS	Strong positive relationship between output per unit of capital input, the private labor-capital ratio, and the ratio of the public capital stock to the private capital input. The increase in the ratio of public to private capital stocks raises total factor productivity by 0.39%***	Estimates at the national level is too large to be credible; Common trends induced spurious correlation; Reverse causality; Production function estimate is inadequate; Endogeneity; Measurement error
	Munnell (1990)	US National	1948 to 1987	Cobb-Douglas; Log levels	OLS	One percent increase in public capital would raise productivity by 0.31 to 0.39 percent	Common trends induced spurious correlation; Reverse causality; Endogeneity; Measurement error
	Munnell and Cook (1990)	US States	1970 to 1986	Cobb-Douglas; Log levels	OLS	States that have invested more in infrastructure tend to have greater output, more private investment, and more employment growth. The coefficient on public capital is 0.15***	
	Evans and Karras (1994)	US States (Private Nonagricultural Sectors)	1970 to 1986	Cobb-Douglas; Log levels	FE	There is no evidence that government activities are productive except investment in education. Government capital often has negative productivity (-0.048)	Reverse causality; Endogeneity; Measurement error
	Holz-Eakin (1994)	US Regions	1969 to 1986	Cobb-Douglas; Log levels	OLS; FE	Region-level estimates are essentially identical to those from state data (FE estimate is -0.12*), suggesting no quantitatively important spillover effects across states	Production function estimate is inadequate; Differencing out useful information; Measurement error
		US States			OLS; FE; IV	Only OLS estimates of state production functions find substantial productivity impacts (0.203***). Estimates of production functions that use FE reveal no role for public-sector capital in affecting private sector productivity (-0.0517*)	
	Wylie (1996)	Canadian National	1946 to 1991	Cobb-Douglas; Log levels	OLS	Aggregate production function method yields estimates of high returns to infrastructure investment in terms of goods-sector productivity in Canada over the 1946-1991 period. Total infrastructure capital stock per hour worked is estimated to be a significant contributor to goods-sector output per hour, with a productivity elasticity of 0.517*	Endogeneity; Common trends; Reverse causality; Measurement error

				Translog; Log levels	SUR	The marginal product of infrastructure is 0.248*		
	Sturm (1997)	Netherland National	1949 to 1993	Generalized McFadden Cost Function, Log levels	SUR	Cost elasticity of public infrastructure has negative sign (-0.676***). Sheltered sector of the Dutch economy benefits more from infrastructure investment		Common trends induced spurious correlation; Reverse causality;
	Demetriades and Mamuneas (2000)	12 OECD Economies	1972 to 1991	Levels	SUR	Public infrastructure capital has significant positive effects on profit (0.36*** to 2.06***) in all runs		Reverse causality; Measurement error
	Paul, Sahni, and Biswal (2004)	Canadian Manufacturing Industries	1961 to 1995	Translog Cost Function; Log levels	SUR	For most industries, the cost elasticities vary in the range between -0.10 and -0.40 and are statistically significant, implying cost saving		Endogeneity; Common trends
Employment	Munnell and Cook (1990)	US States	1970 to 1986	Levels	OLS	State's investment in public capital had a significant positive impact (0.35***) on that state's private employment growth		Common trends induced spurious correlation; Production function estimate is inadequate
	Seitz (2000)	West German cities	1980 to 1995	Log levels	FE	An increase in the growth rate of the local public capital stock by 1 percent increases employment in the manufacturing sector growth by 0.15 percent and in the service sector by about 0.05 percent		Reverse causality; Measurement error
	Demetriades and Mamuneas (2000)	12 OECD Economies	1972 to 1991	Levels	SUR	The effect of public capital on labor demands is positive in all runs		Reverse causality; Measurement error
Income	Duffy-Deno and Eberts (1991)	US Metropolitan areas	1980 to 1984	Log Levels	OLS; 2SLS	Both public investment and public capital stock have a positive and statistically significant effect on per capita personal income. OLS and 2SLS estimates are not statistically different for public capital stock (0.094* vs 0.081*) but they are for public investment (0.037* vs 0.113*)		Measurement error; Endogeneity
	Dalenberg and Partridge (1997)	US States	1972 to 1991	Log Levels	FE	Highway	Aggregate average annual earnings and manufacturing production worker hourly wages are positively related to highway and net public capital without statistical significance	
					FE	Net Public Capital	Aggregate average annual earnings and manufacturing production worker hourly wages are positively related to highway and net public capital without statistical significance	
					2SLS	Highway	For the aggregate private sector, increased highways reduce eanrings (-0.015***)	
					2SLS	Net Public Capital	For the aggregate private sector, increased highways reduce eanrings (-0.015***)	
GDP Growth Rate	Hulten and Schwab (1991)	US Regions	1970 to 1986	First Derivative; Levels	OLS	Value added-MFP growth	Link between public infrastructure and economic performance is weak. Estimates are -0.1795 and -0.344 respectively	Implausible coefficients for labor and private capital as well as for public capital due to first differencing; First differencing destroys long-term relationship in the data; Production function
						Gross Q-MFP growth		

