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The Impact of Infrastructure on Development Outcomes

A Qualitative Review of Four Decades of Literature

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Abstract

Policy makers have long used investing in public infrastructure as a means of reducing geographical disparities and promoting growth. The goal of this paper is to provide insights to development practitioners on designing interventions to maximize the development impact of infrastructure. For this, the paper presents a systematic qualitative overview of the literature, covering more than 300 studies conducted between 1983 and 2022, focusing on specific infrastructure sectors, namely digital, energy, and transport. The study also considers various dimensions of development impact, including output and productivity, poverty and inequality, labor market outcomes, human capital formation, and trade, to develop a nuanced understanding of the mechanisms through which infrastructure contributes to these development outcomes, focusing on low- and middle-income countries. As such, it is the most substantive effort of its kind to date. Overall, despite some mixed results, the overwhelming balance of evidence suggests that infrastructure improvements are critical in supporting the development process. Studies on digital infrastructure show that firm productivity, employment, and welfare increase with the arrival of broadband internet coverage. In addition, the availability of mobile phones improves coordination between producers and traders and hence reduces the price dispersion of agricultural products. Turning to rural electrification, significant literature documents the positive impact of infrastructure on household welfare, structural transformation, and human capital formation through increased labor force participation, more time spent on education, and increased indoor air quality. Investments in the reliability of power supply also contribute to firms' productivity. However, studies based on randomized controlled trials have not tended to find a substantial short-term impact in the context of dispersed rural populations. Finally, there is rich literature on various transport infrastructure-to-development linkages, particularly for rural roads and for Sub-Saharan Africa. While households' income and consumption benefit from the existence of rural roads, highways are also found to contribute to firms' competitiveness. Similarly, public transportation, railways, and ports have positive impacts on the development process.

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The Impact of Infrastructure on Development Outcomes: A Qualitative Review of Four Decades of Literature

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1. Introduction

That modern infrastructure is a prerequisite for economic development seems almost a truism and one that is widely accepted by politicians around the world. However, rigorous measurement of the causal relationship between infrastructure and development has proved challenging for economists, due to methodological difficulties in unravelling the direction of causation exacerbated by significant data limitations. Attempts to answer this question began in the 1980s and relied primarily on high-level cross-country panel data econometrics incorporating rather coarse proxies for infrastructure quantity (and sometimes) quality (Straub, 2008). Since 2010, however, there have been significant methodological innovations as well as new sources of data, spawning an unprecedented volume of empirical microeconomic research often exploiting economic geography approaches and spatially granular data. This second wave of literature provides a much more parsimonious analysis of the specific channels through which specific types of infrastructures contribute to specific dimensions of the development process. It has also resulted in a notable expansion in the volume of studies available that look specifically at the developing world.

The purpose of this paper is to provide a systematic qualitative overview of this more novel microeconomic literature covering over 300 research papers focusing primarily on specific infrastructure sectors, especially in developing countries. While the dataset covers studies conducted between 1983 and 2022, more attention is given to the period since 2010, during which an increasing volume of studies has looked at how different types of infrastructure drive microeconomic development outcomes. As such, it is the most substantive effort of its kind to date. The paper is targeted primarily at development practitioners, and hence the emphasis is on surfacing the insights these papers provide regarding the underlying processes through which infrastructure drives development outcomes. These include household welfare, employment, and human capital, as well as firm-level productivity, output, job creation, and trade; but, also, the impact on spatial patterns of economic activity in the urban and rural spheres. Such insights are relevant to inform the selection and design of investments and policy interventions. A forthcoming companion paper (Foster et al, 2023)[1] reviews the same body of literature from a more quantitative perspective, conducting an econometric meta-analysis to define the magnitude of impacts that emerge from the literature, and pinpoint the contextual and methodological factors that drive the empirical results.

The remainder of the paper is structured as follows. Section 2 describes the methodological framework and selection criteria for papers, providing a brief overview of the literature coverage.

[1] The two companion papers are based on the same initial database with some different selectivity criteria between this paper and Foster et al (forthcoming, 2023). The latter focuses on a subset of papers reporting infrastructure elasticities as well as considers additional papers focusing on elasticities.

Sections 3 to 5 discuss the central findings of the literature for digital, energy, and transport infrastructures, respectively. Section 6 draws out the main findings and conclusions of the review.

2. Methodology and Literature Review

The systematic literature review process followed standard procedures that can be briefly described as follows: identifying studies that meet the search criteria and coding the attributes of eligible studies into a database (Seuring and Müller, 2008; Stanley and Doucouliagos, 2012). The analysis aims not only at papers published in peer-reviewed journals, but also working papers with a focus on policy-relevant work, excluding solely theoretical papers. Studies focusing on types of infrastructure other than digital, energy, and transport were not considered (e.g. water). While the focus is almost entirely on studies covering low- and middle-income countries, where there is a more limited knowledge base, some seminal studies of high-income economies are also briefly cited to provide a wider context. The keywords used to identify suitable studies include “infrastructure”, “digital”, “energy”, and “transport”, each in combination with "development” and/or “growth”.

An important starting point was to incorporate existing literature review and meta-analysis papers. The first set of papers identified – García et al (2017); Bom and Ligthart (2014); and Straub (2008) – take more of a cross-cutting view of infrastructure and focus on its impact on overall economic output, as opposed to different dimensions of development. In addition, the process identified literature review papers focusing more narrowly on transport, energy, and digital infrastructures. This group includes the works of Burgess et al (2020), Greenstein (2020), Lee et al (2020), Redding and Turner (2015), Redding and Rossi-Hansberg (2017), and Vergara-Cobos and Malasquez (forthcoming). An overview of the most relevant literature review articles surveyed is provided in Table 1.

Beyond these literature reviews, the search for related publications was mainly conducted as a structured key word search, drawing on major public databases such as Elsevier (www.sciencedirect.com), Springer (www.springerlink.com), and Wiley (www.wiley.com), as well as databases developed by various institutions such as the World Bank, the Bureau of Economic Analysis, International Monetary Fund, and the World Economic Forum of the Organization for Economic Cooperation and Development. Cited references from papers found in the initial search were also used as a secondary source of literature. Although the search was carried out in English, papers written in other languages were also reviewed, if they were cited in the selected literature review papers. Finally, to ensure that more recent (as yet unpublished) research was captured by the review, a global call for new papers on this theme was conducted in preparation for the 2022

Infrastructure for Development (Infra4Dev)[2] Conference, organized jointly by the World Bank and the International Growth Centre at the London School of Economics and Political Science.

Table 1: Survey of existing literature reviews on infrastructure and development

Author(s)	Relationship between …	No. of studies	Period (publication)
General infrastructure papers			
Foster et al (forthcoming, 2023)*	infrastructure and development	201	1983 - 2022
Attigah & Mayer-Tasch (2013)	electricity access and economic growth	79	1986 - 2012
Bertschek et al (2016)	broadband and economic growth	52	1991 - 2016
Bom & Ligthart (2014) *	public capital and private sector production	68	1983 – 2008
Celbis et al (2015) *	infrastructure and trade	36	1999 – 2012
Elburz et al (2017) *	public infrastructure and regional growth	42	1995 – 2014
Garcia et al (2017) *	infrastructure and economic growth	150	1993 – 2015
Nijkamp & Poot (2004) *	public infrastructure and long-run growth	93	1983 – 1998
Pereira & Andraz (2013)	public investment and economic growth	143	1985 - 2010
Schweiki & Obermaier (2019)	IT investment and firms' productivity	86	1985 - 2018
Straub (2008)	infrastructure and development	77	1989 - 2007
Timilsina et al (2020)	infrastructure, growth, and poverty reduction	105	1970 - 2020
Vagliasindi and Gorgulu (2021)	Infrastructure, employment, and income	170	1958 - 2021
Sector-specific papers			
Melo et al (2013) *	productivity and transport infrastructure	33	1988 – 2007
Redding and Turner (2015)	spatial distribution of economic activity and transport costs	105	1958 - 2014
Redding and Rossi-Hansberg (2017)	economic geography and development with a focus on transport infrastructure	126	1967 - 2016
Burgess et al (2020)	treating electricity as a right and universal access to reliable electricity	44	1955 - 2019
Greenstein (2020)	internet infrastructure and development	50	2005 - 2020
Lee at al (2020)	household electrification and economic development	47	1994 - 2020
Vergara and Malasquez (forthcoming, 2023)	digital technology adoption, jobs, and economic transformation	112	2003 - 2021

Source: Compiled by the authors. Note: * represents studies using meta-analysis techniques.

While the companion Foster et al (forthcoming, 2023) paper focuses on a subset of papers reporting infrastructure elasticities, in sum, a total of 300 papers were identified as meeting the criteria for this literature review[3], with the majority (just over 60 percent) published in the period post-2010. Of these, approximately two-thirds have been included across a variety of existing literature reviews, and the remainder were identified from other relevant and/or more recent

[2] https://www.worldbank.org/en/events/2021/11/19/infra4dev-2022

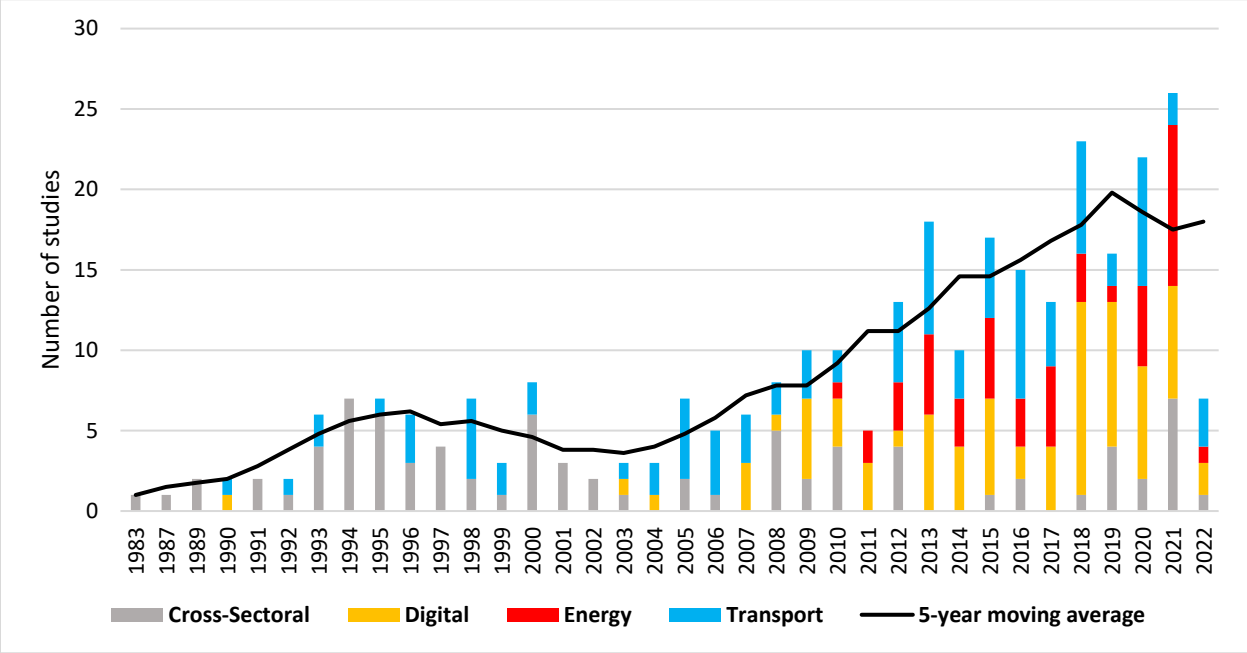
[3] While the papers included in the data set are shown by an asterisk, the papers actually used in this literature review are identified by a double asterisk in the references.

sources not previously covered. The combination of all these sources makes this review among the largest and most thematically comprehensive undertaken. In contrast to earlier work, the review will focus mainly on specific types of infrastructure – namely energy, digital, and transport – and specific dimensions of development impact – such as output and productivity, poverty and inequality, labor market outcomes, human capital formation, and trade. In this way, the paper seeks to develop a more nuanced understanding of the pathways through which infrastructure contributes to the development process. To avoid publication bias, the corpus of papers contains a significant number of unpublished working papers and reports. Nevertheless, about 70 percent of the papers are published in peer reviewed journals, and 80 percent include at least one academic co-author.

Following the selection of the papers, their most salient characteristics were recorded in a database, from which it is possible to obtain a descriptive overview of the literature under review. What emerges very clearly is the large and sustained increase in the volume of research addressing infrastructure and development linkages since 2005, with over 60 percent of the articles considered being published in the last decade, 2011-2021 (Figure 1). However, in terms of the historical period analyzed within these papers, two-thirds relate to data representing the period 1980-2000 (e.g., Bogart, 2009; Burgess et al, 2010; Haines and Margo, 2006), while only around one-third is based on post-2000 data (e.g., Aggarwal et al, 2018; Rodríguez-Castelán et al, 2022). About 70 percent of the studies are based on longitudinal data exceeding one decade in length.

