

Infrastructure, Growth, and Inequality

An Overview

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Abstract

Academics and policy makers have long considered an adequate supply of infrastructure services to be essential for economic development. This paper reviews recent theoretical and empirical literature on the effects of infrastructure development on growth and income distribution. The theoretical literature has employed a variety of analytical settings regarding the drivers of income growth, the degree to which infrastructure represents a public or a private good, and the extent of market distortions, notably in capital markets. In turn, the empirical literature has used various

econometric methodologies on time-series and cross-section macro and microeconomic data to test for the effects of infrastructure development. However, these empirical tests face challenging issues of measurement, identification, and heterogeneity. Overall, the literature finds positive effects of infrastructure development on income growth and, more tentatively, on distributive equity. Still, the precise mechanisms through which these effects accrue, and their full impact on welfare, remain relatively unexplored.

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1. Introduction

An adequate supply of infrastructure services has long been considered essential for economic development by both academics and policymakers. The role of transport infrastructure, for instance, in fostering economic prosperity goes back to Adam Smith's *Wealth of Nations*, which listed "the duty of erecting and maintaining certain public works" among the three core obligations of the sovereign.

Over the last quarter century, research has devoted considerable attention to the contribution of infrastructure development to the growth of productivity and aggregate income. A vast literature has explored a multitude of theoretical scenarios characterizing the economic role of productive public services and their financing, and has examined the empirical evidence on the growth impact of infrastructure development in a variety of cross-section, time-series and panel data settings.

In addition to its impact on aggregate income, infrastructure can also have an impact on income inequality, and this issue has attracted increasing theoretical and empirical attention in recent years. Conceptually, there are good reasons why infrastructure development may have a differential effect on the incomes of the poor, over and above its impact on aggregate income. Infrastructure facilitates the poor's access to productive opportunities, raising the value of their assets. It can also improve their health and education outcomes, thus enhancing their human capital. More broadly, access to and use of infrastructure services—including telecommunications, electricity, roads, safe water and sanitation—play a key role in the integration of individuals and households into social and economic life (World Bank 2003).

If infrastructure helps both raise income levels and reduce income inequality, its development could offer a powerful tool for poverty reduction. Partly for this reason, infrastructure development has become a policy priority in many countries. In fact, infrastructure absorbed a major share of the fiscal stimulus deployed in the wake of the 2007–08 global crisis: on average, emerging and developing economies devoted 40 percent of the stimulus to infrastructure spending, while advanced economies devoted 21 percent (International Labor Organization 2011).

This paper reviews recent theoretical and empirical literature on the effects of infrastructure development on growth and income distribution, with particular emphasis on developing

countries. Because the literature has grown massively over the last two decades, the review is necessarily selective rather than exhaustive. It also leaves aside the effects of infrastructure on other dimensions of the development process, as well as the political economy and other factors underlying infrastructure policies.

The rest of the paper is organized as follows. Section 2 reviews the literature on the growth effects of infrastructure while Section 3 deals with its effects on income distribution. Section 4 highlights key challenges faced by the empirical literature on both topics. Finally, Section 5 offers some closing remarks.

2. Infrastructure and growth

Starting with the work of Aschauer (1989), a vast analytical and empirical literature has been concerned with the effects of infrastructure development on income growth, productivity and welfare. Below is a summary view; more comprehensive accounts can be found in Irmen and Kuehnel (2009) and Romp and De Haan (2007).

2.1 Analytical approaches

Much of the relevant literature examines the growth effects of public investment rather than infrastructure. But the two concepts may differ, for two reasons. First, in many countries the government's involvement in productive activities is not limited to infrastructure. Second, while the public sector has traditionally played the leading role in the provision of infrastructure, private sector participation has been on the rise across the world.

Following the seminal work of Arrow and Kurz (1970), the output impact of infrastructure has been modeled by including either the stock of infrastructure assets or the flow of infrastructure services as an additional input in the economy's aggregate production function, and further assuming that infrastructure is a gross complement for non-infrastructure inputs -- labor and non-infrastructure capital. In this framework, an increase in the volume of infrastructure services raises output not only directly, but also indirectly, by 'crowding-in' other inputs owing to the accompanying rise in their marginal productivity. This indirect effect may take place instantaneously (for variable inputs in elastic supply) or over time (for fixed inputs such as human and non-infrastructure physical capital).