							estimate is inadequate; Measurement error
	Sturm and De Haan (1995)	US National	1949 to 1985	Cobb-Douglas;	OLS	Applying first-differencing method to Aschuer (1989a), estimated output elasticity is 0.26* for the US and 1.15** for the Netherland.	Endogeneity; Reverse causality; Measurement error
		Netherland National	1960 to 1990	Log Difference Level			
	Holtz-Eakin and Schwartz (1995)	US States	1971 to 1986	Cobb-Douglas; Log Difference Level	OLS	There is little support for claims of a dramatic productivity boost from increased infrastructure outlays. The estimated upper bound for the output elasticity is 0.10	Relying on assumptions; Aligned with the weaknesses of growth model
	Nourzad and Vrieze (1995)	7 OECD Countries	1963 to 1988	Log Difference levels	GLS	There is a statistically significant positive relationship between public capital formation and the growth rate of labor productivity. Estimated output elasticity is 0.059***	Endogeneity; Reverse causality; Measurement error
	Morrison and Schwartz (1996b)	US States	1970 to 1987	Generalized Leontief Cost Function; First derivative; Log Levels	SUR	Infrastructure investment provides a significant return to manufacturing firms and augments productivity growth	Reverse causality; Common trends; External validity
	Morrison and Schwartz (1996a)	New England (Manufacturing Industry)	1971 to 1987			In the short run, public capital expenditures provide cost-saving benefits that exceed the associated investment costs due to substitutability between public capital and private inputs. Over time, however, stimulating investment in private capital increases economic performance more effectively than public capital expenditures alone. Present value return of one-dollar investment in public capital is 1.108 to 2.638	
	Wang (2002)	East Asian Countries	1979 to 1998	First Derivative; Levels	GLS	Spillover effects between private and public sectors coexist in analyzing the interrelation between public infrastructure and private production. Elasticity of the public infrastructure is 0.24***	Endogeneity; Reverse causality; Measurement error

The dependent output variable is followed by the output to public capital stock/ investment elasticity value, where p<0.01 is denoted by ***; p<0.05 is denoted by **; and p<0.1 is denoted by *

Table 2: Examples of studies analyzing the relationship between physical infrastructure and economic variables

Dependent variable	Study	Level of aggregation	Period	Specification	Infrastructure variable	Method	Findings	Limitations in the methodology used
AGDP/Income	Garcia-Mila and McGuire (1992)	US States	1970 to 1983	Cobb-Douglas; Log levels	Highway	OLS	Two publicly provided inputs – highways and education have significant and positive effects on output. Estimated effect of highway is 0.045***	Endogeneity; Reverse causality; Common trends
	Rives and Heaney (1995)	US Community	1990	Levels	Index of sewer capacity, water plant capacity, and highways	OLS	A composite measure of the level economic development (index as a function of population, employment, property values, and income) is affected positively by physical infrastructure (0.205**)	Endogeneity; Reverse causality
	Lewis (1998)	Kenyan municipalities	1994	Levels	Roads and water	OLS 2SLS	Impact of public infrastructure in the roads and water sectors on municipal incomes is significant using OLS estimator (0.009*), but becomes insignificant employing 2SLS (0.026)	Endogeneity
	Lall 1999	Indian States	NA	Cobb-Douglas; Log levels	Public investments in physical infrastructure	OLS FE SUR 2SLS	OLS estimate indicates that an increase in economic infrastructure investment has positive effect on regional output. However, FE, SUR and 2SLS models indicate negative relationship. Results are robust across lagging, intermediate and leading states	Measurement error; Reverse causality
	Estache, Speciale, and Veredas (2005)	Sub-Saharan African Countries	1976 to 2001	Cobb-Douglas; Log levels	Telecoms, roads, electricity, and water	GLS	All infrastructure sub-sectors, are shown to be statistically significant engines of growth (0.19*** to 0.57***)	Relying on assumptions; Aligned with the weaknesses of Solow model
	Zou et al. (2008)	Chinese Provinces	1994 to 2002	Cobb-Douglas; Y-Log levels; X-Levels	Road density	FE	Higher growth level in East and Central China comes from better transport infrastructure. Estimated coefficient for road is 4.224***	Reverse causality
	Banerjee et al. (2012)	Chinese Counties	1986 to 2003	Log levels	Distance of transportation lines	FE	Proximity to transportation networks have a moderate positive causal effect on per capita GDP levels across sectors. Elasticity between the distance to the line and per capita GDP is -0.0672***	Endogeneity
	Sahoo and Dash (2009,2010,2012)	Indian National	1970 to 2006	Cobb-Douglas; Log levels	Index of infrastructure stocks	OLS 2SLS DOLS	Physical and social infrastructures have a significant positive impact on output (0.18* to 0.46**). Further, infrastructure development contributes significantly to output growth	NA
		South Asian Countries	1980 to 2005			OLS		
		South Asian Countries				FMOLS		
	Sahoo, Dash, and Nataraj (2012)	Chinese National	1975 to 2007			ARDL		
		Chinese National				GMM		