Over time, there has also been a noticeable shift from articles focusing on cross-sectoral infrastructure broadly defined, to research that examines specific types of energy, digital and transportation literature, again primarily during the last decade (Figure 1). From 2010 the literature became more oriented towards micro-economic approaches, exploiting increasingly granular data that is often spatially explicit. In particular, the availability of satellite images, maps, and georeferenced surveys allows for a much higher degree of resolution in examining infrastructure and development linkages. This has allowed the literature to examine a broader range of development impact variables, with household welfare captured through expenditure, employment status, wages, human capital formation, or poverty and inequality, and firm performance captured through output, exports, or productivity. Moreover, spatially disaggregated data allows local output to be captured at the municipality, district, or city level. Nevertheless, just under half of the studies identified are still concerned with investigating the impact of broad infrastructure aggregates on macroeconomic measures of output.

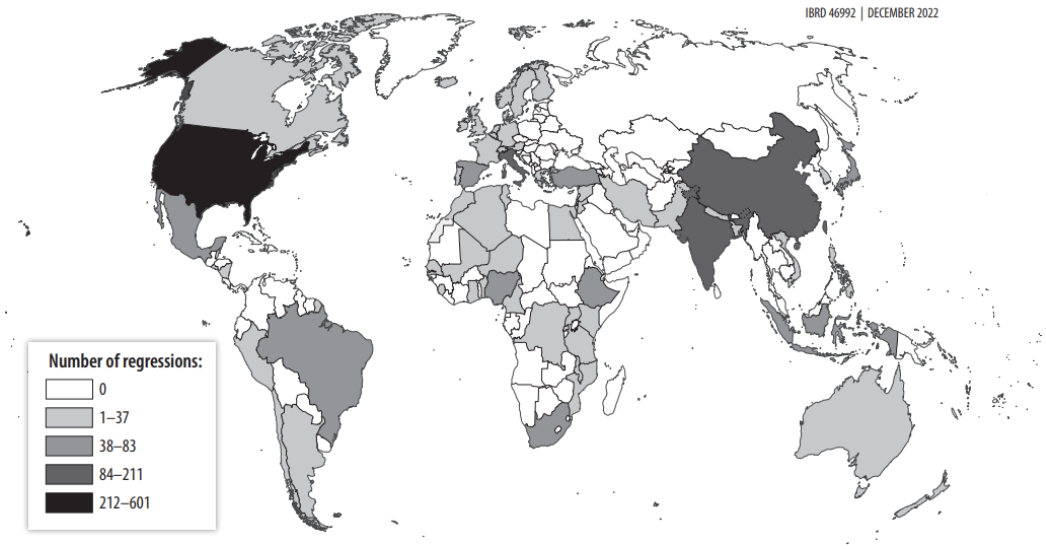
Figure 1: Evolution of number and focus of studies on development impact of infrastructure



Source: Authors' calculation. The number of papers in 2022 represents the first quarter in which the literature search process ends for this research.

When it comes to the geographic focus of the literature, 40 percent of the studies focused on developed countries, while 47 percent of them studied the impact of infrastructure investments on the growth of developing countries, and the remainder are global in reach encompassing both developed and developing economies (Figure 2). About two-thirds of the studies focus on the impact of infrastructure on development in a single country, with the remainder being cross-country studies. By far the most widely studied countries, as shown on the map, are the United States, India and China; although there has also been significant coverage for Ethiopia, Nigeria, South Africa, Spain, Türkiye and Brazil. The literature on developing countries focuses primarily on those in the middle-income bracket, with a reasonable spread across continents. The paucity of data is likely an impediment to research on low-income economies. While this literature review will briefly reference studies covering developed countries to provide a wider context, the main focus of the exposition will be on those studies that feature low- and middle-income countries.

Figure 2: Geographic coverage of studies on a single country



Source: Authors' elaboration.

3. Development Impact of Digital Infrastructure

A substantial literature on the development impact of digital technologies in OECD countries finds significant positive effects on economic growth, job creation and consumer welfare; although the impacts on firm productivity have been harder to gauge. An early study by Roller and Waverman (2001), for instance, finds that about 33 percent of per capita gross domestic product (GDP) growth in 21 OECD countries for the 1970 – 1990 period can be attributable to investments in telecommunications infrastructure. Subsequently, an increasing number of macroeconomic analyses have confirmed the contribution of broadband penetration in spurring economic growth in the European Union and OECD countries (Castaldo et al, 2018; Czernich et al, 2011; Koutroumpis, 2009). In addition, Crandall et al (2007) and Gillet et al (2006) show that the availability of broadband connections speeds up employment growth in the United States.

However, when it comes to the role of broadband internet technology in firms' productivity in advanced economies, the results are mixed. As an example, while Colombo et al (2013) find that the impact of the adoption by Italian small and medium-sized enterprises of basic broadband applications is negligible, Grimes et al (2012) find that broadband connections do increase firms' productivity in New Zealand. Similarly, van Reenen et al (2010) explain the gap between the levels of U.S. and EU output per worker in terms of the U.S. ICT production and market services sector. Finally, mobile broadband, such as that provided to smartphones, has important welfare effects. Rennhoff and Routon (2016) find that the introduction of smartphones increases consumer welfare in the United States by approximately $426 per consumer annually. This is mainly due to access to expanded consumer choice sets, which account for more than half of the welfare gain.

When it comes to developing countries, most of the papers reviewed in this section indicate a positive and significant relationship between economic development and the expansion of digital technologies. ICT use and technology adoption are also associated with positive effects on household welfare (Bahia et al, 2020; Masaki et al, 2020), and firms' productivity, organization, and labor demand (Abreha et al, 2021; Atiyas and Dutz, 2021; Iacovone and Pereira – Lopez, 2018), as well as employment (Hjort and Poulsen, 2019). Studies also show that access to cellphone coverage improves output (Edquist et al, 2018; Haftu, 2019), human capital (Aker et al, 2012), employment (Klonner and Nolen, 2010)), as well as welfare in terms of greater consumption and a reduction of poverty (Blumenstock et al. 2020; Klonner and Nolen 2010), while also reducing price dispersions (Aker, 2010; Aker and Fafchamps, 2015). A more recent strand of the literature highlights also the political role of digital technologies in facilitating collective action, although not always with positive consequences (Manacorda and Tesei, 2020; Pierskalla and Hollenbach, 2013). Perhaps contrary to prior expectations, the findings of this emerging literature suggest that broadband internet coverage is not only relevant to affluent households and skilled workers but can in the context of developing countries bring about welfare improvements for poorer households and less-skilled workers.

Table 2 provides an overview of which types of linkages between digital technology and development have been studied at the country level for emerging economies. The table illustrates that this literature is still relatively sparse in terms of individual country coverage, and is largely focused on Sub-Saharan Africa. These papers will be further discussed below, where a more detailed tabulated summary of the papers is also provided for internet adoption (Table 3) and mobile phones (Table 4).

Table 2: Overview of coverage of the thematic and geographic coverage of the literature on the development impact of digital infrastructure in developing countries

	Development Indicators				
	Food security	**Poverty/ Inequality**	**Jobs/ Employment**	**Education**	**Conflict**
Sub- Saharan Africa					
Cross- Country			Internet Coverage, Mobile Phones		Mobile Phones
Ethiopia			Internet Coverage		
Niger	Mobile Phones			Mobile Phones	
Nigeria		Internet Coverage	Internet Coverage		
Senegal		Internet Coverage	Mobile Phones		
South Africa			Mobile Phones		
Latin America and the Caribbean					
Mexico			Internet Coverage		
South Asia					
India	Mobile Phones				

Source: Compiled by the authors.

3.1 Internet Coverage

Hjort and Poulsen (2019) were among the first to exploit the arrival of submarine internet cables between 2000 and 2010 in Africa by using a difference-in-differences estimation to show the impact of fast internet on employment. They find that the probability that an individual is employed increases between 3.1 and 13.2 percent when fast internet becomes available. In all nine countries covered by relevant household surveys (Benin, Ghana, Kenya, Madagascar, Mozambique, Nigeria, Senegal, Tanzania, and South Africa), the probability of being employed in a skilled occupation increases, but the probability of holding an unskilled job is statistically unaffected when fast internet becomes available. While the impact on the overall process of structural change is likely modest, fast internet appears to shift employment shares towards higher-productivity occupations. The average incomes rise in the areas that see changes in employment when fast internet arrives. Overall, the results imply that expanded access to lower cost ICT resulting from the availability of fast internet increases employment rates in Africa, and that in at least some countries, this happens in part due to the technology's impact on increasing firm entry, raising firm productivity, and facilitating participation in export markets.

More recently, Masaki et al (2020) identify the relationship between access to broadband internet and household welfare. This research is based on household surveys conducted in Senegal in 2011 and 2018, which provide data on household consumption and poverty level as a proxy for welfare. Addressing the concern of endogeneity by employing two-stage least squares (2SLS) regression analysis (using as an instrument the distance to 3G coverage in neighboring areas outside the immediate vicinity of a given area), the results show that mobile broadband coverage is associated with greater household consumption and reduced poverty incidence, both in rural and urban areas, though to a greater extent in the latter. The total consumption of households with 3G coverage is about 14 percent greater than the consumption of households without 3G coverage. Similarly, 3G coverage is associated with a 10 percent decline in the extreme poverty rate, based on a poverty line of $1.9 per day. In addition, the analysis finds a positive correlation between 3G coverage and salaried employment (although no significant impact on overall employment) and monthly earnings, supporting the hypothesis that digital technologies can increase employment in "better" jobs.

Bahia et al (2020) conduct a similar difference-in-differences analysis of the impact of mobile broadband coverage on consumption and poverty, this time in Nigeria between 2010 and 2016. Again, mobile broadband coverage had large and positive impacts on household consumption levels. Households that had at least one year of mobile broadband coverage experienced an increase in total consumption of about 6 percent. These beneficial effects were found to increase over time, albeit at a decreasing rate. Mobile broadband coverage also reduces the proportion of households below the poverty line by about 4.3 percentage points for extreme poverty and

2.6 percentage points for moderate poverty after one year of gaining mobile broadband coverage. Households in areas covered by mobile broadband internet witnessed an increase in labor force participation and wage employment of about 3.3 and 1.4 percentage points, respectively, with these effects materializing more slowly after three or more years of coverage.

Turning to Latin America, Iacovone and Pereira – Lopez (2018) study the effects of ICT adoption on Mexican firms' labor structure and wages between 2008 and 2013 by using an Instrumental Variable technique (based on the interaction between the ICT-intensity classification of sectors, the average elevation of the municipality, and the coefficient of variation of locality elevations). ICT adoption increased labor demand for white-collar workers in the manufacturing sector, such that a 10-percentage point increase in ICT use is associated with a 12 percent increase in the number of white-collar workers. At the same time, no resulting differences were observed in the wage gap between white-collar and blue-collar workers, whether in the manufacturing or services sectors. However, a change of 10 percentage points in the share of labor that uses computers is associated with a change of 0.024 in the ratio of white-collar to blue-collar workers (which is about 10 percent of the mean value for this ratio). The authors explain the results in the manufacturing sector in terms of the increasing sophistication of blue-collar workers, as a direct result of the adoption of digital technologies, due to greater availability of information and improved training opportunities. Thus, Iacovone and Pereira – Lopez (2018) find that promotion of ICT use can be an effective tool, not only to enhance a firm's productivity, but also to reduce wage inequality between workers.

Table 3: Survey of selected papers on the development impact of internet coverage

Author	Level of Analysis	Country/ Region	Development Indicators	Main Finding(s)
Hjort and Poulsen (2019)*	Households	Africa	Jobs	The probability of employment increases by 3 to 13 percentage points with access to fast internet, with a shift towards higher skilled occupations.
Masaki et al (2020)+	Households	Senegal	Consumption, Poverty	3G coverage is associated with a 14% rise in household consumption, a 10% decline in extreme poverty, and more salaried employment.
Bahia et al (2020)+	Household	Nigeria	Consumption, Poverty, Jobs	3G coverage is associated with a 6% rise in household consumption, a 4% decline in extreme poverty, and higher better-paid employment.
Abreha et al. (2021)	Firms	Ethiopia	Jobs, Production	Firms with enhanced internet access tend to hire 23-26% more workers compared to firms in areas without 3G. This translates into more formal employment and wages. Similarly, firms in areas with 3G experience a 17-18% increase in total factor productivity.
Iacovone & Pereira -López (2018)*+	Firms	Mexico	Jobs, Wages	A 10-percentage point increase in ICT use is associated with a 12 percent increase in the number of white-collar workers.

Source: Compiled by the authors. Note: Findings column is based on the main finding of the paper. Asterisk identifies papers published in peer-reviewed journals. Plus identifies papers following the instrumental variable approach.

3.2 Mobile Telephony

Mobile broadband is the dominant channel through which people access the internet in many developing countries. In a global cross-country study, Edquist et al (2018) analyze the impact of mobile broadband diffusion on GDP between 2002 and 2014 by using a difference-in-differences model and show that a 10 percent increase in mobile broadband adoption boosts economic growth by creating a 0.6 to 2.8 percent increase in GDP. Similarly, Williams et al (2012) show that a 10 percent substitution from 2G to 3G increases GDP per capita growth by 0.15 percentage point in a cross-country study including Brazil, Canada, China, France, Germany, India, Italy, Japan, the Republic of Korea, Mexico, the Russian Federation, South Africa, the United Kingdom, and the United States. Haftu (2019) also analyzes the impact of mobile phones and the internet on per capita income in 40 Sub-Saharan African countries for the period of 2006 – 2015. A 10 percent increase in mobile phone penetration results in a 1.2 percent change in GDP per capita. Internet penetration, on the other hand, appears not to contribute to per capita GDP, potentially due to low technology penetration, low skills, lack of sufficient local content, and the relatively immature state of the technology in the continent.