However, the expansion of infrastructure needs to be financed, and this represents a countervailing force: increasing taxation to finance public infrastructure crowds out the use of other inputs, which offsets partly or fully the crowding-in effect via productivity. This was highlighted by Barro (1990) in an endogenous growth framework in which the government's contribution to current output is captured by the flow of productive public expenditure (rather than the stock of public capital) financed through proportional income taxation. The welfare-maximizing level of productive expenditure is shown to be the same as that which maximizes the economy's growth rate, and it is achieved when the share of productive government expenditure in GDP (and hence the tax rate) equals the elasticity of aggregate output with respect to the same variable – what is often called the '*Barro rule*.' If productive expenditure exceeds this level, the additional distortionary taxation needed to finance it diverts non-infrastructure investment away to the point that income growth is reduced.¹

Many of the theoretical contributions after Barro (1990) use an endogenous growth framework allowing infrastructure to impact the economy's long-run growth rate. In many cases, however, the focus is on the stock of infrastructure assets rather than the flow of infrastructure-related expenditure. The underlying logic is that, while the flow-based approach offers the important advantage of analytical tractability, the availability of infrastructure services (e.g., road transport) often relates more closely to the stock of infrastructure assets (e.g., the stock of public highways) than to the flow of expenditure on infrastructure-related activities (e.g., annual spending on road construction).²

Following this logic, Futagami, Morita and Shibata (1993) extended Barro's (1990) model to include both public and private capital, with the rate of public investment as the government's key decision variable. This framework yields some new results. On the one hand, the economy displays nontrivial transitional dynamics. On the other, the growth-maximizing level of public investment (as share of output) is still equal to the elasticity of output with respect to public capital; however, its welfare-maximizing level is lower. Intuitively, public investment takes time

¹ Similar results apply in broader settings; for instance, Fisher and Turnovsky (1998) show that, in the Ramsey-type framework of Arrow and Kurz (1970) and with a Cobb-Douglas technology, an increase in the stock of public infrastructure raises the private capital stock only if infrastructure spending is below the level defined by the Barro rule. With more general technologies, the elasticity of substitution between infrastructure and other capital also comes into play; on this see Eden and Kraay (2014).

² Indeed, Aschauer's (1989) pioneering empirical analysis was framed in terms of the productivity of the public capital stock.

to become productive, and this delay entails an additional sacrifice of current consumption for future consumption.

In reality, infrastructure provision requires both capital and recurrent expenditure; e.g. to build and maintain roads, respectively. Tsoukis and Miller (2003) and Ghosh and Roy (2004) examine how the above results are affected when the stock of public capital and the flow of non-investment spending are considered simultaneously. Overall, the earlier results stand: the welfare and growth-maximizing levels of recurrent expenditure coincide, but they differ in the case of investment expenditure, for which growth maximization implies public investment in excess of the welfare-maximizing level.

Modeling infrastructure just like another input in production is a natural way to capture producers' direct use of electricity or transport services. But infrastructure may also enter the production function as a determinant of aggregate TFP, i.e. an 'unpaid factor' with spillover effects on the productivity of other inputs (Hulten and Schwab 2000).³ For example, Bougheas, Demetriades and Mamuneas (2000) and Agenor (2013) argue that transport and telecommunications services facilitate innovation and technological upgrading by reducing the fixed cost of producing new varieties of intermediate inputs. In a Romer-style framework, this raises output growth.

Aside from its role in the production function, another strand of the literature highlights the role of infrastructure in the accumulation of other inputs. For example, better transport networks may reduce installation costs of new capital (Turnovsky 1996). Likewise, improved access to electricity may raise educational attainment and reduce the cost of human capital accumulation (Agenor 2011). In these cases, the growth-maximizing output share of infrastructure spending is not given just by the elasticity of output with respect to infrastructure capital: one must also account for the output effect accruing through the accumulation of other inputs, and this tends to make the growth-maximizing rate of infrastructure provision (as well as its welfare-maximizing level) higher than when the latter effect is absent.

Contrary to what much of the literature assumes, few infrastructure services are pure public goods. In particular, congestion tends to make most services rival; think of road transportation,

³ While the distinction between both scenarios is conceptually clear-cut, it is blurred in empirical applications using Cobb-Douglas technologies, which confound both effects.

for example. Further, many services—such as power and telecommunications, or even toll roads— are excludable, and thus suitable for financing through user fees (and for private provision).⁴

The literature has considered two forms of infrastructure congestion. Under absolute congestion, services received by an individual user depend negatively on aggregate usage. Under relative congestion, they depend positively on the individual's usage relative to aggregate usage. Analytical details vary depending on the chosen option as well as the production technology (Barro and Sala-i-Martin 1992, Eicher and Turnovsky 2000). Nevertheless, some basic results from the models without congestion continue to hold. For example, in an endogenous-growth setting with infrastructure modeled as a service flow, the welfare-maximizing level of public infrastructure spending is still dictated by the Barro rule. If infrastructure is viewed instead as a stock, such rule leads to excessive accumulation, just like in the absence of congestion (Turnovsky 1997). However, in an exogenous growth setting, the crowding-in effect of infrastructure on non-infrastructure capital tends to be diminished, or even reversed, especially when the financing is done through distortionary taxes (Fisher and Turnovsky 1998).