	Mostert and Van Heerden (2015)	South African Provinces	NA	Levels	Railway	CGE	In the long run the building of the railway line will lead to a 4.46 % increase in GDP, while aggregate employment in will increase by 1.97 %	Hard to capture the dynamic structure
GDP Growth Rate	Shi et al. (2017)	Chinese municipalities	1990 to 2013	Y-Log Difference level; X-Log levels	Railway, roads, telphones, and electricity generation capacity	VEC	Inverse U-shaped relationship between infrastructure investment and growth posits a "crowding-out effect" of private capital when infrastructure investment becomes too dominant	Reverse causality
	German-Soto and Bustillos (2014)	Mexican Urban Cities	1985 to 2008	Y-Log Difference levels; X-levels	Roads	OLS	Urban area where major infrastructure provision exists, higher rates of growth are also taking place. Estimated output elasticity for roads is 0.2663* and is 0.0097** for general physical capital	Endogeneity; Reverse causality; Measurement error
					Physical capital			
	Banerjee et al. (2012)	Chinese Counties	1986 to 2003	Log Difference levels	Distance of transportation lines	FE	Proximity to transportation networks have no effect on per capita GDP growth	Endogeneity
	Czernich et al. (2011)	OECD Countries	1996 to 2007	Log Difference levels	Broadband penetration	IV	A 10-percentage point increase in broadband penetration raised annual per capita growth by 0.9 to 1.5 percentage points	External validity
	Calderón and Servén (2010)	Sub-Saharan African Countries	1960 to 2005	Y-Log Difference Level; X-Levels	Synthetic Infrastructure Index (telephone, road, and electricity)	GMM	Infrastructure development contributes to growth across Africa. Estimated coefficient for the quantity index is around 2	NA
	Herrerias (2010)	Chinese National	1964 to 2004	Log Difference levels	Railway and highway	VAR	Infrastructures have played a significant role in accounting for long-run growth in China. Estimated coefficient for railway is 0.08**	No cross-sectional variation; Endogeneity
	Esfahani and Ramırez (2003)	Cross Countries	1965 to 1995	Cobb-Douglas; Log Difference Level	Telephone	IV	Cross-country estimates of the model indicate that the contribution of infrastructure services to GDP is substantial. Estimated output elasticity is 0.0779*** for the telephone and 0.1277*** for the power production capacity	NA
					Power production capacity			
	Fernald (1999)	US Industries	1953 to 1989	Value-added growth; First Derivative; Levels	Roads	SUR	When growth in roads changes, productivity growth changes disproportionately in U.S. industries with more vehicles. Cobb-Douglas coefficient is 0.35*	External validity
	Sanchez (1998)	Latin American Countries	1970 to 1985 and 1980 to 1992	Log Difference levels; X-Log Levels	Physical units index	OLS	Indicators of investment in physical units of infrastructure are positively and significantly correlated with growth in two different samples of countries (Estimated coefficients are 0.0031** and 0.0086**)	Endogeneity; Reverse causality
		Cross-country	1971 to 1985					

[#] The dependent output variable is followed by the output to public capital stock/investment elasticity value, where p<0.01 is denoted by ***; p<0.05 is denoted by **; and p<0.1 is denoted by *

Subsequent literature extends the research frontier to different regions in the world, including Europe, Africa, East Asia, South Asia, and South America. Following Duffy-Deno and Eberts (1991), Lewis (1998) shows that the impact of public infrastructure through roads and water on municipal economic development in Kenya is significant. Nketiah-Amponsah (2009) find that government expenditure on infrastructure promotes economic growth in Ghana. Focusing on the Sub-Saharan African (SSA) countries, a region that lacks public infrastructure, Kodongo and Ojah (2016) show that spending on infrastructure, as well as making increments in the access to infrastructure, positively influences economic growth in the region. Effects are more significant in less developed economies where lack of infrastructure is a bottleneck for economic development (Kodongo & Ojah 2016).

In addition to the empirical evidence, a few studies focusing on African countries estimated the relationship between infrastructure and growth using either a growth model or general computational equilibrium (CGE) model. For example, using a CGE model, Mostert and Van Heerden (2015) confirm a positive link between infrastructure investment and economic growth.