Beyond macroeconomic effects, the widespread growth of mobile phone coverage in many developing countries has the potential to contribute to human development outcomes through the improvement of education outcomes. Aker et al (2012) look at the impacts of an adult education program in 113 villages in Niger. The goal of the program is to teach students how to use mobile phones, which enables them to practice their literacy skills outside class by sending and receiving text messages, making phone calls, and using mobile money applications. Adults in villages in which an education program was offered were tested immediately after the program and received test scores in writing and mathematics that were 0.19 – 0.26 standard deviations higher than those that did not participate. Moreover, standardized math test scores remained higher seven months after the end of the program. These results suggest that simple information technology can be harnessed to improve educational outcomes and build skills even among remote rural populations.

Mobile phone technology also contributes to labor market outcomes. Klonner and Nolen (2010) study the labor market effects of the rollout of mobile phone coverage from 1995 to 2000 in rural South Africa. The findings show that localities that received network coverage experienced a 15-percentage point increase in employment, primarily among women no longer burdened with large childcare responsibilities. The authors also find a significant shift in occupational patterns in rural areas; with agricultural employment decreasing substantially, especially among males.

Mobile connections not only accelerate economic growth but also improve inequality in the income distribution. Using panel data of 177 countries for the period 1990 – 2019 and GMM-

Instrumental Variable techniques, Calderon and Cantu (2021) find a causal, positive and significant impact of digital infrastructure on economic growth. When considering the connections of 3G and 4G technologies jointly, a 10-percentage point increase in the number of connections would result in a 0.23 percentage increase in the growth of output per worker. Both capital accumulation and total factor productivity play a role. In addition, arrival of new technologies reduces the inequality in income distribution (measured by the Gini coefficient). A 10-percentage point increase in the joint expansion of 3G and 4G connections per capita results in a decline in the Gini coefficient of 1.35 percent. The growth benefits are largest in African countries. The study also finds that investments in complementary factors, such as human capital (skills) and other infrastructure (electricity), is necessary to gain the full benefit of digital infrastructure for development.

The rapid spread of mobile phone coverage reduces the costs of obtaining information about local market conditions, enabling consumers and producers to connect rapidly and at lower cost (Aker and Mbiti, 2010). Aker (2010) estimates the impact of mobile phones on consumer price dispersion across local grain markets for millet in Niger between 2001 and 2006 by using a difference-in-differences model. The introduction of mobile phone service explains a 10 to 16 percent reduction in consumer price dispersion, as a result of reduced search costs. The effect is stronger for market pairs with higher transport costs, such as for more remote localities and those connected by unpaved roads. The effect is also larger when a higher percentage of markets have coverage, suggestive of network externalities. These results show that mobile phone infrastructure can have positive spillover effects on markets but cannot replace investments in other infrastructure necessary for sustainable development, such as upgrading of rural roads.

A subsequent investigation examines whether mobile phones are also effective in improving market efficiency for producers as well as consumers. Still in Niger, Aker and Fafchamps (2015) estimate the impact of mobile phone coverage on producer price dispersion for three commodities with varying perishability, namely millet, sorghum, and cowpea, between 1999 and 2008. With mobile phone coverage, spatial producer price dispersion decreased by 6 percent for cowpea, a semi-perishable commodity. These impacts get stronger for remote markets and during certain periods of the year. Producer price dispersion for millet and sorghum, on the other hand, was not impacted by the introduction of mobile coverage. The authors attribute this to the fact that these two staples are less perishable and are usually stored by farmers. Although the introduction of mobile phones generates net efficiency gains in agricultural markets, understanding whether these gains translate into higher average prices for the primary suppliers of agricultural commodities is also important.

Table 4: Survey of selected papers on the development impact of mobile phone adoption

Author	Level of Analysis	Country/ Region	Development Indicators	Main Findings
Edquist et al (2018)*+	Country	Global	Economic Growth	A 10% increase in mobile broadband adoption leads to an increase in economic growth of between 0.6-2.8 percentage points.
Williams (2012)+	Country	14 countries in various income groups	Economic Growth	A 10% substitution of 2G with 3G in mobile broadband adoption leads to an increase in economic growth of 0.15 percentage points.
Haftu (2019)+	Country	Africa	GDP	A 10% increase in mobile phone penetration results in a 1.2% change in GDP per capita.
Calderon and Cantu (2021)+	Country	Africa	GDP, Gini	A 10-percentage point increase in the number of broadband-capable connections (3G+4G) would enhance the growth rate of output per worker by 0.23 percentage point per year, and lead to a decline in the Gini coefficient of 1.35 percent.
Atiyas and Dutz (2021)	Firm	Senegal/ Africa	Employment, Productivity	The use of 2G mobile phone is significantly positively associated with employment, productivity, and sales.
Klonner and Nolen (2010)+	Municipality	South Africa	Employment	Employment increases by 15 percentage points when a locality receives network coverage.
Aker et al (2012) *	Individual student	Niger/ Africa	Education	Students in villages that received training on use of basic mobile phones achieved higher test scores in both writing and mathematics.
Aker (2010) *	Localities	Niger/ Africa	Food Security	The introduction of mobile phone service explains a 10 to 16 percent reduction in spatial consumer price dispersion for millet grains.
Aker and Fafchamps (2015) *	Market	Niger/ Africa	Food Security	Mobile phone coverage reduces spatial producer price dispersion, with strongest effect for perishable crops in remote locations.
Jensen (2007) *	District	India/ South Asia	Food Security	The adoption of mobile phones led to a dramatic reduction in price dispersion for fish, improving producer and consumer welfare.
Manacorda and Tesei (2020) *+	Country	Africa	Social Capital: Protests	Civic protests per capita when GDP falls, increased by 8-23 percent in localities with full 2G coverage compared to those with none.
Pierskalla & Hollenbach (2013) *+	Geospatial pixels	Africa	Social Capital: Conflict	The availability of cell phone coverage significantly and substantially increases the probability of violent conflict.

Source: Compiled by the authors.

Note: Findings column is based on the main finding of the paper. * represents peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

These findings indicate that the impact of technology can differ substantially by the type of crop, the type of market, and the time of year, even within the same country. The importance of perishability in determining how ICT will affect agricultural market pricing dynamics is confirmed by Jensen's 2007 study which investigates the major fishing industry in the Indian state of Kerala. Mobile coverage was introduced in Kerala between 1997 and 2001, and the adoption of mobile

phones by fishermen and wholesalers is associated with a dramatic reduction in price dispersion, and increased market efficiency, given the high degree of perishability of fish. As a result, both consumer and producer welfare increased. The overall net effect is positive on the producer side, with profit increases coming from the changes in the price and quantity sold in the market, partially offset by the costs associated with mobile phones and increased travel to take advantage of arbitrage. On the consumer side, prices decrease on average with the introduction of mobile phones.

Finally, mobile phone coverage also has the potential to trigger collective action as well, by enabling people to acquire and spread information about living conditions and to organize a civic response. Manacorda and Tesei (2020) test whether mobile phone technology has the potential to foster mass political mobilization and explore the underlying channels of impact in the context of Africa between 1998 and 2012. The results show that a fall in national GDP growth of 4 percentage points leads to a differential increase in protests per capita of between 8 and 23 percent, comparing areas with full 2G mobile phone coverage to those that have none. In a similar vein, Pierskalla and Hollenbach (2013) investigate the impact of cell phone technology on violent collective action in Africa. The availability of cell phone coverage significantly and substantially increases the probability of violent conflict by improving cooperation and coordination within rebel groups in the continent.

4. Development Impact of Energy Infrastructure

There is a strong link between energy and economic development. Many studies on advanced economies focus on the historical impact of grid access on rural households. Electrification increases demand for labor in the rural areas in the United States (Kitchens and Fishback, 2015), provides workers with stronger bargaining power in Sweden (Molinder et al, 2021), and drives structural change through the decline of employment share in agriculture in the United States (Gaggl et al, 2021) and Norway (Leknes and Modalsli, 2020). Lewis and Severnini (2020) show that the rural U.S. counties with early access to electricity experienced increased economic growth compared to their counterparts. This impact persisted decades after the county was fully electrified. Electrification also has long-lasting effects on the productivity of firms. Using city-industry level data from the United States for the years 1890 – 1940, Fiszbein et al (2020) show a rapid increase in the labor productivity rates in the manufacturing sector.

As in developed economies, electricity is a key input to producing goods and services and improving the quality of life in developing countries. Therefore, achieving universal access to electricity is an important policy goal for developing countries. Despite large investments, relatively little is known about the causal effects and channels of electrification on economic outcomes, such as on household welfare, firm productivity, or economic growth. This section

reviews the socioeconomic impact of energy infrastructure with a focus on the electrification of rural households and improvements in the reliability of supply for both firms and households. Electrification contributes positively to agricultural production (Rud, 2012), structural transformation (Akpandjar and Kitchens, 2017; Herrera Dappe and Lebrand, 2021; Perez-Sebastian et al, 2020; Rud, 2012), and employment (Carlowitz, 2021; Dinkelman, 2011; Grogan and Sadanand, 2013; Lipscomb et al, 2013). In addition, studies show that electrification improves health and education outcomes (Barron and Torero, 2014; Barron and Torero, 2015; Khandker et al, 2013), lowers out-migration from villages (Fried and Lagakos, 2021) as well as increases households' income, consumption, and welfare (Chakravorty et al, 2016; Khandker et al, 2013; van de Walle et al, 2017; Ratledge et al, 2022). However, another strand of the literature focusing more on Randomized Controlled Techniques does not identify such significant development impacts from electrification (Aevarsdottir et al, 2017; Aklin et al, 2017). Reliability of supply is also associated with an increase in household income (Samad and Zhang, 2017), employment (Mensah, 2018), and the size and productivity of firms (Alby et al, 2013, Grainger and Zhang, 2019; Zhang and Ji, 2018).

Table 5 provides an overview of which types of linkages between energy infrastructure and development have been studied at the country level. The literature offers a moderate amount of material covering over a dozen individual developing countries. The focus is primarily on electrification and how it affects a wide range of development outcomes, with a smaller number of studies examining the impact of unreliable electricity supply, particularly in the productive context. These papers will be further discussed below, where a more detailed tabulated summary of the papers is provided for electrification (Table 6) and reliability of supply (Table 7).

Table 5: Overview of coverage of the thematic and geographic coverage of the literature on the development impact of energy infrastructure in developing countries

	Development Indicators						
	Agricultural production	Firm Productivity/ Size	Structural Transformation	Consumption /HH Welfare	Income	Jobs/ Migration	Education/ Health
Sub- Saharan Africa							
Ethiopia	Electrification	Electrification	Electrification				
Ghana		Electrification	Electrification			Electrification	Electrification
Kenya				Electrification			
South Africa						Electrification	
Tanzania				Electrification		Electrification	Electrification
Uganda							Electrification
Latin America and the Caribbean							
Brazil			Electrification			Electrification	Electrification
El Salvador					Electrification		Electrification
Nicaragua						Electrification	
Peru						Electrification	
South Asia							
Bangladesh					Reliability	Reliability	Reliability
India		Electrification	Electrification	Electrification			
Pakistan		Reliability					
East Asia and the Pacific							
China		Reliability					
Indonesia		Electrification				Electrification	
Philippines					Electrification	Electrification	
Vietnam					Electrification		Electrification

Source: Authors' elaboration.

4.1 Electrification

The development literature on electrification in this section has shown that electricity access has important linkages with: structural change (Akpandjar and Kitchens, 2017; Herrera Dappe and Lebrand, 2021; Lebrand, 2022; Perez-Sebastian et al., 2020), migration (Fried and Lagakos, 2021), employment (Dinkelman, 2011; Lipscomb et al, 2013), industrial output (Rud, 2012), educational attainment (Barron and Torero, 2014; Khandker et al, 2013; Lipscomb et al, 2013), household income (Chakravorty et al, 2016; van de Walle et al, 2017) and both industrial and agricultural productivity (Fisher-Vanden et al, 2015; Allcott et al, 2016) as well as female employment and business ownership (Carlowitz, 2021; Dasso and Fernandez, 2015; Grogan and Sadanand, 2013) and market competition (Kassem, 2021), while increasing reliance on renewable energy sources also brings significant air quality and health benefits (Barron and Torero, 2017).

A first set of studies examines the contribution of electrification to national development in large countries that have gradually rolled out a coverage program across their territories. Such studies have been undertaken for Brazil, Ethiopia, India, and Indonesia and rely on spatial variation across sub-national jurisdictions, such as states, counties or villages, or alternatively look at firm level outcomes.

Lipscomb et al (2013) estimate the development effects of electricity grid expansion in Brazil over the period 1960 – 2000. The authors take advantage of the fact that Brazil relies almost exclusively on hydropower to meet its electricity needs, forecasting hydropower dam placement and grid expansion to show how the electrical grid would have evolved over the period of the study, had infrastructure investments been based solely on geographic cost considerations, ignoring demand-side concerns. A county that goes from zero to full electrification would experience a 17-18 percentage point increase in the probability of employment. Electrification also contributes to human capital development. Going from zero to full electrification leads to a reduction in the illiteracy rate of 8 percentage points and in the proportion of the population with less than four years of education of 21 percentage points. Counties with electricity become attractive for migrants. A 10 percent increase in electrification would increase the migrant share of the population by 1 percent, potentially contributing to human capital development. Overall, the rate of return on electricity investments in Brazil was much higher – 18.4 percent – than the 10-12 percent return guaranteed to electricity companies through the electricity tariffs. The findings suggest large positive effects of electrification on development are underestimated when one fails to account for endogenous targeting of electrification towards areas of higher economic potential (Lipscomb et al, 2013).