Another important feature of infrastructure is the presence of network effects, which can lead to strong nonlinearities in its marginal productivity. For example, road construction may have limited effects until the road network is minimally developed, at which point the marginal output contribution of additional roads may rise sharply. Once the entire network has been completed, however, additional road building is likely to have rapidly declining output effects (see Fernald 1999). Under appropriate conditions, these nonlinearities may lead to multiple equilibria and to an enhanced role of infrastructure development policy: with a poor infrastructure endowment, the marginal productivity of infrastructure is low, and only a low-growth equilibrium may be attainable by the economy; however, a sufficient expansion of infrastructure networks would raise the productivity of infrastructure and permit reaching the high-growth equilibrium (Agenor 2013).

2.2 Empirical studies

⁴ Ott and Turnovsky (2006) examine the implications of congestion and excludability for the optimal financing of infrastructure services in a macroeconomic setting. Absent excludability, distortionary taxation reduces over-utilization of infrastructure and thus congestion. With full excludability, user fees provide the optimal form of infrastructure financing.

Few in academic or policy circles would dispute the view that infrastructure development fosters growth, but there is little consensus on the actual size of the effect and the factors that shape it. The empirical literature concerned with this issue took off following Aschauer (1989), who found that the stock of public infrastructure capital is a significant determinant of U.S. aggregate TFP. However, his estimates of the elasticity of output with respect to infrastructure were implausibly large (around 0.40), owing to a ‘spurious regression’ problem (see Gramlich 1994).

The massive empirical literature that followed focused on the impact of infrastructure on the level and growth rate of aggregate output or productivity, with numerous papers employing a large variety of data and empirical methodologies. Many authors estimated the elasticity of GDP with respect to infrastructure in an aggregate production function setting, using national or subnational data and time-series or panel techniques suitable for dealing with nonstationary variables and spillover effects. Early applications to panel data on U.S. states found much smaller elasticities than those estimated by Aschauer (e.g., Holtz-Eakin 1994; Baltagi and Pinnoi 1995). Drawing from a large number of subsequent empirical studies using aggregate data, primarily from industrial countries, a meta-regression analysis of the elasticity of output with respect to public capital yields an average estimate around .10, although the individual estimates from the underlying studies vary widely, from -1.73 to +2.04 (Bom and Ligthart 2014).

These studies use monetary measures of public capital, constructed by accumulating investment flows. Alternatively, others employ physical measures of infrastructure assets encompassing multiple infrastructure sectors — sometimes aggregated into a synthetic indicator. Empirical studies using the latter approach on cross-country panel data typically report a significant GDP (or productivity) contribution of infrastructure; see Canning (1999), Calderón and Servén (2003) and Calderón, Moral-Benito and Servén (2014).⁵

In the Cobb-Douglas framework used by many of these papers, it is not possible to assess the extent to which the effects of infrastructure reflect its TFP-augmenting role. This is the focus of relatively few studies. Hulten and Schwab (2000) use a growth decomposition approach to examine the contribution of public capital to manufacturing TFP growth across U.S. states. They fail to find significant effects. Hulten, Bennathan and Srinivasan (2006) apply a similar approach

⁵ Regarding individual sectors, Roller and Waverman (2001) find a large output impact of telecommunications infrastructure in industrial countries, while Fernald (1999) reports similar results for roads using industry-level data for the U.S.

to data from Indian states, using physical indicators of infrastructure assets in transport and power, and find that infrastructure development accounted for almost half of the observed TFP growth. Duggal, Saltzman and Klein (1999) allow for nonlinear production technologies. Using aggregate U.S. data, they find that public infrastructure capital is an important determinant of TFP. Duggal, Saltzman and Klein (2007) extend the framework to include also privately-supplied IT infrastructure, which contributes to production both as a standard input and as a driver of TFP. Both types of infrastructure are found to have a significant positive effect on productivity.

A related line of research, pioneered by Berndt and Hansson (1991), takes a dual approach and focuses on the estimation of cost and/or profit functions augmented by either infrastructure or public capital stock measures. The empirical finding in most cases is that infrastructure reduces production costs or increases profits – see Demetriades and Mamuneas (2000) on OECD cross-country data, and Cohen and Morrison Paul (2004) on U.S. state data.

A different strand of literature evaluates the long-term growth impact of infrastructure, typically using a reduced-form growth-regression framework relating long-run growth to suitable indicators of infrastructure, public capital or public investment, often in conjunction with standard control variables from the empirical growth literature. Measures of infrastructure and conditioning variables differ across studies, so they are not easy to compare. However, those papers using monetary measures of public capital stocks or public investment yield mixed results – e.g. Holtz-Eakin and Schwartz (1995) and Crihfield and Panggabean (1995) find no significant growth effects of infrastructure across U.S. states and metropolitan areas. In turn, Easterly and Rebelo (1993) find that public investment in transport and communications significantly raises growth across countries. Devarajan et al. (1996) find a negative relationship between the share of infrastructure in total public expenditure and economic growth in panel data for developing countries, while Gupta et al (2005) find the opposite result in a different cross-country panel data set.