Several studies have investigated the relationship between infrastructure and economic growth at the regional level, multi-country level, national level and sub-national level (e.g., Lall 1999; Sahoo & Dash 2009, 2012; Sahoo et al. 2012; Haider et al. 2012; Shi et al. 2017; Srinivasu & Rao 2013; Roy et al. 2014). These studies employ statistical methods to establish the relationship between economic growth and physical infrastructure with the exception of Srinivasu and Rao (2013), who use a growth model. Among these studies, Lall (1999), Roy et al. (2014), and Shi et al. (2017) find ambiguous or heterogeneous links between infrastructure and regional economic growth. Lall (1999) finds that an increase in infrastructure investment has either a negative or insignificant effect on regional output at the state level in India. Roy et al. (2014) show that the association of the components of infrastructure with the level of industrial development is weak at the district level in Jharkhand state of India. Haider et al. (2012) find no long-run relation between infrastructure and aggregate output in Pakistan, but they find a strong relationship between infrastructure investment and economic development in the short-run. Shi et al. (2017) find a mixed relationship across time periods and regions for the contribution of infrastructure investment to economic development at the municipality level in China. On the other hand, Sahoo and Dash

(2009), Sahoo and Dash (2012), and Sahoo et al. (2012) find a positive correlation between infrastructure investment and economic growth in India, South Asia and China, respectively.

A few studies are carried out for South America (German-Soto & Bustillos 2014; Urrunaga and Aparicio 2012). Following Holtz-Eakin (1994), German-Soto and Bustillos (2014) estimated the production function using panel data with fixed effect and found positive links between infrastructure and growth. Urrunaga and Aparicio (2012) find that public infrastructure is important in explaining temporary differences in regional output.

3.2 Economic Growth Effects of Sector-Specific Infrastructure

Instead of investigating the impact of aggregate public infrastructure investment, a few papers aimed at specific sectors, studying the economic growth effects of sector-specific infrastructure investment (Zou et al. 2008; Herrerias 2010; Czernich et al. 2011; Banerjee et al. 2012), mostly for the case of China. Specifically, Zou et al. (2008) use both panel and time-series data along with fixed effect and Granger causality test to examine the effect of transportation infrastructure on economic growth, suggesting that the greater growth level is, to some degree, attributed to the better transportation system. A meta-analysis conducted on the effect of transport infrastructure investment on economic growth (Melo et al. 2013) suggests that transport's impacts are larger for the United State than Europe; the effects are also larger when using roads compared to other modes of transportation. It also shows that if the study is not controlling for unobserved heterogeneity and spurious correlations, then it will obtain higher estimates. Herrerias (2010) investigates whether an investment in equipment/machinery impacts the economic growth effect in China and finds that it does significantly. Banerjee, Duflo and Qian (2012) also study the effect of the transportation system on regional economic performance in China. They find that the transportation infrastructure could increase sectoral output, but it does not necessarily boost GDP growth.

Czernich et al. (2011) study the effect of broadband infrastructure on the economic growth in the panel of OECD countries and find positive and significant impacts. Czernich et al. address endogeneity concerns using an IV approach where pre-existing voice telephony and cable TV networks predict maximum broadband penetration. However, since the model derives its first stage from a non-linear logistic diffusion model, it is under the suspicion of relying on the nonlinearity instead of homogeneity to isolate the impact of faster internet.

A large body of literature that has started since Kraft and Kraft (1978) examined the causal relationship between energy consumption and output. However, the results are mixed. Review studies by Oztruck (2010) and meta-analysis by Bruns et al. (2014) conclude that economic growth drives energy consumption instead of the other way around. There are some exceptions though, which suggest that energy consumption drives economic growth.[5]

4. Infrastructure and Income Inequality

Is there any empirical evidence to demonstrate that increased infrastructure investment or service provisions increase the incomes of poor households (i.e., reduces poverty) and thereby reduces income inequality? A few studies examine this issue (Démurger 2001; Calderón and Chong 2004; Calderón & Servén 2004, 2010; Chatterjee and Turnovsky 2012; Chotia and Rao 2017a, 2017b; Hooper et al. 2018). Table 3 summarizes the methodologies used and the findings of these studies.

Calderón and Chong (2004) investigate the relationship between physical infrastructure stocks and income inequality using data from more than 100 economies around the world for the period 1960-1997. Relationships of different infrastructure stocks – telecommunications, energy, roads, and railways – with income distribution were investigated individually and in aggregation. Using alternative empirical techniques (e.g., cross-country and GMM on dynamic panel data), they found that infrastructure stock is negatively linked with inequality (i.e., higher the infrastructure stock, the lower is the income inequality); the relationship is more prominent in low-income countries. Calderon and Serven (2004) expanded the study in terms of the number of economies (121 instead 101 before) and time horizon (1960-2000 instead of 1960-1997 before) using the same methodology. They show that not only the increased quantity of infrastructure stocks reduces income inequality but also the improved quality of infrastructure services does the same. Calderón & Servén (2010) conducted a similar analysis focusing on Sub-Saharan Africa, where the level of economic development is low and where the trade-off between the investment on immediate

[5] Please see Oztruck (2010) and Bruns et al. (2014) for more details.

welfare services (health care, food) and long-term infrastructure services is more acute for the scare public finance resource. They further extended the data until 2005. It also finds that the increased access to infrastructure services (i.e., improved quantity and quality of infrastructure) would decrease income inequality as their econometric models show a strong negative correlation between the income inequality measure (Gini coefficients) and the synthetic indices used to measure infrastructure quantity and quality. The correlation coefficients vary between -0.47 and -0.56. The study also shows that improved infrastructure not only reduced income inequality and poverty in Sub-Saharan Africa but also all over the world, more prominently in East and South Asia.