In a more recent study of the same economy, Perez-Sebastian et al (2020) focus instead on how Brazilian electrification contributed to the structural transformation of the economy. They show that a 1 percentage point increase in electricity access in Brazil increases the share of the services

sector by 1.06 - 1.14 percentage points whereas the shares of agriculture and manufacturing decline, respectively, by 0.65 - 0.7 and 0.42 - 0.43 percentage points over the period 1970 – 2006. Almost one-third of the observed increase in GDP per capita is explained by the expansion of electricity infrastructure, which is a relatively high estimate.

Turning to India, Rud (2012) analyzes the effect of electricity provision on industrialization between 1965 and 1984, by using the introduction of a new irrigation technology as a natural experiment. Agricultural productivity is linked with timely irrigation that could be cheaply supplied by electrified pump sets. As the demand for these irrigation technologies increases, so does the demand for electricity. Hence, the availability of groundwater explains the divergence in electricity network expansion and hence industrial outcomes. The author finds that electrification has a larger impact on industrialization than groundwater availability. An increase of one standard deviation in the measure of electrification is associated with an increase of around 14 percent in manufacturing output for a state at the mean of the distribution. In addition, network expansion encourages the entry of small firms. These results suggest that the expansion of electricity networks could be used as a means of promoting industrial development, although the effectiveness of electrification will depend on the presence of other development constraints, such as lack of transport infrastructure.

Using panel data of rural Ethiopian villages, Fried and Lagakos (2021) show that rural electrification not only facilitates structural change but also alters migration patterns by slowing out-migration from rural villages. Non-electrified villages are 2.3 percent less likely to receive migrants, while electrified villages are 7.0 percent more likely. Similarly, non-electrified villages are 4.7 percent more likely to be net senders of migrants, while electrified villages are a dramatic 20.9 percent less likely to be net senders of migrants.

Electrification also lowers market entry costs for firms, increasing competition, and forcing unproductive firms to exit more often. Kassem (2021) studies the effect of the extensive margin of electrification (grid expansion) on the extensive margin of industrial development (firm entry and exit) in Indonesia from 1990 to 2000. Electrification causes industrial development by increasing the number of manufacturing firms, manufacturing workers, and manufacturing output. Electrification increases firm entry rates, but also exit rates. Higher turnover rates lead to higher average productivity and induce reallocation towards more productive firms.

A second body of work examines the impacts of electrification at the household level, including resulting changes in consumption, employment, and broader social outcomes such as health and education.

Chakravorty et al (2016) document short-run welfare gains from electricity expansion in the context of the Philippines. In most villages, the physical cost of electricity infrastructure expansion is recovered after one year of realized expenditure gains, showing that the benefits of rural electrification may be significantly high, even in the very short run. Findings also show that the arrival of electricity in a village increases annual household expenditures (income) by 38 (42) percent. Hence, increases in agricultural income seem to account for a meaningful share of the income gains from electrification rather than an increase in employment.

Similarly, Akpandjar and Kitchens (2017) show that individuals with a residential electricity connection are more likely to operate a non-agricultural small business, are less likely to work in agriculture, and are more likely to be employed in wage-earning occupations in Ghana.

A pair of recent studies – focusing on two fragile sub-regions around Lake Chad and the Horn of Africa – examine how the benefits of rural electrification interact with the presence of other complementary infrastructures, such as paved rural roads. They find that the presence of electricity significantly reduces the share of agricultural employment while increasing the share of employment in manufacturing and services. This structural transformation is further amplified when electricity and roads are both made available to rural communities (Herrera Dappe and Lebrand, 2021; Lebrand, 2022).

In contrast to these econometric studies, a recent paper based on a randomized controlled trial in Kenya finds much more limited impacts from rural electrification, indicating that households may not internalize significant economic benefits in the short and medium term (16-32 months) (Lee et al 2020). To measure the impact of electric grid infrastructure on economic and non-economic outcomes, a randomly selected group of households were offered subsidized grid connections. Surprisingly, large subsidies – of the order of 60 percent of construction costs – were needed simply to induce a 25 percent uptake in electrification. While noting that these patterns might not be the same across countries, the authors state that low demand might be related to the low grid reliability, long bureaucratic processes, and the household credit constraints. Given that most people living in these rural communities are at the bottom of the income distribution, financial constraints limit their ability to purchase appliances and hence impact their consumption and demand for electricity.

Yet in another randomized field experiment with 1,401 households in rural Kenya, Rom et al (2016) show that access to a solar light reduced the energy consumption of households by about USD 0.5 to 1.5 per month. This corresponds to 1 to 2.5 percent of total cash expenditure.

Turning to educational impacts of electrification in El Salvador, Barron and Torero (2014) provide experimental evidence, by randomly allocating incentives to get a grid connection, which generates exogenous variation in the probability of households' grid connection. Grid connection leads to increased investments in education. School-aged children's participation in education-related activities such as studying at home increased by 78 percent. The probability of owning a computer increased by 14 percentage points, which is likely to amplify the effects of greater time allocated to education. Electrification also increased women's participation in income generating activities and led to a 46-percentage point increase in participation in non-farm employment and 25 percentage point higher probability of operating a home business. While highlighting the contribution of electrification to income generation, the study also notes that the identification of whether a household has formal (as opposed to informal) access to the grid is important to determine the full benefits.

Another channel through which electrification may contribute to household welfare is through improved health outcomes, by displacing use of polluting kerosene lamps for lighting purposes. Barron and Torero (2017) go on to analyze the relationship between household electrification and indoor air pollution in El Salvador. Two years after baseline, overnight PM2.5 concentration was on average 67 percent lower among households that were randomly encouraged to connect to the power grid compared to those that were not. This change was driven by reductions in kerosene use. As a result, the incidence of acute respiratory infections among children under six fell by 65 percent among connected households. Estimates of exposure measures suggest large health gains for all household members, but these gains were unequally distributed by gender, with adult males benefitting the most with 59 percent lower PM2.5 exposure. Adult females benefited the least, with 33 percent reductions in PM2.5 exposure, because of their involvement in cooking activities.

Finally, with the increasing prevalence of off-grid solar solutions to bring first-time electricity access to remote rural populations, some studies have begun to examine the specific impacts of this more limited form of electrification, which may consist of small solar lamps or more extensive solar home systems.

Lack of electrification undermines children's ability to study at home and consequently inhibits their academic performance. Kerosene candles are generally used as a main source of lighting when there is no electrification. The bright and clean light of solar lamps can be a potential solution to improve the poor household study environment in regions where electricity is scarce and unreliable. However, based on experimental evidence in Uganda, Furukawa (2014) finds no statistically significant support for this argument. Solar lamps increased reported daily study time by approximately half an hour, but the test scores of students with solar lamps at home decreased by five points (out of 100) due to low product reliability. The findings highlight the

importance of long-term field evaluation of product durability to ensure that the technology delivers the intended benefits.

Table 6: Survey of selected papers on the development impact of electrification

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Lipscomb et al (2013)*+	County	Brazil	Jobs/ Education	A county that goes from zero to full electrification would experience an increase (a decrease) in the probability of employment (illiteracy).
Perez-Sebastian et al (2020)+	Municipal	Brazil	Structural Transformation	Electrification supports structural transformation, with rising output share for services and declining output share for agriculture and manufacturing.
Fried & Lagakos (2021)*	Village	Ethiopia	Migration/ Enterprise	Electrified villages had higher (lower) rates of in-migration (out-migration), and higher (lower) ownership of trading (agricultural) businesses.
van de Walle et al (2017) *+	Village	India	Labor Market	Electrification brings significant consumption gains from households, mainly due to additional work by males, with no effect on average wage rates.
Rud (2012) *+	State	India	Structural Transformation	Electrification supports structural transformation, with a rising output share for manufacturing, and increased entry by small firms.
Kassem (2021)+	Locality	Indonesia	Enterprises	Electrification increases manufacturing firms/workers/output, by lowering entry costs and intensifying competitive pressures.
Dinkelman (2011) *+	Community	South Africa	Jobs	Electrification increases employment on the intensive margin for women, leading them to work more hours per week.
Carlowitz (2021)+	Firm	Ghana	Enterprise	Increasing district-level electrification leads to the formation of more female-owned businesses.
Chakravorty et al (2016)+	Household	Philippines	Income/Jobs	Village electrification increases annual household expenditures and income.
Akpandjar & Kitchens (2017)*	Household	Ghana	Structural Transformation	Individuals with a residential electricity are less likely to work in agriculture, and more likely to run a non-farm SME, or be wage-employed.
Herrera Dappe & Lebrand (2021)+	Household	Horn of Africa	Structural Transformation	Households in proximity to power and roads infrastructure are less likely to work in agriculture and more likely to work in manufacturing and services.
Khandker et al (2013)*+	Household	Vietnam	Consumption/ Education	Household electrification can raise consumption, as well as affecting children's school attendance.
Grogan & Sadanand (2013)	Household	Nicaragua	Jobs	Electricity increases the propensity of rural women to work outside the home by about 23% yet has no impact on male employment.
Dasso & Fernandez(2015)	Household	Peru	Jobs	Electrification reduces secondary employment for males, while raising employment/hours worked for females, and reducing gender wage gaps.
Lee et al (2020)	Household	Kenya	Consumption/ Education	Demand for subsidized grid connections was relatively low and did not lead to significant medium-term impacts on (non-)economic outcomes.
Barron & Torero (2014)+	Household	El Salvador	Income/ Education	Electrification leads to an increased investment in education and higher participation in income-generating activities among women.
Barron & Torero (2017)	Household	El Salvador	Health	Two years after electrification, household overnight PM2.5 concentration fell, reducing child acute respiratory infections by 65%.

Furukawa (2014)*	Student	Uganda	Education	Solar lamps increased reported study time, but nonetheless lowered student test scores, perhaps due to inappropriate usage.
Aevarsdottir et al (2017)+	Household	Tanzania	Consumption/ Jobs	Solar lamps, reduce expenditure on lighting and phone charging, and lead to more employment and greater household consumption and well-being.
Aklin et al (2017)	Household	India	Welfare	Access to off-grid solar power decreases black market kerosene expenditures, without systematically affecting other outcomes.
Ratledge et al (2022)	Village	Uganda	Welfare	Grid access improves village-level asset wealth in rural Uganda by up to 0.15 standard deviations.

Source: Compiled by the authors.

Note: Findings column is based on the main finding of the paper. * represents peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

As a part of a field experiment in rural India, randomly chosen households were offered to set up a solar microgrid if at least 10 households within the area subscribed at a price that corresponds to about 2 percent of the monthly baseline household expenditure. The electrification rates for the households offered solar power under the experiment increased around 30 percent faster than other households. However, the study was not able to identify any consistent impacts of electrification, such as the use of lighting for study or power for the creation of new businesses (Aklin et al, 2017).

4.2 Reliability of Supply

Based on World Bank Enterprise Surveys conducted between 2010 and 2020, 8.4 percent of the firms in the world chose electricity as the biggest obstacle affecting their businesses. The main reason for this is the unreliability of power supply, with outages taking place 29 times on average per month in South Asia and eight times per month in Sub-Saharan Africa.[4] Despite the negative impacts of electricity shortages on growth and productivity, empirical evidence remains limited. However, the emerging literature supports the positive contribution of a reliable electricity supply to firm productivity (Grainger and Zhang, 2019; Fisher-Vanden et al, 2015) and competitiveness (Mensah, 2018), as well as to household income (Samad and Zhang, 2017).

One of the first studies to address this issue was Fisher-Vanden et al (2015), which examined how firms responded to severe power shortages in China in the early 2000s. The research found that firms in regions with greater shortages decreased factor shares of electricity for production, while substituting other factors of production, but without any evidence of an increase in self-generation of electricity. An overall decrease in other non-electrical sources of energy indicates that these primary energy sources are complementary inputs in producing the intermediate products that have been outsourced in response to electricity shortages. The unit production

[4] https://www.enterprisesurveys.org/en/data/

costs increased by 13 percent due to greater spending on input materials to compensate for the growing shortages of electricity from 1999 onward, although this was partially offset by a 5 percent reduction in unit cost due to savings in the other inputs and small total factor productivity improvements.

In fact, we find an overall decrease in other non-electricity energy sources, suggesting that these primary energy sources are complementary inputs in producing the intermediate products that have been outsourced in response to electricity shortages. The overall effect of electricity shortages, which we proxy for with a measure of scarcity, was to increase production costs. From 1999 to 2004, firms' costs rose by 8 percent, primarily due to input factor substitutions.

Grainger and Zhang (2019) go further by investigating the ultimate impact of unreliable power supply on manufacturing productivity, using firm survey data for Pakistan covering the period 2010 – 2011. They show that an additional average daily hour of unexpected power shortages decreases annual revenues by almost 10 percent, decreasing annual value-added at the firm level by approximately 20 percent, and increasing the labor share of output. Their findings underscore the importance of a reliable electricity supply to sustain firm productivity.