In contrast, growth regressions using physical indicators of infrastructure stocks almost invariably find significant growth effects. In many cases, they use the number of telephone lines to proxy for infrastructure (e.g. Easterly 2001). In others, they use synthetic indicators capturing physical stocks in multiple infrastructure sectors – transport, power, and telecommunications.

Sanchez-Robles (1998) and Calderón and Servén (2004, 2010a,b) find that these summary measures are positively and robustly related to per capita GDP growth in panel data sets combining industrial and developing countries. The magnitude of the effects is substantial: a 1-percent increase in physical infrastructure stocks, given other variables, temporarily raises GDP growth by as much as 1-2 percentage points, although the growth acceleration gradually tapers off as the economy approaches its long-run per capita income.

The literature cited so far takes a country-level perspective. However, there are also studies that examine the effects of infrastructure development for income growth at a more disaggregated level. For example, Rud (2012) investigates the impact of electricity provision on manufacturing output across Indian states. Electricity provision is not exogenously assigned, and to deal with this problem the study takes advantage of the introduction of a new irrigation-intensive agricultural technology, viewed as a natural experiment. Adoption of new varieties of high-yield seeds required, among other things, timely irrigation, for which electric pumps were used. Thus, the initial availability of groundwater across states is employed to control for the endogeneity of the expansion of the electricity network. The evidence shows that, on average, a one-standard deviation increase in the measure of electrification is associated with a 14 percent expansion in state manufacturing output.

In turn, Datta (2012) examines the consequences of a major road improvement program in India -- the Golden Quadrilateral Program (GQP) -- for the performance of firms. The location of each individual firm relative to the upgraded highway provides firm-specific exogenous variation in the degree to which the quality of the roads improved as a result of the GQP. The study finds that firms located on the highways targeted by the program improved significantly their inventory management and reduced their input costs by switching suppliers.

The bulk of the empirical literature summarized here focuses on measuring the output (or productivity) gains from infrastructure assets. Less attention has been paid to the cost of acquiring and operating these assets. Yet comparison of (social) marginal costs and benefits is necessary to determine whether infrastructure is under- or over-provided.⁶

⁶ To some extent, the reduced-form growth regressions mentioned in the text shed light on this issue, given that their estimates of the impact of infrastructure allow for the adjustment of other production inputs as well as the changes in fiscal parameters required to accommodate infrastructure shocks.

Canning and Pedroni (2008) use a simple empirical model in the spirit of Barro (1990) to compare physical infrastructure stocks with their growth-maximizing levels in a panel of countries. Their finding is that infrastructure is under-provided in some countries and over-provided in others, and the verdict shows no clear correlation with countries' per capita income. On average, the level of infrastructure is 'just about right' from the point of view of growth maximization, so there is no evidence of a generalized infrastructure shortage. Using a similar framework, Kamps (2005) likewise concludes that there is no shortage of public capital in EU countries. In turn, Eden and Kraay (2014) assess public capital shortages in low-income countries, using a Ramsey-type framework that highlights the degree of substitutability between public and private capital. Their estimate of the marginal return on public capital exceeds the user cost, given by the rate of depreciation plus the world real interest rate (thus implicitly assuming non-distortionary taxation). They conclude that, on average, public capital is under-provided in their sample countries.

3. Infrastructure and income inequality

The preceding discussion refers to the effects of infrastructure on the economy's average income. But does infrastructure also have an effect on the distribution of income -- specifically, through its differential impact on the income of the poor? For example, if an enhanced infrastructure network helps connect lower-income segments of the population to markets for their inputs and outputs – by reducing transport and logistic costs to affordable levels -- their incomes may rise more than the average, as may the value of their assets (land or human capital).

The theoretical literature on the linkages between infrastructure and inequality is not as vast as that on infrastructure and growth. It has examined the distributional effects of infrastructure development under various assumptions about income distribution dynamics, economic distortions – notably in capital markets – and infrastructure-driven externalities. Empirical research has likewise employed a variety of approaches, from cross-country and time-series regressions using macroeconomic data, to micro-level studies assessing the impact of infrastructure-related interventions on the incomes of the poor, especially in rural areas.

3.1 Analytical approaches

Attempts to model the relationship between public investment and inequality are grounded on the literature on wealth distribution dynamics in the presence of capital market imperfections — see Banerjee and Newman (1993), Galor and Zeira (1993) and Piketty (1997). In these models, wealth redistribution towards the poor or the middle class can improve productive efficiency (Aghion and Bolton 1992, 1997). Enhanced availability of productive services—such as education, health and infrastructure— to the general population may not only improve efficiency but also help reduce inequality. In this vein, Ferreira (1995) builds a model with private-public capital complementarity in an environment with capital market imperfections. The government participates in the production of certain goods and services in which it has a comparative advantage (e.g., infrastructure, education and health), and only higher-income individuals can afford to purchase private alternatives to public services. In this context, expanding public infrastructure services reduces the inequality of opportunity among entrepreneurs, increases the return on investment, and raises entrepreneurial activity among the less-favored segments of society.