Chatterjee and Turnovsky (2012) developed a general equilibrium growth model to analyze the impacts of investment on income inequality (and also on infrastructure and economic growth). Considering four alternative sources to finance the public investment: lump-sum tax, capital income tax, labor income tax and consumption tax, their model shows that public spending on infrastructure (public capital) would have differing impacts between the short-run and long-run. In the short-run, public investment causes income inequality to decline; however, the declining trend decreases over time, and income inequality gets worse (increase) in the long-run.

Using state-level panel data on infrastructure investment and per capita income for the 1950 -2010 period, Hooper et al. (2018) investigates the relationship between infrastructure and income inequality. The study finds that investment in physical infrastructure (highways) and human capital (higher education) reduces income inequality (Gini indices) in the United States. The relationship is found stronger at the bottom 40 percent of the income distribution. The study also finds that investments in highways are more effective at reducing inequality. US states with a higher Gini coefficient at the bottom 40 percent had lower infrastructure investment during the previous decade. The finding suggests that infrastructure investment is an important factor in reducing poverty and income inequality not only in developing countries but also in developed ones.

There does not exist that many studies to directly investigate the relationship between infrastructure investment and poverty reduction. Chotia and Rao (2017a) is one of them among the few studies. Employing an autoregressive distributed lag (ARDL) bounds testing approach on annual data for the 1991-2015 period, this study finds that infrastructure development[6] reduces poverty in India. It finds a positive and unidirectional causality running from infrastructure development to poverty reduction. Sasmal and Sasmal (2016) also investigates the impact of public investment on poverty alleviation in India. Using panel data analysis, this study shows that Indian states where public expenditures on the development of infrastructure (e.g., road, irrigation, power, transport, and communication) is higher, per capita income is also higher, and the incidence of poverty is lower. Chotia and Rao (2017b) examine the relationship between infrastructure development, rural-urban income inequality, and poverty in BRICS countries (Brazil, the Russian Federation, India, China, and South Africa) using Pedroni's panel co-integration test and panel dynamic ordinary least squares (PDOLS) method. It finds that infrastructure development and economic growth lead to poverty reduction in BRICS countries; the rural-urban income inequality aggravates poverty further.

Some studies examine the impacts of infrastructure investment on other forms of inequality. Fan and Zhang (2004) investigate non-farm productivity inequality in rural areas across Chinese provinces. The study finds that investments in rural infrastructure and education are a major driver of productivity growth in China, and non-farm rural productivity varies across Chinese provinces depending upon the level of investment in infrastructure and education. The lower productivity in western China is found to be associated with a lower level of rural infrastructure and education in that region. Similarly, Démurger (2001) provides empirical evidence of inequality across the Chinse provinces in response to infrastructure investment. Using panel data from a sample of 24 provinces for the 1985-1998 period, it finds that provinces with higher infrastructure endowment also had better economic performance (measured in terms of provincial GDP). The study also concludes that transportation infrastructure is the main factor in explaining provincial economic inequality. Cohen and Paul (2004) investigate cross-state variations of public infrastructure in the united states using state-level manufacturing data for the 1982-1996 period. They find that the productivity gains caused by the public infrastructure investment during the period vary significantly across the states. It finds the largest effects in the western states, whereas the effects are smallest in the eastern and southern states.

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[6] Infrastructure development was represented through indices for transport, water and sanitation, telecommunications and energy sectors constructed through principal component analysis.

Table 3. Examples of studies analyzing relationships between infrastructure investments, income inequality and poverty reduction

Study	Methodology	Findings
Calderon and Chong (2004)	GMM on dynamic panel data set for 101 economies for the year 1960-1997	Infrastructure stock is negatively linked with inequality; the relationship is more prominent in low-income countries. Estimated elasticity -1.3830**
Calderon and Serven (2004)	GMM on dynamic panel data set for period 1960-2000 from 121 countries	Infrastructure investment played a larger role to lower income inequality in East and South Asia, where it did only a modest role in Sub-saharan Africa. Estimated elasticity: -0.0464**
Calderon and Serven (2010)	Panel data analysis of 87 countries for 1960-2005 period focusing on Sub-Saharan Africa; GMM technique for the econometric analysis; two scenarios for infrastructure shocks	The increased access to infrastructure services (i.e., improved quantity and quality of infrastructure) would decrease income inequality; the income inequality, measured in terms of Gini Coefficient, is found strongly negatively correlated with the synthetic indices used as measures of infrastructure quantity and quality; the correlation values range from -0.47 to -0.56.
Chatterjee and Turnovsky (2012)	A general equilibrium model of a closed economy	Public spending on infrastructure would reduce income inequality in the short-run, whereas it would increase in the long-run.
Sasmal and Sasmal (2016)	Panel data analysis for Indian states	The lager is the public expenditures on the development of infrastructure, the higher is per capita income and lower poverty headcount
Chotia and Rao (2017a)	Auto-regressive distributed lag (ARDL) bound testing approach	Infrastructure development reduces poverty in India
Chotia and Rao (2017b)	Pedroni's panel co-integration test and panel dynamic ordinary least squares (PDOLS) method	Infrastructure development and economic growth lead to a reduction of poverty and urban-rural inequality in BRICS countries
Hooper et al. (2018)	US state-level panel data for 60 years (1950-2010)	Infrastructure investment reduces income inequality; the relationship is stronger at the bottom 40 percent (by income) population