Mensah (2018) additionally explores the implications of unreliable power supply for employment. He finds that firms respond to the productivity losses arising from power outages by cutting jobs. To estimate the causal impact of electricity shortages on employment, Mensah (2018) employs household data from the Afrobarometer and Enterprise Surveys from more than 20 African countries. The results show that outages reduce the total factor productivity of African firms by more than 2.3 percent and reduce the probability that an individual is employed by between 35 and 41 percentage points. Significantly, the negative impact on employment is concentrated in high-skilled high-wage employment in non-agriculture sectors.

Finally, power outages also have negative impacts on development outcomes for households, which partially offset the benefits of electrification. Using household survey data from rural households for 2005 and 2010 in Bangladesh, Samad and Zhang (2017) find that a one hour increase in power outages per day is associated with a 0.3 percent reduction in annual income. Indeed, the income differential between electrified and non-electrified households disappears if the power outages last longer than 21 hours a day. The study also finds that the benefits of electrification increase over time, albeit at a decreasing rate, such that each additional year of being connected to the grid is associated with a 1 percent increase in annual income.

Table 7: Survey of selected papers on the development impact of reliable power supplies

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Zhang & Ji (2018)*+	Province	China	Firm Productivity	More power plants should have been built in China, considering trade-offs between environmental costs and economic benefits.
Fisher-Vanden et al (2015) *+	Firm	China	Production Costs	Firms in regions most affected by shortages decreased factor shares of electricity and increased factor shares of materials.
Grainger & Zhang (2019) *	Firm	Pakistan	Firm Productivity	An extra daily hour of unexpected outages decreases annual revenues and value-added and increases the labor share of output.
Mensah (2018)+	Firm	Africa	Jobs/ Firm Productivity	Electricity shortages reduce employment chances of workers and depress firms' total factor productivity by 2.3 percent.
Alby et al (2013) *	Firm	Cross-Country	Firm Size	Electricity-intensive sectors in high-outage countries are characterized by a significantly lower share of small firms.
Samad & Zhang (2017)+	Household	Bangladesh	Income	An hour increase in power outages leads to a 0.3% drop in household income, after 21 hours of outages no benefit from electrification

Source: Compiled by the authors.

Note: Findings column is based on the main finding of the paper. An asterisk identifies peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

5. Development Impacts of Transportation Infrastructure

Studies show that efficient and extensive infrastructure in the transport sector is an important component of development outcomes in high-income countries. Investments in transportation positively support output, employment, and city/regional growth. For instance, a 1 percent increase in road accessibility leads to a 0.3 to 0.5 percent increase in establishments and employment in Britain (Gibbons et al, 2019). Duranton and Turner (2012) find that the stock of highways in a city contributed to the growth in city population in the United States between 1980 and 2000. Similarly, Garcia-Lopez et al (2015) find that highways cause about the same rate of population growth in Spanish cities.

This section discusses the size and distribution of benefits from transport investments in developing countries. It shows that investments in the transport sector are key to promoting economic growth and spreading growth geographically by lowering trade costs (e.g., Donaldson, 2018; Martincus et al, 2013), accelerating firm growth (e.g., Datta, 2012; Lu, 2020), enhancing competition (e.g., Asturias et al, 2019; Brooks et al, 2021), expanding agricultural productivity as well as farm and non-farm production (e.g., Aggarwal et al, 2018; Binswanger et al, 1993; Levy, 1996), expanding trade (e.g., Buys et al, 2010; Martincus and Blyde, 2013), increasing welfare and reducing poverty (e.g., Ali et al, 2015; Gonzalez-Navarro and Quintana-Domeque, 2016); in addition to enabling commuting by workers (e.g., Asher and Novosad, 2020). These studies are grouped into five main sub-categories based on their sub-sectoral focus: rural roads, trunk roads,

rail freight, ports, and urban transportation. Not surprisingly, most of the papers focus on Sub-Saharan Africa because of a critical shortage of transport infrastructure stock and the poor quality of existing transport infrastructure. These studies highlight the importance of transport infrastructure promoting structural transformation in Sub-Saharan Africa as well as in other developing countries.

Table 8 provides an overview of which types of linkages between transport infrastructure and development have been studied at the country level. The literature offers a substantial volume of material covering some 20 individual developing countries, across multiple regions, albeit with an emphasis on Sub-Saharan Africa. The focus is primarily on rural roads and how they affect a wide range of development outcomes, but there are also a significant number of papers studying national highway networks, and urban transportation, as well as rail and port infrastructure. These papers will be further discussed below, where a more detailed tabulated summary of the papers is provided for rural roads (Tables 9-10), national highways (Table 11-12), railroads (Table 13), ports (Table 14) and urban transportation (Table 15).

Table 8: Overview of coverage of the thematic and geographic coverage of the literature on the development impact of transport infrastructure in developing countries

	Development Indicators								
	Agricultural production	Firm Productivity/ Production/ Competition	Food security	Consumption/ HH Welfare	Income/ Poverty	Jobs/ Informality	Regional/ Urban Development	Education	Conflict
Sub- Saharan Africa									
Benin			Rural R.						
Cameroon					Rural R.				
Congo Basin Countries									Trunk R.
Democratic Republic of Congo			Rural R.						Trunk R.
Ethiopia				Rural R.	Rural R.				
Ghana			Rural R.						
Mali			Rural R.						
Nigeria					Rural R.	Rural R.			
Senegal			Rural R.						
Sierra Leone			Rural R.						
Tanzania	Rural R.						Rural R.		
Latin America and the Caribbean									
Brazil						Trunk R., Rail, Urban T.			
Chile		Trunk R.							
Mexico				Trunk R.		Rural R.			
Peru		Rural R.				Rural and Trunk R.			
South Asia									
Bangladesh	Rural R.			Rural R.	Rural R.			Rural R.	
India		Trunk R.	Rail		Rail	Rural R.			
Nepal					Rural R.				
East Asia and the Pacific									
China				Rural R.	Trunk R.	Trunk R.	Trunk R., Urban T., Rail	Rural R.	Urban T.
Indonesia						Urban T.			

Source: Compiled by the authors

Note: Rural R. = Rural Roads, Trunk R. = Trunk Roads, Rail = Freight Rail, Urban T. = Urban Transportation

5.1 Rural Roads

Transport infrastructure plays a central role in rural development. Given that a rural population of about 1 billion worldwide does not have access to an all-season road within a walking distance of 2 km (Roberts, Shyam and Rastogi, 2006; World Bank, 2019), improving access to markets, especially for the rural poor, is a central element of poverty alleviation and economic

development. Rural roads are an important form of public infrastructure, providing cheap access to both markets for agricultural output and supplies of modern inputs. According to the literature, rural roads have been found to foster growth in rural enterprises (Lokshin and Yemtsov, 2005), greater earnings, higher productivity, employment and consumption, as well as reduced poverty, and other household benefits such as improved education and health may follow especially for women and girls (Bryceson and Howe, 1993; Levy, 1996).

Unlike in Asia, investments in rural roads are found to have unambiguously favorable effects on different development indicators in Africa, with the greatest benefits accruing to the most remote locations. The importance of rural roads in overall welfare (e.g., Ali et al, 2015b; Kebede, 2021; Nakamura et al, 2019), agricultural technology adoption (e.g., Aggarwal et al, 2018; Minten et al, 2013; Suri, 2011), food security (e.g., Casaburi et al, 2013; Fafchamps et al, 2004; Minten and Kyle, 1999), and migration patterns (e.g., Gachassin, 2013; Jedwab and Storeygars, 2022) in the region has been recognized in the literature.

Nakamura et al (2019) analyze the impacts of major rural road development in Ethiopia on welfare and economic outcomes, finding that this has substantially increased household welfare, while improving resilience to severe droughts. Concretely, rural road access increased household consumption by 16.1 percent on average between 2012 and 2016 (equivalent to 3.8 percent per year). The effects of rural road development were largest in the most remote communities, where household consumption rose by as much as 27.9 percent. Furthermore, in the communities most affected by the El Niño drought, the likelihood of falling into poverty was 14.4 percent lower between 2012 and 2016 if the community was connected by a rural road.

A second study of rural road expansion in Ethiopia finds comparable welfare impacts. Kebede (2021) estimates that road expansion resulted in a 13 percent increase in real agricultural incomes on average. This increase is attributed to the mechanisms suggested in the Ricardian trade model: the prices of villages' comparative advantage crops increase, and villages reallocate land towards these crops following decreases in trade costs. Highways and railroads primarily serve the urban population and the manufacturing sector, while the feeder roads mainly favor the agrarian rural population and the wider agriculture sector – posing trade-offs between urban-focused versus rural-focused development policies.

Turning to Nigeria, Ali et al (2015b) use a simulation-based approach to assess the differential development impacts of alternative road construction projects, drawing from the program supported by the New Partnership for Africa's Development (NEPAD). They find that a 10 percent reduction in transport costs increases local GDP (wealth index) by 5.4 (2.3) percent, as well as raising crop revenue (non-agricultural income) by approximately 6.2 (3.2) percent. From a household perspective, lowering transport costs to market by 10 percent reduces a household's

probability of being multi-dimensionally poor by 2.6 percent, and decreases the probability of being employed in the agriculture sector by 4 percent among male household members and 5.3 percent among females. Hence, reducing transportation costs plays an important role in income diversification and structural change.

Nevertheless, the effects of road interventions are neither systematic nor uniform. Drawing on the 2001 National Household Survey for Cameroon, Gachassin et al (2015) demonstrate that better road access increases the number of economic activities within reach of households living in the most isolated locations, based on a "pull" factor, which draws them into new and higher-earning opportunities. However, the impacts of isolation on household well-being via labor market opportunities are heterogeneous and depend on local characteristics.

An important channel through which rural roads generate economic benefits is by improving the productivity of the agriculture sector. Dorosh et al (2012) examine the relationship between transport infrastructure, population location, and agricultural production in Sub-Saharan Africa. Both population and agricultural production are spatially concentrated near large cities. A 10 percent decrease in travel time from a local crop production location to a nearby city of more than 25,000 people increases local crop production by 23 percent in the long run. A 1 percent reduction in travel time to the nearest city with 100,000 people or more increases low-input (high-input) crop production by 2.9 (1.6) percent. In a similar vein, Kiprona and Maksumoto (2018) show that rural road infrastructure improvements in Southwestern Kenya increase agricultural productivity and market participation by rural smallholder farmers.

Developing countries, especially in Sub-Saharan Africa, have lagged in agricultural technology adoption, despite widespread experimentation with input subsidies. To understand the reasons for this, Aggarwal et al (2018) quantify market access in the 1,183 villages in rural Tanzania and examine the extent to which it constrains agricultural productivity. They find that less favorable input and output prices in remote areas resulted in lower profitability leading to lower agricultural technology adoption in these locations. For instance, a village in the 90^{th} percentile of the travel-cost adjusted price distribution faces input and output prices 40 to 55 percent less favorable than a village at the 10^{th} percentile. The rates and magnitudes of fertilizer use and maize sales also display a large and significant distance gradient. An additional standard deviation of travel time is associated with 20 to 25 percent lower input adoption and output sales for remote villages.

These findings are in line with other studies on this topic. Suri (2011) shows that many Kenyan farmers do not adopt hybrid seeds with high returns due to high fixed costs of obtaining seeds, possibly related to travel costs. Minten et al (2013) document significant farmer-to-retailer transaction costs to reach price-controlled input cooperatives in a rugged region in northwestern

Ethiopia. Increasing transaction and transportation costs over a 35-kilometer distance, along a route mainly accessible to only foot traffic, led to a 50 percent increase in the price of chemical fertilizer and to a 75 percent reduction in its use. Most strikingly, farmers living about 10 kilometers from the distribution center faced per unit transaction and transportation costs as high as the costs needed to bring the fertilizer over the distance of about 1,000 kilometers from the international port to the distribution center.

Spatial variation in food prices is a well-known phenomenon in low-income countries and is often related to the availability and quality of road infrastructure. Minten and Kyle (1999) examine producers' wholesale price margin for domestic products between the urban center of Kinshasa, Democratic Republic of Congo, and rural areas. The analysis demonstrates that food price dispersion, both between products and across regions, is significantly related to transport cost differentials, with road quality being an important factor in determining transportation costs. Transportation is, on average, twice as costly on poorly maintained unpaved roads as on paved roads and reduces the price of the product even more due to the damage incurred from transiting on a bumpy road. Moreover, the average daily wage of the itinerant trader increases significantly the further he travels on the river or on poor quality dirt roads, with the highest pay-off on dirt roads where the wage increases by around 20 percent for every additional 100 kilometers traveled by the trader.

Agricultural markets throughout Sub-Saharan Africa are characterized by high levels of fragmentation and poor transport infrastructure, with intermediaries playing a central role (Fafchamps et al, 2004). Casaburi et al (2013) study the impacts of improvements in rural road infrastructure on crop prices in rural markets in Sierra Leone. A rehabilitation program led to improved road quality along 800 kilometers of roads in 2003, reducing transport costs significantly and thereby lowering prices of the two main domestically-produced staples – rice and cassava – along the affected corridors. The benefits were shown to be heterogeneous, with the largest effects found in the markets furthest away from main urban centers. Moreover, given that agricultural intermediary markets in this setting are best characterized by a framework that includes search frictions, there is a possible complementarity between road upgrades and other interventions aimed at reducing search costs, such as increasing digital connectivity in rural areas.