Building on this framework, more recent contributions model the joint dynamics of public investment, growth and inequality in a general equilibrium setting with heterogeneous agents that differ in their initial endowments of private capital. In these models, a pure public good or service (e.g., infrastructure) interacts with private capital in the production of other goods. Getachew (2010) presents a two-sector growth model with capital market imperfections in which public capital not only contributes to the production of goods, but also promotes the accumulation of private (human) capital. Like in earlier models, income inequality hinders growth. Increased provision of productive public services not only raises aggregate growth, but can also influence the distribution of income (and thereby exert a further indirect impact on growth) if the services accrue heterogeneously across individual households. Specifically, greater provision of public infrastructure benefits the poor more than proportionally because of their lesser access to private substitutes.

Chatterjee and Turnovsky (2012) likewise examine the dual role of public capital as growth engine and determinant of inequality. In their setting, public capital affects both productivity and labor-leisure choices.. Greater public investment raises factor incomes through the productivity channel, while also affecting relative factor returns and the distribution of income and welfare through the labor-leisure choice.. However, the mode of financing public investment matters for

factor income shares and income inequality. Numerical simulation of the model shows that any distributional gains may be only temporary if public investment is financed through non-distortionary taxes. On the other hand, income distribution improves both in the short and long run when public investment is financed by levies on capital.

Another dimension of income inequality that may be affected by public infrastructure development is the skill premium. It is examined by Pi and Zhou (2012) using a static multi-sectoral model with skilled and unskilled labor, in which public infrastructure is an input in the production of the different goods. A greater supply of public infrastructure raises the marginal productivity of both skilled and unskilled labor—and, hence, their respective remuneration. The effect on the skill premium depends on factor intensities: if the sector using unskilled labor is relatively more intensive in public infrastructure services, there will be an outflow of capital from the skilled to the unskilled sector. Hence, the wage rate of skilled labor will decline and that of unskilled labor will increase. This reduces skilled-unskilled wage inequality. Of course, the effect is the opposite if the sector using skilled labor is more intensive in the use of the publicly-provided infrastructure input.

The literature has devoted particular attention to the distributive impact of opening up infrastructure provision to private sector initiative. The impact may accrue through changes in employment, in the composition of public spending, and in the access and affordability of infrastructure services for the poor (Estache et al. 2000). Employment effects are particularly controversial, as former public enterprises acquired by private providers often become profitable by downsizing (Estache et al. 2002). In turn, the distributive impact of downsizing depends on the proportion of lower-income workers in the infrastructure labor force, and on the monetary compensation to laid-off workers. In addition, if the investment by newly-reformed providers of infrastructure promotes growth and new jobs, downsizing in the public infrastructure sector may be offset by job creation in other sectors (Benitez, Chisari and Estache, 2003).

Aside from employment effects, private sector participation in infrastructure also affects public revenues and expenditures. Subsidies to the provision of infrastructure services may be eliminated, and revenues from privatization may be generated. What happens with inequality depends also on what is done with the increased fiscal resources. If they are devoted to

improving the efficiency and coverage of public (infrastructure and non-infrastructure) service provision, income inequality may decline (Estache, Gomez-Lobo and Leipziger, 2000).

Finally, infrastructure reform may lead to price and/or supply responses that reduce the access and affordability of services for the poor. For example, removing subsidies may lead to higher post-reform prices, new private providers may charge higher connection fees than government-owned providers, or they may be reluctant to reach poorer areas (Estache, Foster and Wodon, 2002). As a result, infrastructure services may become unaffordable to lower-income groups. The likelihood of this outcome depends on the overall design of the reforms. In practice, however, there are numerous episodes in which the access by the poor improved after reforms involving private participation.

3.2 Empirical Studies

The empirical literature on infrastructure and inequality broadly follows two main strands. One is concerned with the effects of infrastructure stocks and/or service flows on standard inequality indicators. It includes the majority of the studies using macroeconomic data. The other examines the effects of specific infrastructure interventions, usually focusing on the income of poor households or backward geographic areas.

A few studies have directly examined the inequality impact of infrastructure at the aggregate level, by regressing Gini coefficients and similar inequality measures on indicators of infrastructure development in a cross-country panel data setting. Among them, López (2004) proxies infrastructure development by fixed telephone density, while Calderón and Chong (2004) consider the quantity and quality of different infrastructure sectors (telecommunications, energy, roads and railways) both separately and jointly, using a qualitative summary indicator in the spirit of Hulten (1996). In turn, Calderón and Servén (2004, 2010a,b) employ synthetic indices of infrastructure quantity and quality combining multiple infrastructure sectors, built through a principal components procedure. These papers find that, *ceteris paribus*, income inequality is negatively related to their respective measures of infrastructure development. In a similar setting, Seneviratne and Sun (2013) reach the same result for ASEAN countries, but they also find that public investment does not bear any significant relation with inequality. This again suggests that public investment data offer a poor proxy for infrastructure development,

The literature also advances the testable hypothesis that increased access to infrastructure services should help raise the income and the value of the assets of the poor. However, the availability of information on access to infrastructure services varies dramatically across countries and infrastructure sectors. For telecommunications, water and sanitation, existing data provide fairly good coverage across countries and over time. For power and transport, availability is sparse, especially in the time dimension. Subject to these constraints, Calderón and Servén (2010b) find a negative correlation across countries between measures of access to multiple infrastructure services and standard indicators of inequality – although it is not obvious to what extent this result may reflect a causal relation.