5. Some Issues Related to Infrastructure and Economic Growth or Inequality

There are several issues related to the relationship between infrastructure and economic growth, as well as inequality. These include: how much the quality of infrastructure matters; is the marginal effect of infrastructure diminishing? What are the channels through which infrastructure affects economic growth and inequality (such as increased productivity of firms, employment, or labor market). Short-term vs. long-term impacts of infrastructure, infrastructure, and institutions, and so on. Each of these issues could be the topic of a separate paper and cannot be discussed in this paper. Below, we highlight a few of them. Some of these issues require further studies for better understanding and are highlighted in the next section.

5.1 Quality of Infrastructure

The existing literature on infrastructure and economic growth deals mostly with the quantity of infrastructure. Studies analyzing the impacts of infrastructure quality are limited due to the lack of time-series data representing the quality of infrastructure. A few studies, however, address this issue, although the findings are inconclusive. For example, Calderon and Serven (2010) find, using data from more than 100 countries, a positive relationship between infrastructure quality and economic growth. On the other hand, Kodongo & Ojah (2016) do not find impacts of infrastructure quality on economic growth in Sub-Saharan Africa. Similar findings are also reported by Chakamera and Alagidede (2018) for the same region. It shows that although the combined effects of infrastructure stock and their quality are larger than the stock effects alone in countries with high infrastructure quality, the opposite was the case in countries with poorer infrastructure quality. Some studies use the CGE model to analyze the impacts of infrastructure quality on economic output (GDP). For example, using a CGE model of Nepal, Timilsina et al. (2018) find that electricity load shedding, which represents the poor quality of electricity supply, would have caused 7% GDP loss during the 2008-2016 period.

5.2 Short-Run vs. Long-Run Impacts of Infrastructure

While capturing the average effect of infrastructure investment, many studies have found economic performance (e.g., output levels and growth rate) is positively related to the public capital in the short run. However, when considering the impacts at a margin, it may not be a case that infrastructure investment could consistently power the economic growth in the long run because the benefits of public capital investment diminish to some point where the cost outweighs the return. Experimental studies (e.g., Lenz et al. 2017) can provide insight on short-term impacts of infrastructure changes for certain users but have less to say about the longer-term impacts across the economy. Long-term structural models can provide that information, but such models are more complex to build and estimate. There exist only a few studies differentiating the short-run vs. long-run impacts of infrastructure (e.g., Roberts et al. 2012; Haider et al. 2012). As mentioned earlier, Haider et al. (2012) find, in the case of Pakistan, a short-run relationship between the infrastructure and aggregate economic output, no such relationship in the long-run.

Long-term impacts of infrastructure are more related to investment in human capital infrastructure (e.g., education), technology & innovation, although investment in physical infrastructure also has long-term impacts (Acemoglu & Autor, 2012; Diebolt & Hippe, 2019). However, physical infrastructure tends to have immediate benefits to the economy in the sense that an economy does not need to wait several years to reap the benefits. On the other hand, investment in education is meant to prepare human capital in the future, which will boost economic growth (Benhabib & Spiegel, 1994; Ciccone & Papaioannou. 2009). The literature addressing the long-term impacts of soft infrastructure (e.g., education, innovation) is rich. This literature entails the endogenous growth theory (Solow 1956, Romer 1986; Lucas 1988)); it is beyond the scope of this study.

5.3 Marginal Returns of Infrastructure

Several studies observed that marginal returns of infrastructure investment are declining (see e.g., Garcia-Mila and McGuire, 1992; Lynde and Richmond, 1992; Morrison and Schwartz, 1996a; Cain, 1997; Fernald, 1999; Bougheas et al. 2000; Kodongo and Ojah, 2016; Shi et al. 2017).