An important factor affecting crop prices in rural areas is the mark-ups associated with transportation. Lall et al (2009) investigate the main determinants of transport costs in the context of Malawi. The main finding is that both infrastructure quality and the market structure of the trucking industry are important contributors to regional differences in transport costs, with relatively thin transportation markets leading to larger mark-up on freight transportation depending on the degree of market power. While the quality of trunk roads is not a major

constraint for rural access, differences in the quality of feeder roads connecting villages to the main network have a significant bearing on transport costs.

In view of the positive linkages between transport costs, agricultural productivity, and rural food prices, it is hardly surprising that transport infrastructure turns out to play an important role in providing safe, nutritious, and reliable food supplies. Blimpo et al (2013) study the extent of the relationship between political marginalization, public investment in transport infrastructure, and food security in Benin, Ghana, Mali, and Senegal and show that there is a strong relationship between food security and road infrastructures. A one standard deviation increase in kilometers of road per square kilometer of land relates to a reduction in the number of stunted children. The higher number of stunted children in marginalized areas is thus an indirect effect of political marginalization, which restricts access to investments in transport infrastructure.

Transport costs play an important role in driving rural-urban migration and hence the scale of cities. Jedwab and Storeygard (2022) estimate the average and heterogeneous effects of transportation investments on the population of African cities in the longer term. The authors use changes in market access due to distant road construction as a source of exogenous variation. A 10 percent increase in market access induces a 0.8 to 1.3 percent increase in city population on average over the following 30 years. The size of the effects varies substantially depending on the context, being smaller for larger and less isolated cities, more politically favored constituencies, more agriculturally suitable areas, and foreign rather than domestic markets.

Examining the same question of urban-rural migration from a rural angle, Gachassin (2013) analyzes how road access affects labor migration in Tanzania. On average, a road quality improvement decreases the probability of migrating away from a rural location by 7.2 percent in the communities studied, likely due to the associated positive and significant impact on per capita consumption. However, the dampening effect of road infrastructure on migration turns out to be greater in communities that are already relatively well connected to begin with.

Finally, transport costs also affect the relative economic fortunes of cities. Storeygard (2016) began by investigating the role of intercity transport costs in determining the income of Sub-Saharan African cities, showing that almost quadrupling the oil price increase (from $25 to $97) between 2002 and 2008 induced the income of cities near the port to increase by 7 percent relative to otherwise identical cities 500 kilometers farther away, rising to 29 percent relative to cities 2,360 kilometers away. The implied elasticity of city income with respect to transport costs is estimated at -0.28 at 500 kilometers from the port. While cities connected to the port by paved roads are mainly affected by transport costs to the port, cities connected with unpaved roads are more affected through their connections to secondary centers.

Table 9: Survey of selected papers on the development impact of rural roads in Africa

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Nakamura et al (2019)	Household	Ethiopia	Consumption	Rural road development increased household consumption by 16-28%, and reduced poverty incidence by 14% in drought-affected areas.
Kebede (2021)	Household	Ethiopia	Income	Road expansion resulted in a 13% increase in real agricultural income, on average.
Ali et al (2015b)	Household	Nigeria	Poverty/ Jobs	Reducing transport costs increases local GDP /wealth and lowers households' probability of being poor and agriculturally employed.
Gachassin et al (2015) *+	Household	Cameroon	Earnings	Better road access increases the number of economic activities within households that are most isolated.
Dorosh et al (2012) *+	Country	Sub-Saharan Africa	Agricultural Production	A 10% (1%) decrease in travel time from crop production areas to small (large) towns increasing production by 23% (3%) in the long run.
Aggarwal et al (2018)	Village	Tanzania	Agricultural Production	A village in the 90th percentile of the travel-cost adjusted price distribution faces input and output prices 40-55% less favorable than a village at the 10th percentile.
Minten et al. (2013)	Household	Ethiopia	Agricultural Production	Increasing transportation costs over a 35 km distance, leads to a 50% increase of the price of chemical fertilizer and to a 75% reduction in its use.
Minten and Kyle (1999) *	Trader	Democratic Republic of Congo	Food Prices	Transportation costs explain most of the food price differential between producing regions, with road quality an important driver of transportation costs.
Casaburi et al (2013)	District	Sierra Leone	Food Prices	Improved rural road quality reduced prices for two main domestically produced staple crops (rice and cassava) particularly in more remote areas.
Lall et al. (2009)	Household	Malawi	Trade	Both infrastructure quality, and market structure of the trucking industry, are important contributors to regional differences in transport costs.
Blimpo et al (2013) *	Local admin. Unit	Benin, Ghana, Mali, Senegal	Food Security	There is a strong correlation between food security and availability of road infrastructures.
Gachassin (2013) *	Household	Tanzania	Migration	Road quality improvements decrease the probability of migration by 7%, and even more so in well-connected communities.
Jedwab and Storeygard (2022) *+	Location	Sub-Saharan Africa	Migration	Greater market access increases city population on average; particularly for smaller and more isolated cities and for domestic markets.
Storeygard (2016) *	Pixel	Sub-Saharan Africa	Income	An oil price hike induces the income of cities near that port to increase by 7% relative to otherwise identical cities 500 km farther away.

Source: Compiled by the authors.

Note: Findings column is based on the main finding of the paper. An asterisk identifies peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

Sub-Saharan Africa is the region with the highest degree of isolation, scoring just 30 percent on the Rural Access Index, for the percentage of the population living within two kilometers of an all-season road. Nevertheless, South Asia and Latin America, with Rural Access Index scores of 58

and 54 percent, respectively, also face significant challenges in this regard (Roberts, Shyam, and Rastogi, 2006).

Evidence on the development impact of rural roads in Asia is quite mixed. While the improvements in road access appear to positively contribute to socio-economic outcomes in several developing Asian nations (Emran and Hou, 2013; Khandker et al, 2009; Muralidharan and Prakash, 2017), the effects are not always found to be substantial (Asher and Novosad, 2020; Jacoby, 1999; Li et al, 2019). The available literature for Latin America is much more limited, but highlights the significant positive contribution of rural road investments to creating job opportunities in remote areas (e.g., Blankespoor et al, 2017) as well as stimulating the growth of firms through lower-cost access to markets (e.g., Martincus et al, 2017).

Emran and Hou (2013) present evidence on the effects of access to domestic and international markets on the per capita consumption of rural households in China. The results, based on a household survey in 1995, show that better access to both domestic and international markets has positive effects on per capita income, with the domestic market effect being the larger one. A 10-kilometer reduction in the distance to a domestic (international) market increases per capita consumption by 42.10 (29.68) yuan when the household is initially located 150 kilometers away from both the domestic and international markets, which is equivalent to 8 (6) percent of the rural poverty line income. The authors also find evidence of complementarity between access to domestic and international markets, with a reduction in the distance to one market yielding a higher benefit for a household when it is located closer to the other market.

Khandker et al (2009) find that the overall effect of road improvement on household per capita annual consumption was about 8 –10 percent across affected project areas in Bangladesh. In addition, road improvements have led to a poverty reduction of 3 – 6 percent on average over the period of about 5 years. This implies that extreme poverty fell by about 1 percent each year, solely due to rural road improvements. Road improvement also has a significant positive impact on aggregate crop output and price indices. In addition, school enrollment of boys and girls increased significantly in both project samples.

Jacoby (1999) investigates the benefits from road projects at the household level using the relationship between the value of farmland and its distance to agricultural markets in Nepal based on the 1995 – 96 Living Standards Survey. Providing extensive road access to markets would confer substantial benefits on average, many of these going to poor households. However, the benefits would not be large enough or targeted efficiently enough to appreciably reduce income inequality in the population. The results highlight that rural road construction is not always the magic bullet for poverty alleviation.

Asher and Novosad (2020) estimate the economic impacts of India's $40 billion national rural road construction program. Four years after road construction, the main effect of new feeder roads is to facilitate the movement of workers out of agriculture. However, there are no major changes in agricultural outcomes, income, or assets. Employment in village firms expands only slightly. Even with better market connections, remote areas may continue to lack economic opportunities. This paper suggests that even in a fast-growing economy such as India in the 2000s, rural growth is constrained by more than the poor state of transportation infrastructure. Instead of facilitating growth of village farms and firms, the main economic benefit of rural transportation infrastructure may be the connection of rural workers to new employment opportunities elsewhere.

Transportation improvements increase access to markets and play a critical role in facilitating the specialization of localities and the resulting concentration of industries to achieve higher economic growth. Blankespoor et al (2017) estimate the impacts of road improvements on local employment and specialization in Mexico for the period 1986 - 2014. A 10 percent increase in market access results in a 2.9 to 6.5 percent increase in employment, and a 13 percent increase in output specialization. The effects are heterogeneous across sectors, with employment in commerce and services benefiting more than manufacturing, from road improvements.

Upgrades in transport infrastructure can have a significant positive impact on firms' exports and thereby on employment. Martincus et al (2017) look at the impact of road infrastructure on international trade between 2003 and 2010 in Peru, where regions were exposed to an asymmetric infrastructure shock. Improved domestic road infrastructure translates into increasing firm exports, with a distance elasticity of exports of around 1.2. In addition, infrastructure driven exports accounted for 4 percent of the (net) new jobs that exports created during the study period.

Finally, human capital accumulation is also an important determinant of long-term productivity growth. However, access to roads can alter rural households' opportunity costs of human capital investments. On the one hand, better transport infrastructure may reduce students' travel costs to school, improving attendance. On the other hand, greater transport connectivity also exposes students to more immediate job opportunities, potentially incentivizing them to drop out of school to join the labor market. Li et al (2019) look at the impact of highway investments on educational choices in rural China. Using 2005 population census data, the authors find that highway access significantly reduces the enrollment rate of senior high schools in rural areas by as much as 9 percent, without affecting the enrollment rates for junior high and elementary schools. This negative effect is more significant on students in rural regions than in urban regions, indicating that better transport connectivity may improve the income of rural households in the

short run at the expense of regional growth rates in the long run, due to reduced educational attainment. Policy makers need to consider this negative externality when making rural development policies.

Table 10: Survey of selected papers on the developing impact of rural roads in other regions

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Emran and Hou (2013)*	Household	China	Consumption	Reducing distance to domestic market, and to a lesser extent international market, increases per capita consumption reducing rural poverty.
Khandker et al (2009)*	Household	Bangladesh	Consumption/ Agriculture	Road improvement increases household per capita annual consumption, and significantly boosts aggregate crop output, crop price indices and education.
Jacoby (1999)+	Household	Nepal	Income Inequality	Providing extensive road access to markets confers higher incomes, but not enough to materially improve inequality.
Asher & Novosad (2020)*	Village	India	Structural Transformation	New feeder roads facilitate movement of workers out of agriculture, but without any major changes in agricultural outcomes, income, or assets.
Blankespoor et al (2017)	Localities	Mexico	Jobs, Specialization	A 10% increase in market access results in a 2.9-6.5% increase in employment, and a 13% increase in specialization, particularly for commerce and services.
Martincus et al (2017) *	Firms	Peru	Exports, Employment	A 22% reduction in distance to the nearest port, led to 3.8% faster growth in exports, with associated expansion of employment.
Li et al (2019)	Hukou (district)	China	Education	Rural highway access reduces the enrollment rate of senior high (but not junior high or elementary) schools due to improved access to jobs.

Source: Compiled by the authors.

Note: Findings column is based on the main finding of the paper. An asterisk identifies peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

5.2 National Highways

Like rural roads, the expansion of quality trunk roads supports economic growth through various development indicators from output growth to more employment opportunities in remote areas. However, recent research (e.g., Ali et al, 2015; Damania and Wheeler, 2015) also points out that new road constructions also leads to significant economic costs, unless measures are taken to enhance security in conflict-affected zones and overcome negative environmental externalities due to deforestation.

Numerous papers explore the economic impacts of the construction of two of the biggest transportation investment programs in the world, namely the Chinese National Expressway Network and the Indian Golden Quadrilateral (GQ) Project. The former is designed to connect all Chinese cities with a population of more than 200,000 (World Bank, 2007), the latter aims to connect the largest metropolitan areas across India: Delhi (in the north), Calcutta (in the east), Chennai (in the south), and Mumbai (in the west). GQ spans 5,846 km, reaching 95 percent

completion between 2001 and 2006, and making it the largest highway system in India. Both these Chinese and Indian networks rank among the longest in the world, extending over vast areas and connecting remote locations with urban centers. This has allowed researchers to disentangle the widespread impacts of these two transport projects, affecting competition, trade, and labor market migration within and across regions.

Egger et al (2020) document the unprecedented change in the size and the quality of China's transport-infrastructure network between 2000 and 2013. The changes are summarized and portrayed as the shortest possible transport times for people and goods between 330 prefectures of mainland China. A quantitative model suggests that the long-run consequences of the transport-infrastructure changes were to induce regional convergence of prefectures initially lagging in terms of population density and, to a lesser extent, real per-capita income. The study found that not only changes in highway and high-speed railway networks were quantitatively important, but also those in the lower-level road and railway networks. The most important drivers behind these effects are the facilitation of goods transportation, as well as the diffusion of technology, while the reduction of personal mobility costs and the diffusion of amenities appeared less important.