At the microeconomic level, another strand of literature examines the poverty effects of infrastructure interventions using matching techniques that combine samples of beneficiaries with samples drawn from regular household surveys (taken as control group). These studies usually evaluate the impact on income of a particular intervention affecting a given group of households or a specific geographic area. The implicit rationale is that, if such an impact is found, similar interventions targeted to poor households and/or low-income areas can reduce poverty and inequality.

Some studies of this type find that physical infrastructure in roads and communications facilitates spatial access and information flows, raising labor mobility, boosting rural non-farm economies, and reducing the incidence of poverty in some geographic areas (Jalan and Ravallion 2003, Zhu and Luo 2006, Reardon et al. 2007). They also show that public infrastructure provides a boost for local community and market development. For instance, rehabilitating rural roads in Bangladesh raised non-agricultural wage employment in targeted households and fostered markets that have become increasingly diversified across sectors —with the largest impact on households in the second-lowest quartile of the income distribution, the most mobile in changing activity from agriculture to non-farm work (Khandker and Koolwal, 2007, 2010). This type of intervention has also proved successful in Vietnam by increasing workers' wages and developing local markets in poor communities (Mu and van de Walle 2007).

Granting access to new and improved roads in rural areas has also expanded the set of opportunities in non-agricultural activities in Peru (Escobal and Ponce 2008) and in non-farm activities among women in Georgia (Lokshin and Yemtsov 2005). There is also evidence from

large emerging markets such as China and India. For example, public investment in rural roads and electrification has contributed to rapid growth in agricultural production across Chinese regions. However, the impact on poverty and inequality was boosted when infrastructure expansion was accompanied by public investment in education, science and technology (Fan and Zhang 2004, Zhang and Fan 2004). On the other hand, an expansion of regional infrastructure facilities (e.g. power and roads) in certain regions and districts of India was found to have improved average living standards and lowered the share of people living below the poverty line, even when infrastructure investment was accompanied by divestitures in education and health (Majumder 2012).

Recent literature examines the impact of electrification programs on rural areas in developing countries. Dinkelman (2011) evaluates the effect of the massive roll-out of the electricity grid in rural South Africa on employment –and, most notably, female employment. This roll-out, started in 1995, targeted low-capacity household use in rural areas rather than industrial users. The study employs the land gradients of the communities to adjust for the endogenous location of projects. The main finding is that electrification leads to rising female employment on both the extensive and the intensive margins. For instance, women work nearly 9 hours more per week in districts that experienced an average increase in electrification. This occurs as households with access to electricity replace wood burning at home with electricity for cooking and lighting, which frees up female time from home to market work. It also provides new opportunities to produce home-based goods and services for the market, either through self-employment or micro-enterprises.

One particular intervention found to have significant distributional effects is the construction of large irrigation dams. Duflo and Pande (2007) find that the benefits of building a dam on irrigated areas, in terms of agricultural production and rural poverty, accrue to the districts located downstream from the dam –as opposed to those districts where the dam is built. Furthermore, downstream districts can use the dam as insurance against rainfall shocks while agricultural production in districts where the dam is built is more vulnerable. In sum, rural poverty falls in districts located downstream, but this decline is smaller in magnitude than the increase in districts where the dam was built.

Other empirical studies shed light on the theoretical claim that improved access to infrastructure services can raise the income of the poor through its impact on human capital -- specifically,

education and health outcomes. Better transportation systems and safer roads help raise school attendance (Brenneman and Kerf 2002), while improved access to electricity allows more time for study and the use of computers (Leipzig et al. 2003). Cross-country research shows that enhanced access and use of basic infrastructure services reduces rates of child and maternal mortality. Likewise, Jalan and Ravallion (2003) find that the prevalence and duration of diarrhea in children under five in rural India is lower among households with piped water, although the impact on the poor is amplified if public investment in water and sanitation is accompanied by other interventions in education and income-poverty reduction. Analogous benefits resulted in Argentina when privatization expanded access to water and sanitation by the poor -- child mortality fell by 8 percent (Galiani et al. 2005).

Recent evidence shows that the benefits to the poor of improved access to water may go beyond the conventional health effects. Better access reduces time devoted to water collection, and thus it frees up time for additional leisure or production. It reduces important sources of stress and tension within the household and/or community. Moreover, it provides women greater mobility and opportunity to socialize and improve their well-being. Overall, welfare gains may result even in the absence of income or health gains; see Devoto et al. (2011) for evidence from the city of Tangiers.