Several early studies that investigate the impacts of public expenditure on economic growth report marginal returns of such expenditure. For example, Garcia-Mila and McGuire (1992) study the human capital investment and find that although education and median years of schooling are significantly and positively related to output, the importance of the education variable with respect to output (i.e., output elasticity of education investment) is diminishing. Bougheas et al. (2000) find a non-monotonic (inverted-U) relationship between the long-run growth rate and the stock of infrastructure scaled by the level of national output. From the historical perspective and taking road construction as an example, Fernald (1999) states that additional road investments do not appear unusually productive, because at the outset the interstate system is already highly productive; roadbuilding through a one-time, unrepeatable boost increased productivity in the 1950s and 1960s but the benefits from further expanding roads are much smaller. Morrison and Schwartz (1996a) explain that the diminishing marginal benefits of public investment is caused by its crowding out of investment in private capital, which, in the long run, maybe more productive. In a study for Canada, Paul, Sahni, and Biswal (2004) find that the magnitude of output elasticity in most industries is declining. Similarly, Majumder (2005) finds that in the regions where facilities are already concentrated, marginal benefits of further expansion of infrastructural facilities are less than the marginal costs in India.

Recent studies also provide empirical evidence of diminishing marginal benefits of infrastructure investment (Kodongo & Ojah 2016; Shi et al. 2017). Kodongo and Ojah (2016) find that infrastructure spending is more productive in less developed economies than that in relatively more developed economies, thereby implying the diminishing marginal benefits of infrastructure investment. Similarly, Shi et al. (2017) find an inverse U-shaped relationship between infrastructure investment and economic growth in China, which also suggests the diminishing marginal returns of infrastructure investment.

6. Research Gaps

Although the research on infrastructure and economic growth is relatively rich, there still exist several gaps on several fronts. Some of the research gaps are identified below.

6.1 Infrastructure Stock vs. Access

Intuitively, economic growth is more linked to access to infrastructure rather than the stock of infrastructure. It implies that infrastructure investment would have higher impacts in those economies where lack of access to infrastructure curtailing economic activities and therefore slow down economic growth. Existing literature, however, has not examined this hypothesis. It requires detailed data on physical access to infrastructure services. The study could be done across countries or across different regions within a country. For example, an investigation of whether economic growth is faster in regions with a good provision of infrastructure vs. in regions struggling with access to basic infrastructure. A few studies have tried to examine this issue experimentally (Lee et al. 2016) or with panel microdata (Asher and Novosad, 2018). It is important to note that addressing the bottleneck of one infrastructure service does not boost economic growth when the economy is constrained by the lack of multiple infrastructure access. For example, World Bank (2018) finds that the impact of improved access to electricity in rural areas is positively related to road access: the benefit of improved capacity for producing goods and services due to electricity access depends on access to markets, which in turn depends on proximity to roads and their quality.

6.2 Infrastructure Quality

Several studies have attempted to incorporate the quality of infrastructure in their analysis. However, these studies are severely limited, due to either limited data or wrong selection of variables. For example, studies such as Calderon and Serven (2010), Chakamera & Alagidede

(2018) use electricity transmission and distribution (T&D) losses to measure the quality index for electricity infrastructure. However, T&D loss is not an indicator of electricity service quality; it simply represents energy lost in the transmission and distribution system; power outages and voltage fluctuations are the quality indicators for the electricity supply system. Power sector reliability is a critical factor to be considered to represent the quality of the power supply system. Calderon and Serven (2010) use waiting time for the installation of main telephone lines as a quality index for telecommunication infrastructure. This is also not the right quality indicator; instead of waiting for installation time, the study should have taken the frequency and duration of service disruptions. Studies that can identify appropriate quality indicators and put more effort into collecting data on those indicators are needed. Otherwise, the findings could be misleading. For example, findings of Kodongo & Ojah (2016) and Chakamera and Alagidede (2018) that suggest no relationship between infrastructure quality and economic growth in Sub-Saharan Africa could be a result of selecting wrong indicators for infrastructure quality.

6.3 Marginal Returns of Infrastructure Investment

Some studies show that infrastructure development has an inverted U-shape relationship with economic growth. For example, Bougheas et al. (2000) find an inverted U-shaped relationship between infrastructural development and economic growth for the United States. The threshold infrastructure development level above which infrastructure investment has negative marginal returns will vary across countries depending on several factors, including climate, land area, and spatial distribution of inhabitants across the country. Wylie (1996) illustrates this with a finding that Canada needs a much higher level of infrastructure as compared to the United States due to its colder climate and highly scattered inhabitants across the country. The nature of the threshold in turn, affects how the marginal return to infrastructure investment changes as infrastructure grows toward the threshold. However, more studies needed to understand the peak infrastructure level, after which the marginal impacts of infrastructure on economic growth is declining. Does the threshold level vary across countries? What does historical experience or data demonstrate? Is it true that the relationship between infrastructure and economic growth in today's developed countries was stronger while they were achieving the 'developed' status? Is this true for newly emerging economies – China, Brazil? What about the Eastern European and Former Soviet

Republics where governments heavily invested in infrastructure before they transited to a market economy?