Faber (2014) exploits China's National Trunk Highway System as a natural experiment to understand the impacts of large-scale transport infrastructure investments on trade costs and economic activities across regions. To avoid endogeneity issues, Faber (2014) looks at counties that – while not explicitly targeted by the highway program – benefited circumstantially due to being en route between targeted destinations. The economic outcomes for such locations could be compared with unconnected more peripheral locations. Faber (2014) finds that National Trunk Highway System connections for such "in between" locations have on average reduced GDP growth by about 18 percent over a 9-year period between 1997 and 2006 compared to non-connected peripheral counties, while local government revenue growth has been reduced by approximately 23 percent. At the same time, network connections have led to a reduction in GDP growth among non-targeted peripheral counties, driven by a significant reduction in industrial output growth.

Not only do major highway systems spatially reallocate economic activity, but they also drive migration potentially favoring regional primate cities over smaller cities. Baum-Snow et al (2020) investigate the effects of the Chinese National Highway System constructed between the late 1990s and 2010 on local economic outcomes. On average, roads that improve access to local markets have small or negative effects on prefecture economic activity and population. However, these averages mask a distinct pattern of winners and losers. With better regional highways, economic output and population increase in regional primates at the expense of hinterland prefectures. For instance, a 10 percent increase in roads within 450 km of a prefecture city

reduces the non-primate prefecture population by 1.7 percent but increases the primate prefecture population by 1.1 percent. Highways also affect patterns of specialization. Regional primates specialize more in manufacturing and services through better regional highways. On the other hand, peripheral areas lose manufacturing but gain in agriculture. Better access to international ports promotes greater population, GDP, and private sector wages on average, effects that are probably larger in the hinterland than in primate prefectures. These findings suggest that highways allow regions to specialize in their comparative advantage in China, meaning that centrally located prefectures focus on manufacturing while those in the hinterland concentrate on agriculture.

Similarly, Roberts et al (2012) also analyze the spatial and national impacts of the construction of the Chinese National Expressway Network. The results indicate that aggregate Chinese real income was approximately 6 percent higher than it would have been in 2007, had the expressway network not been built, although this estimation does not consider the opportunity costs associated with expenditure on the network. The construction not only enhanced intra-national trade, but also accelerated the development of the country's poorest inland regions with the aim of promoting their catch-up with the country's leading coastal areas.

Cosar and Fajgelbaum (2016) introduce internal geography to the canonical model of international trade driven by comparative advantages to study the regional effects of external economic integration. Then they empirically test their model using industry level data from Chinese prefectures, proxying for industries' export orientation with national export-revenue ratios. The direct effect of distance on economic activity is sizable: moving inland by 275 miles (the median distance from the coast across prefectures) decreases industry employment by 17 percent for an industry with an average export-revenue ratio, and by 13 percent for an industry with average labor intensity. But this negative distance gradient is stronger for export-oriented industries: employment shrinks by 32 percent for an industry that has an export-revenue ratio 1 standard deviation higher than average, and by 21 percent for an industry that has labor intensity 1 standard deviation higher than average. Economic activity at the industry-prefecture level is strongly correlated with the interaction between prefecture proximity to coastlines and industry export orientation.

Like China, India had a large-scale highway construction and improvement project, the Golden Quadrilateral (GQ). Datta (2012) estimates the impact on firms' production for those located along the GQ. Such firms reported reducing their inventories by 10.5 days' worth of production, between the outset of the GQ project in 2002 and its completion towards 2005, when much of the project had been implemented, while no such reduction was reported by firms located further away. Firms located along the GQ also showed a greater propensity to change suppliers

over this time period than their counterparts elsewhere, suggesting that they found their existing arrangements sub-optimal once exposed to a wider choice set. At the same time, these firms became much less likely to report that transportation was a major obstacle to production than had been the case prior to the implementation of the project.

Ghani et al (2016) study the impact of transport infrastructure on the organization of manufacturing activity and find that the Golden Quadrilateral upgrades led to a substantial increase in manufacturing activity. This growth included higher entry rates, improvements to incumbent productivity, and adjustments in the spatial sorting of industries, and improved allocative efficiency in manufacturing industries initially located along the GQ network. The largest growth in manufacturing activity was found in districts located within 10 kilometers from the GQ highway, where output levels grew by 49 percent over the decade after construction began. Such growth was not observed in districts located 10 – 50 kilometers from the GQ network, nor in districts adjacent to another major Indian highway system scheduled for a contemporaneous upgrade that was subsequently delayed.

Finally, highway infrastructure investments also promote competition in the marketplace by disrupting monopsony power. Brooks et al (2021) find that the monopsony power of Indian manufacturing firms in labor markets is reduced among firms near newly constructed highways relative to firms that remain far from highways. The impacts of highway construction are pro-competitive in both output and input markets, increasing labor's share of income by about 1.8 to 2.3 percentage points.

Table 11: Survey of selected papers on the development impact of trunk road investments in China and India

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Egger et al (2020)+	Prefecture	China	Output, Population	Trunk (and other) infrastructure upgrades promote long-run convergence of lagging regions, in terms of population and to a lesser extent income.
Faber (2014)*+	County	China	Output	Localities incidentally benefiting from National Trunk Highway System experienced 18% GDP growth in 9-years, while peripheral localities saw industrial decline.
Baum-Snow et al (2020)	Prefecture	China	Output, Population	Better regional highways shift population towards regional primate cities, and accentuate industrial specialization, while hinterland becomes more agricultural.
Roberts et al (2012) *	Sector	China	Income, Inequality	China's National Trunk Highway System boosted aggregate real income by 6% (unadjusted for opportunity cost) and drove convergence of lagging inland regions.
Cosar & Fajgelbaum (2016) *	Prefecture	China	Jobs	Economic activity and industry export orientation at the industry-prefecture level is strongly correlated with proximity to coastlines.
Ghani et al (2016) *+	County	India	Firm production	Localities within 10kms of India's GQ Highway saw a large rise in manufacturing, driven by firm entry, productivity growth and more efficient spatial sorting.

Datta (2012)*	City	India	Firm production	Firms along India's GQ highway benefited from reduced inventories and improved suppliers and were less likely to report transport as an obstacle to business.
Brooks et al (2021) *	Firm	India	Firm competition	The impacts of highway construction are pro-competitive in both output and input markets, leading to an increase in labor's share of income.

Source: Compiled by the authors.

Note: Findings column is based on the main finding of the paper. An asterisk identifies peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

The creation of a high-quality well-integrated continental road network in Sub-Saharan Africa is a longstanding political goal (African Development Bank, 2019). Buys et al (2010) quantify the economics of upgrading a primary road network that connects the major urban areas (83 cities) in Sub-Saharan Africa. The results indicate that continental network upgrading is worth serious consideration from an economic perspective. Simulations suggest that overland trade among Sub-Saharan African countries might expand by about $250 billion over 15 years, with major direct and indirect benefits for the rural poor, while generating millions of construction and maintenance jobs in some of Africa's poorest regions. The magnitude of the potential benefits highlights the need for a serious discussion and coordination of upgrading by African states and international donor institutions.

Morten and Oliveira (2018) ask whether infrastructure facilitates the movement of labor. By using a general equilibrium trade model and rich spatial data, the authors are able to explore the impact of a large, plausibly exogenous, shock to highways in Brazil on both goods markets and labor markets. The results indicate that the road improvement increased welfare by 13.3 percent. This was almost entirely attributable to a 28 percent reduction in the cost of trade. The 11 percent reduction in the cost of migration also made a minor contribution to the welfare outcome, but the impact was highly heterogeneous due to the cost of migration. Such migration costs indicate the extent to which a location is sticky and may prevent people from moving to take advantage of the benefits flowing from infrastructure improvements.

Internal transport infrastructure, and hence internal transport costs, can be important determinants of trade. Taking advantage of the exogenous variation in infrastructure caused by an earthquake that took place in Chile in 2010, Martincus and Blyde (2013) identify the disruptions in the primary and secondary road network impacting the domestic routes of firms' shipments leading to an estimate of the distance elasticity of exports of -1.42. The earthquake damages to transportation infrastructure had a significant negative impact on firms' exports, primarily due to a reduction in the number of shipments, with exports of more homogeneous goods from large firms particularly affected. Notably, firms whose export shipments had to be

rerouted because their original routes became impassable experienced an export growth rate 33.7 percent lower than their unaffected counterparts.

Ali et al (2015) in their study of the Democratic Republic of Congo show that higher transportation costs have a significantly negative impact on wealth and a significantly positive impact on the probability of being multi-dimensionally poor in conflict-affected areas. The location of conflict is also important in determining its effect. Conflict near households has a strongly negative impact on a household's wealth, and conflict near markets has a large, positive impact on the probability of being multi-dimensionally poor. In areas of the Democratic Republic of Congo with low or no conflict, investment in decreasing transportation cost emerges as a highly effective way of generating economic growth, as long as parallel measures are taken to enhance security.

Turning to the papers on the relationship between transport infrastructure and environmental conflicts, road improvement planning in tropical forest regions is unlikely to maximize welfare unless it anticipates and incorporates negative environmental impacts. Damania and Wheeler (2015) estimate an econometric model of deforestation that incorporates the economics of road improvement. The authors find large, highly significant effects of upgrading on the intensity and extent of forest clearing along road corridors. The results highlight how proprietors' decisions to clear forest are highly sensitive to market access, land opportunity values, official protection status, and topography. The paper also estimates the impact of violent conflict on deforestation in Sub-Saharan Africa, predicting a 10-20 percent increase in deforestation as a result of conflict, though varying widely according to prior road conditions and characteristics of local economies. In addition, many corridors lead to significant extensions in the outer margin of forest clearing.

Table 12: Survey of selected papers on the development impact of national highways in Africa and Latin America

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Buys et al (2010) *	Inter-city	Sub-Saharan Africa	Trade, Jobs	Continental network upgrade would expand intra-African trade by $250 bn over 15 years, while creating jobs and benefiting rural poor.
Bosede et al (2013) *	Locality	Nigeria	Income	Transport investment in national highways can make a significant positive contribution to growth.
Morten and Oliveira (2018)	Locality	Brazil	Trade, Migration	Road improvement increased welfare by 13%, mainly due to a 28% reduction in trade costs, which could increase with more migration.
Martincus and Blyde (2013) *+	Firm	Chile	Trade	Firms with export routes disrupted by an earthquake, saw 33% lower export growth, indicating an export to distance elasticity of -1.42.
Ali et al (2015)+	Household	Congo, Dem. Rep.	Wealth, Poverty	High transport costs have a significant negative impact on wealth and a significant positive impact on poverty, particularly in conflict areas.

Damania & Wheeler (2015)+	Pixel	Congo Basin	Deforestation, Conflict	Road upgrading has a large significant effect on the intensity and extent of forest clearing. Road improvements in forested regions with agricultural potential creates a potential conflict.

Source: Compiled by the authors. Note: Findings column is based on the main finding of the paper. An asterisk identifies peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

5.3 Urban Transportation

Urban transportation systems play an important role in shaping the growth and development of cities. Gonzalez-Navarro and Turner (2018) investigate the relationship between the subway network in the 632 largest cities worldwide and cities' population, spatial configuration, and transit ridership. Large cities are more likely to have subways, although having a subway does not significantly affect the rate of urban growth. The data also indicate that subways cause cities to decentralize, with a doubling of the subway network causing the share of all light rail within 5 km of the center to decrease by about 2.2 percent in an average city. Curiously, subway expansion did not seem to have any impact on bus ridership. However, a 10 percent increase in subway extension does lead to a 6 percent increase in subway ridership.

A similar decentralization effect to the one that subways have on cities has also been observed with radial roads. In an early study of the United States, Baum-Snow (2007) concluded that a single interstate highway causes about 9 percent of the population of a U.S. city to decentralize. The study simulates welfare gains of 2 to 3 percent per additional highway ray for U.S. cities based on commuting cost effects.

Baum-Snow et al (2017) go on to examine similar issues for Chinese cities in the period 1990-2010. Similarly, they found that each radial highway displaces 4 percent of the city center population to surrounding regions, and ring roads displace about an additional 20 percent, with stronger effects in the richer coastal and central regions. The effect of railroads is even more pronounced. Each radial railroad reduces city center industrial GDP by about 20 percent, with ring roads displacing an additional 50 percent. These effects also lead to welfare gains, as the improved access provided by the infrastructure leads to cheaper housing in outlying areas while at the same time lowering the commuting costs per unit of distance traveled. Cheaper space increases firms' allocation of space per worker, thereby increasing real wages and improving residents' welfare. There are also potential productivity gains from railroads facilitating the movement of industrial production out of city centers, freeing up space for less land-intensive activities such as tradable services that stand to benefit more from agglomeration spillovers.

In developing cities, central areas with good accessibility concentrate the bulk of formal jobs, while lower-income peripheral areas, on the other hand, display limited accessibility and a high incidence of informal employment. As urbanization patterns spread out, public transport plays a critical role in ensuring that jobs remain accessible. Moreno-Monroy and Ramos (2021) estimate

the impact of public transport system expansions on local informality rates for the São Paulo Metropolitan Region in Brazil by comparing the average changes in informality in areas that received new public transport infrastructure with the average changes in areas that were supposed to receive infrastructure according to official plans but did not because of delays. Informality rates decreased on average between 1 and 7 percentage points more in areas receiving new public transport infrastructure compared to areas that faced project delays.