Finally, evidence from Latin America shows that privatization of infrastructure sectors often benefited the poorest groups by granting them access to services. For instance, Chisari et al. (1999) and Navajas (2000) find that the privatization of infrastructure services in Argentina hurt the middle class relatively more than the rest of the income groups through the elimination of existing subsidies. However, it benefited the poor by improving their access to services. Estache, Gomez-Lobo and Leipzig (2000) show that the less-favored segments of the population in Latin America had very limited (or no) access to many utility services, and thus did not benefit from their expansion prior to the privatization. However, the extent of the benefits from privatization reaped by the poorest differed across sectors. In many countries, the rapid expansion of mobile telephone networks led to increased access to a wide array of service suppliers. The power sector, on the other hand, moved at a slower pace post-privatization, and reforms often failed to provide low-cost solutions to remote households in rural areas (Foster, Tre and Wodon, 2001). More broadly, an encompassing review of Latin America's experience offers several examples of improved access to infrastructure post-privatization (World Bank

2003). For instance, improved access to electricity, water, and telephones for poorer groups lifted their incomes in Guatemala. The expansion of infrastructure services to rural areas in El Salvador reduced the time required to reach markets, which created significant gains for poorer groups. Lastly, improving road quality had an important impact on income and, especially, on wage employment in Peru.

4. Limitations of the empirical literature

Three major concerns arise from the empirical literature on the development impact of infrastructure: measurement, identification, and heterogeneity. Take *measurement* first. Infrastructure is a multi-dimensional concept, comprising services that range from transport to clean water. However, many studies take a single indicator (most often telephone density) to proxy for “infrastructure”. Omitting other indicators of infrastructure where they are relevant — e.g., in growth empirics— leads to invalid inferences. However, simultaneous consideration of multiple types of infrastructure assets in econometric (especially time-series) estimation will typically lead to imprecise estimates. This motivates the use of synthetic infrastructure indices — see Sanchez-Robles (1998) and Calderón and Servén (2004, 2010a,b).

Furthermore, measures of infrastructure based on spending flows —typically, public investment, or its accumulation via perpetual inventory into public capital stocks— pose their own problems. Public investment and public capital are likely to be poor proxies for infrastructure accumulation if private participation in infrastructure provision is significant, as has become the case in many countries, or if the public investment is partly allocated to non-infrastructure industrial and commercial activities of the public sector. And even aside from these caveats, the link between observed public capital expenditure and the accumulation of infrastructure assets or the provision of services – which is what really matters for growth and equity -- may be weak or nonexistent, owing to inefficiencies in public procurement and outright corruption (Pritchett 2000, Keefer and Knack 2007). Furthermore, investment may not translate into commensurate increases in the supply of infrastructure services because of inefficiencies in the selection and implementation of projects or the absence of high-quality projects in the pipeline (Kilby 2013). These limitations do not apply to physical measures of infrastructure, which may be the reason why studies based on them are more conclusive than those based on monetary measures of infrastructure.

Finally, there is little systematic information on access to, and affordability of, infrastructure services for different percentiles of the income distribution, whether over time or across countries. This makes it very hard to reach robust conclusions regarding the consequences of infrastructure development for the equality of opportunities and incomes across households. Researchers have resorted to aggregate data on access – that is, without a breakdown across income percentiles – under the implicit assumption that changes in access at the margin affect primarily the poorer segments of the population, but this may not always be the case. More fundamentally, even aggregate access figures are available only for a limited number of countries, in most cases without any geographic disaggregation, and only for recent years.

Identification remains a thorny issue. The impact of infrastructure supply on growth that empirical studies aim to estimate may be confounded with increased demand for infrastructure services prompted by rising levels of income (Canning and Pedroni 2008). Analogously, while infrastructure may help reduce inequality, at the same time inequality may hamper the provision of infrastructure services to the poor. The reason is that more unequal societies devote fewer resources to the provision of public goods, including infrastructure (Alesina, Baqir and Easterly 1999). Failure to account for these forms of simultaneity can lead to overestimation of the effects of infrastructure on growth and equity. More broadly, other unobserved factors affecting both development outcomes and infrastructure accumulation may likewise lead to biases.

There is no easy solution for this problem. In theory, one could base inference on the estimation of a full structural model. However, that approach poses difficult specification choices and challenging data requirements. Esfahani and Ramírez (2003) and Cadot, Roller and Stephan (2006) present two-equation models that jointly describe the aggregate production function and the accumulation of infrastructure. The former paper highlights the role of institutional factors for accumulation decisions in a cross-country setting, while the latter puts emphasis on the political economy of investing in transport routes across French provinces. Both papers find that the contribution of infrastructure services to GDP more than exceeds the cost of providing them. Interestingly, Cadot, Roller and Stephan (2006) find that the estimated elasticity of output with respect to infrastructure (around 0.08-0.09) remains invariant regardless of whether one accounts for the likely endogeneity.