6.4 Distributional Impacts of Infrastructure

Over the last decade or so, several studies have attempted to underscore the relationship between infrastructure and its impacts distributed across income groups or inequality (Démurger 2001; Calderón & Chong 2004; Calderón & Servén 2004, 2010; Chatterjee & Turnovsky 2012; Chotia & Rao 2017a, 2017b; Hooper et al. 2018). The common findings from the existing literature are that infrastructure development has a negative relationship with inequality, meaning that infrastructure development helps reduce income inequality. However, what is still not known is how would infrastructure development helps the poor who use the infrastructure services disproportionally less compared to the rich. Some studies have reported that access to infrastructure mainly benefitted to the rich. Khandker et al. (2014) finds that the larger share of benefits of rural electrification in India accrues to wealthier rural households because poorer households use a limited amount of electricity, mostly for lighting only. One may raise a question – to what extent the government spends on infrastructure that disproportionally benefits low-income households. It is possible that these studies might not have investigated indirect benefits that infrastructure investment ultimately brings to the poor. Construction of a rural road will provide farmers better market opportunities for their agricultural products. It is, therefore, necessary to investigate the impacts of infrastructure on the poor from a broader perspective than from the narrow perspective employed by the existing literature.

6.5 Physical Infrastructure vs. Human Capital?

A critical question faced by developing countries, particularly low-income countries, is where they should prioritize their scarce resources and what to prioritize – should they use the resources on physical infrastructure (i.e., road, electricity) or use to improve social welfare (e.g., health care) or use it to strengthen their long-term human capacity (e.g., education). How to optimize the allocation of resources between increasing human capital versus or strengthening physical capital? Earlier literature such as Samuelson (1954), Arrow and Kurz (1970) provide textbook guidance on the optimal theory of public expenditure. The question is not limited to public expenditure only – it is an issue of overall investment in physical as well as human infrastructure. Some existing studies, such as Jimenez (1994), Devarajan et al. (1996), also point out this research gap. There might not be a generic answer to this question. The optimal mix of investments between the physical infrastructure and human capital could vary across countries, depending on their specific situations. It would, therefore, be interesting to investigate this variation and provide insights to policy makers.

6.6 Long-Run Impacts of Infrastructure Investment

Panel data studies such as Calderón and Servén (2010) pick up the combined effects of infrastructure adjustment processes over time for countries with differing initial economic and institutional levels of development. Such studies can be used to assess statistically both the impact effects of changes in infrastructure development and longer-term effects. However, such research does not in itself provide insight on how infrastructure affects development over the longer-term. Experimental studies (e.g., Lenz et al. 2017) can provide insight on short-term impacts of infrastructure changes for certain users but have less to say about the longer-term impacts across the economy. Long-term structural models can provide that information, but such models are more complex to build and estimate, and the literature contains only a few exceptions (see, e.g., Roberts et al. 2012).

7. Conclusion

Developing countries are facing a crucial question: what to prioritize when the financial resources needed for economic development are limited. Should they invest more in physical infrastructures, such as roads, rail, electricity supply systems, or should they focus on services, such as health care and education? Researchers have attempted to address this question through empirical analysis over the past three decades. This paper aims to review the literature and summarize the insights coming from the existing studies. Both types of studies -- those analyzing the impacts of public investment in general, and those examining the effects of physical infrastructure, in particular, are considered.

Most of the existing studies use statistical/econometric techniques, although a few use structural modeling techniques, particularly the computable general equilibrium modeling. Earlier studies using the statistical methods have suffered from several limitations, such as spurious correlation, endogeneity, and reverse causality. These limitations are, however, addressed in more recent studies. Studies that investigate the impacts of public investment in general use monetary values for public investment as independent variables, whereas the studies that examine the impact of physical infrastructure use the stock of physical infrastructure. However, since physical infrastructures are measured using different units, most studies develop indices to combine various types of physical infrastructure.

The findings of studies analyzing public investments, in general, are mixed. Several studies find positive impacts of public investments on economic growth. In most of the cases, public investments are found to increase the productivity of private firms. Some studies, on the other hand, do not find a positive relationship or even report a negative relationship. Most studies examining the impacts of physical infrastructure on economic growth report a significant positive relationship between the possession of physical infrastructure and economic growth. The relationship is more prominent in low-income countries than that in high-income countries. Studies investigating the impacts of physical infrastructure on income inequality and poverty reveal that infrastructure investments help reduce inequality and poverty.

Our review also identifies several research gaps in the literature. Some of these gaps are: would investment in infrastructure be more productive in economies where access to infrastructure constrains economic development than in economies where access is not a problem? A similar question would be whether the marginal returns to infrastructure investment are diminishing. How to balance between the investment in physical infrastructures and social infrastructure or human capital is a crucial question, especially in developing economics that are constrained by limited financial resources. Studies empirically examining the role of infrastructure in poverty alleviation are highly limited, additional studies are needed on this issue. Overall, there exists a significant gap in the area of infrastructure investment, economic growth, and poverty alleviation; therefore, additional studies are necessary.

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