Bird and Straub (2020) study the impact of the rapid expansion of the Brazilian road network on the growth and spatial allocation of population and economic activity across the country's municipalities. The analysis reveals that better access to large urban centers generates agglomeration effects in terms of population and income growth. The shape of a highway network impacts local income and population through improved transport access, the economic strength of the municipality, as well as the economic characteristics of the interconnected points.

Table 13: Survey of selected papers on the impact of urban transportation

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Gonzales-Navarro & Turner (2018) *+	City	Global	Urban growth	Large cities are more likely to have subways, which do not contribute to urban growth, but do cause cities to decentralize.
Baum-Snow et al (2017) *	Prefecture	China	Urban growth	Each radial highway displaces 4% of city center population to surrounding regions, reducing city center GDP by about 20%.
Bird & Straub (2020) *	Municipality	Brazil	Urban Growth	The heterogeneity of impact of a transport cost reduction depends on the characteristics of the end point.
Moreno-Monroy & Ramos (2021) *	Weighted spatial area	Brazil	Labor market informality	Informality rates decreased by 1-7% more in areas receiving new public transport infrastructure compared to those facing project delays.
Gaduh et al (2022) *	Community	Indonesia (Jakarta)	Labor market access	BRT proximity neither reduced vehicle ownership nor travel times, nor increased commuter flows, but rather exacerbated congestion.
Gonzalez-Navarro & Quintana-Domeque (2016)*+	Household	Mexico	Household wealth	First time asphalting of residential streets in poor neighborhoods increases home values by 17% and land values by 72%.
Chen & Whalley (2012) *	Prefecture	Taiwan, China	Local air pollution	Opening the metro reduced air pollution (carbon monoxide) by 5 to 15 percent.
Lu et al (2017)+	City	China (Beijing)	Local air pollution	Workdays during school holidays have 20% lower traffic congestion than others, leading to significant decrease in PM10 concentration.
Tsivandis (2019)+	Census tract	Colombia (Bogotá)	Welfare	BRT would have higher welfare impacts and generate more government revenue if combined with land value capture.
Gu et al (2021)*	Road segments	China	Congestion	After first year of subway line launch, rush-hour speed on nearby roads rises by 4% with time savings valued at US$0.10 per vehicle.

Source: Compiled by the authors.

Note: Findings column is based on the main finding of the paper. An asterisk identifies peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

Rapid increases in population and vehicle ownership have led to unsustainable commuting times and deteriorating air quality (e.g., Brinkman, 2016; Lu et al, 2017; Simeonova et al, 2019). Hence the need for improved public transportation as cities grow. In many settings, subway systems have been shown to reduce congestion (Yang et al., 2018; Gu et al.,2021), improve air quality (Chen and Whalley, 2012; Gendron-Carrier et al., 2022), and increase public transit ridership (Gonzalez-Navarro and Turner, 2018). The handful of studies in the dataset point out that high-quality bus rapid transit (BRT) implementations have also been shown to substantially increase welfare, output, and overall public transit use (Tsivanidis, 2019; Majid et al., 2018).

A counterexample, however, is the public transit system in Jakarta (Indonesia), which actually led to increased congestion, highlighting the importance of implementation quality in urban infrastructure projects. Gaduh et al (2022) study the commuting effects of TransJakarta, one of the world's largest BRT systems. In contrast to earlier work, the authors find that BRT station proximity neither reduced vehicle ownership nor travel times, nor did it increase commuter flows. Instead, the BRT exacerbated congestion along service corridors. This can be attributed to design failures, which make it difficult for commuters to access the system and have led to premature deterioration of sidewalks around stations, as well as the poor quality of feeder bus services and the absence of transit-oriented commercial or residential development.

5.4 Railroads

While the road sector has historically been the primary internal mode of transport for both freight and passengers in many countries, railroads can provide a more efficient means of transport for distant cities or remote production locations. Jedwab and Moradi (2016) study the longer-term effects of transport investments in low-income countries in Africa. They find that railroads had large effects on the distribution of economic activity during the colonial period and these effects have persisted to this day, even though the original railroads collapsed, and road networks expanded considerably after independence. Initial transportation investments may thus have large long-term effects in developing countries. Moreover, contrary to Chandra and Thompson (2000), Jedwab and Moradi (2016) find that railroads produced an increase in the level of economic activity rather than just a spatial reorganization of prior economic activity in Africa.

Donaldson (2018) aims to understand the magnitude of benefits from rail infrastructure, and the channels through which they operate. Based on historical data from colonial India (which corresponds to contemporary India, Pakistan, and Bangladesh), the study concludes that railroads decreased trade costs and interregional price dispersion, hence increasing interregional and international trade. This led to an increase in real agricultural income, which rose by 16 percent on average when the railroad network was extended to a district.

Nevertheless, the unpredictability of monsoon rains left colonial India highly exposed to famines, given its dependence on rain-fed agriculture. By reducing internal transportation costs, the arrival of the railroad networks could potentially allow food to be moved around the country as a means of improving food security. Burgess and Donaldson (2010) investigate the issue of how trade changes the weather-to-death relationship, by employing a colonial era Indian district database for the period 1875 to 1919. They show that the arrival of railroads in Indian districts dramatically limited the ability of rainfall shocks to cause famines in the colonial era. On average, before the arrival of railroads, local rainfall shortages led to a significant rise in the index of famine intensity. But after a district gained railroad access, the effect of local rainfall shortages on famine intensity was significantly muted. Burgess and Donaldson (2010) suggest that investments in transportation infrastructure like railroads that enable internal trade can play an important part in improving food security.

Chen et al (2016) study the heterogeneous effects of inter- and intra-city transportation infrastructure on the growth of 219 Chinese cities for the period 1999 - 2012. The long-term contribution of inter-city infrastructure in the form of highways or railways accounts for 6 percent of city growth, that of intra-city public transit being 2 percent. The core cities are found to benefit more from these infrastructures than peripheral cities. The impacts of transport infrastructures on economic growth are heterogeneous across regions, with more productive impacts in the west. Policy-wise, cities seem to benefit from intra-city transit in the short run, but most of the long-term benefits are brought by inter-city transportation facilities. In addition, infrastructure investments are most productive in core cities at the expense of peripheral cities. It is important to consider these trade-offs between regional inequality and efficiency while designing investment strategies.

Table 14: Survey of selected papers on the development impact of railroads for freight

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Jedwab & Moradi (2016)*+	Cell	Sub-Saharan Africa	Output	Colonial railroads had large and durable effects on the level and spatial distribution of economic activity, even after they were replaced by roads.
Donaldson (2018) *	District	India	Income	Colonial railroads decreased trade costs and increased domestic and international trade, boosting real agricultural income by 16% on average.
Burgess & Donaldson (2010)*	District	India	Food security	Colonial railroads greatly reduced incidence of famine due to drought affecting rainfed agriculture, by allowing food to be traded internally.

Chen et al (2016)*	Prefecture	China	Urban growth	Inter-city infrastructure (road, rail) accounts for 6% of city growth in the long-term, favoring core cities at the expense of more peripheral ones.

Source: Compiled by the authors. Note: Findings column is based on the main finding of the paper. An asterisk identifies peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

5.5 Ports

Port efficiency is an important determinant of shipping costs in which distance, volumes, and product characteristics all matter. For most Latin American countries, transport costs are a greater barrier to U.S. markets than import tariffs. The limited empirical studies in our dataset, focusing mainly on Latin America, find clear evidence that port efficiency materially reduces maritime transport costs, thereby reducing economic distance, boosting competitiveness and expanding trade.

Clark et al (2004) investigate the determinants of shipping costs to the United States from different ports around the world. Improving port efficiency from the 25th to the 75th percentile reduces shipping costs by 12 percent. Bad ports are equivalent to being 60 percent farther away from markets for the average country. Inefficient ports also increase handling costs. At the same time, reductions in country inefficiencies, associated with transport costs, from the 25th to 75th percentiles imply an increase in bilateral trade of around 25 percent. In turn, factors explaining variations in port efficiency include excessive regulation, the prevalence of organized crime, and the general condition of the country's infrastructure. The authors also emphasize that some level of regulation increases port efficiency, but excessive regulation can be damaging.

The positive impact of port efficiency on trade is confirmed by several other studies. By using port efficiency measures from a survey of Latin American port terminals in 1999 and conducting a principal component analysis, Sanchez et al (2003) show that trade cost decreases by 0.06 percent because of a 1 percent increase in port efficiency. Similarly, Wilmsmeier et al (2006) show that a 1 percent increase in port efficiency leads to a 0.38 percent reduction in trade costs in 16 Latin American countries in 2002. Herrera Dappe et al (2017) find that the more efficient the port, the lower the maritime transport costs in the Indian and Western Pacific Oceans. An efficient port sector would reduce countries' average maritime transport costs by up to 14 percent and increase exports by up to 2.2 percent.

Table 15: Survey of selected papers on the development impact of ports

Author	Level of Analysis	Country/ Region	Indicator of Development	Main Findings
Clark et al (2004) *+	County	Global	International Trade	Improving port efficiency from the 25th to the 75th percentile reduces shipping costs by 12%. Bad ports are equivalent to being 60% further away from markets.

Sanchez et al (2003) *	Port	Latin America	International Trade	A 1% improvement in port efficiency leads to a 0.06% decline in maritime transportation costs, affecting a country's relative competitiveness.
Wilmsmeier et al (2006) *	Trade transaction	Latin America	International Trade	A 1% improvement in port efficiency leads to a 0.38% decline in maritime transportation costs, which is much larger than other determining factors.
Herrera-Dappe et al (2017)+	Trade transaction	Asia	International Trade	An efficient port reduces average maritime transport costs by 14%, boosting exports by 2.2%, making this a key determinant of competitiveness.

Source: Compiled by the authors.

Note: Findings column is based on the main finding of the paper. An asterisk identifies peer-reviewed papers. Plus identifies papers following the instrumental variable approach.

6. Conclusions

This paper has provided a qualitative synthesis of the main findings of a new body of literature that has accumulated over the last decade or so, providing micro-economic insights on how different types of infrastructure contribute to the development process in low- and middle-income countries.

When it comes to digital infrastructure, a relatively small emerging literature confirms the positive and significant effects of broadband internet coverage on economic development, both at the macroeconomic and microeconomic levels. Recent studies show that the arrival of broadband internet coverage has boosted firm productivity and led to higher levels of employment, particularly for – though not confined to – those with higher skill levels. At the same time, recent studies suggest that access to the internet has also boosted household welfare and reduced poverty even in lower income African countries. In addition, there is significant evidence that the availability of modern communications improves the efficiency of agricultural markets by reducing price dispersion and improving coordination between producers and traders. More recently, researchers have turned their attention to the role of digital technologies in facilitating public protests.

A significant strand of the literature documents the impact of electrification in low and middle-income countries. Studies focusing on spatial impacts find that electrification supports the process of structural transformation, by allowing migration to higher value-added activities beyond agriculture. At the household level, electrification has been found to increase labor force participation (especially among women), as well as supporting the establishment of non-farm businesses. Some studies also point to benefits in terms of education and indoor air quality. Nevertheless, studies based on experimental rather than econometric methods tend to find much smaller economic impacts from rural electrification.

Given that power supplies in low and middle-income countries are too often characterized by unreliability, a smaller related literature examines the benefits of reducing power outages, focusing mainly on firms. These studies show that more reliable power supply can boost firm productivity, output, and employment.

There is a particularly rich literature on microeconomic transport-to-development linkages, particularly for rural roads and for Sub-Saharan Africa. This brings significant evidence that rural roads reduce poverty and contribute to household welfare by raising income and consumption, expanding (self-) employment opportunities, and improving food security. Rural localities benefiting from improved market access also see an increase in agricultural production, more widespread uptake of modern agricultural techniques, and reduced dispersion of prices. Reducing the isolation of small towns similarly leads to expanded output, increased specialization, and higher exports. Turning to national highway networks, the findings are that these contribute substantially to boost manufacturing output and associated exports, among other things by facilitating greater industrial specialization and enhancing competition. There is evidence that over time this may lead to the convergence of lagging regions, but at the same time tending to concentrate population and economic activity in regional primate cities.

In urban areas, public transportation systems have the dual effect of facilitating the decentralization of cities by improving the accessibility of lower cost outlying residential land, while at the same time facilitating the commuting of workers to access a larger range of employment opportunities in urban centers, thereby reducing informality.

Turning to other transport infrastructures, railways have been found to have a long-term impact on countries' development patterns, with their tendency to lock-in spatial patterns of economic activity. The arrival of railroads in rural areas during the colonial period has been shown to have enhanced agricultural output and trade as well as improving food security. At the same time, inter-city railways have played a role in concentrating urban populations. Though not having comprehensive evidence in the dataset as in the other sub-sectors of transport infrastructure, the findings point out that port infrastructure also plays a vital role in international trade, significantly affecting a country's international competitiveness, and – when operating efficiently – able to compensate substantially for the effect of geographical distance.

The exponential expansion of the academic literature on the development impacts of infrastructure has been fueled by the availability of much richer sources of microeconomic data on firms and households, often with geospatial characteristics, as well as the associated analytical techniques. Compared to the earlier literature that focused primarily on cross-country panel data econometrics based on crude high-level measures of infrastructure, the new body of work provides a much richer and more granular understanding of the specific channels through which different kinds of infrastructure data can contribute to development overall. While the results can sometimes be mixed, and methodological controversies remain, the overwhelming balance of evidence suggests that improvements in infrastructure play a vital role in supporting the development process.

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