Another option recently used by Calderón, Moral-Benito and Servén (2014) in a panel time-series setting is to establish the existence of a single cointegrating relation between infrastructure, aggregate output, and other production inputs, which can then be interpreted as the aggregate production function. If infrastructure and the other productive inputs do not react systematically to temporary deviations from the long-run relation, its parameters can be estimated by conventional single-equation methods (even if the parameters characterizing the short-run dynamics cannot). Formal exogeneity tests confirm that this is the case,⁷ and the estimation places the long-run elasticity of output with respect to a synthetic index of infrastructure in the range 0.08-0.10.

A third alternative is to use an instrumental variable approach, ideally featuring external instruments for infrastructure. In this vein, Calderón and Servén (2003, 2004) employ demographic variables as instruments, alone or in combination with internal instruments, in a GMM panel framework. Roller and Waverman (2001) follow a similar approach.

Recent microeconomic studies concerned with the impact of public infrastructure interventions have used randomized control trials (RCTs) to establish causality. This approach enables researchers to assess whether any changes observed in the population are due to the public infrastructure program, exogenous factors, or unmeasured individual effects. RCTs isolate the impact of interventions by randomly assigning individuals to treatment and control groups. In this vein, several studies have examined the impact of improved water and sanitation on health outcomes (Capuno et al. 2011, Andrés et al. 2014). A limitation of this approach, however, is that the findings may depend on the specific context and time frame in which the experiment is conducted, so evidence of a successful policy intervention might not be relevant to other cities, regions or countries.

Lastly, *heterogeneity* is also a major concern. The contribution of infrastructure to development outcomes may vary across countries and over time for multiple reasons —starting with the heterogeneous quality of infrastructure assets and services themselves. However, few studies take into account the quality dimension, in large part due to data limitations. Hulten (1996) finds that differences in the effective use of infrastructure resources explain one-quarter of the growth differential between Africa and East Asia, and more than 40 percent of the growth differential

⁷ In contrast, Canning and Pedroni (2008) find the opposite result in a similar setting, although their framework excludes non-infrastructure production inputs.

between low- and high-growth countries. Rioja (2003) likewise finds that poor infrastructure quality imposes large output and welfare costs across Latin American countries. Calderón and Servén (2004, 2010a,b) and Seneviratne and Sun (2013) find significant growth effects of a synthetic indicator of infrastructure quality in an empirical framework including also the quantity of infrastructure.

Aside from asset quality, variation across space and time in the effects of infrastructure could arise from many other sources – e.g., network effects that create nonlinearities in the output contribution of infrastructure, institutional factors that constrain the efficient use of infrastructure assets, and so on. This is especially relevant for studies of the effects of specific infrastructure interventions, because their findings may reflect a host of unmeasured (or hard-to-replicate) factors particular to the intervention under consideration.

Assessments of heterogeneity are not abundant in the empirical literature. As an exception, Calderón, Moral-Benito and Servén (2014) test for parameter heterogeneity in a large cross-country sample, using an infrastructure-augmented production-function framework. Their tests consider heterogeneity across countries both of unrestricted form – affecting the parameters of infrastructure or any other input – as well as heterogeneity in the effects of infrastructure related to specific country features. These include the level of per capita GDP, the extent of infrastructure development, and the size of population – to capture network and congestion effects, respectively. All these tests fail to reject homogeneity. The implication is that, other things equal, the percentage increase in real GDP (or its growth rate) that results from a given percentage increase in the availability of infrastructure does not vary much across countries. In the paper’s setting, this means that the marginal productivity of infrastructure is higher, other things equal, where the (relative) stock of infrastructure is lower.

5. Final remarks

In spite of the above caveats, the balance of empirical research does reveal a positive contribution of infrastructure development to aggregate income. In itself, this just confirms that the marginal productivity of infrastructure capital is positive. But there has been also some convergence in quantitative estimates of its magnitude, to levels generally much lower than those found in the earlier macro literature. Still, the precise mechanisms at work remain understudied –

including for example the role of infrastructure quality, the extent of crowding-in effects, and the significance of the TFP channel of transmission. Furthermore, in contrast with the effort devoted to quantify the output impact of infrastructure, research has paid much less attention to the costs of infrastructure development. As a consequence, there are few empirical results regarding the extent to which different infrastructure services may be over- or under-provided across countries or regions. In this context, one key ingredient in need of more attention is the fragile link between infrastructure expenditures and the accumulation of infrastructure assets or the provision of services, and especially how such link is shaped by institutional and political economy factors.

In turn, the more limited research on the distributional implications of infrastructure development offers some suggestive evidence of an equity-enhancing effect. The analytical literature has proposed a number of specific mechanisms, but evidence on their actual relevance is, in most cases, still sketchy. Data limitations bear much of the blame. Infrastructure development should affect poorer households primarily by improving their access to affordable services. However, the limited information available on access and affordability for households at different percentiles of the income distribution represents a major obstacle to progress in establishing the consequences of infrastructure development for inequality and, therefore, its overall contribution to poverty reduction.

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