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Edited by Gregory K. Ingram and Karin L. Brandt

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PREFACE

This volume, based on a conference held in Cambridge, Massachusetts, in June 2012, addresses the links between infrastructure and land, particularly in urban areas. While infrastructure is as old as cities, technological changes and public policies on taxation and regulation produce new issues worthy of analysis, ranging from megaprojects and greenhouse gas emissions to private participation and involuntary resettlement. This is the seventh in a series of volumes that address land policy as it relates to a range of topics including climate change, municipal revenues and value capture, fiscal decentralization, and property rights.

In addition to the authors and conference participants, many others have contributed to the design of the conference and the production of this volume. We thank Armando Carbonell, Martim Smolka, and Joan Youngman for their advice on the selection of topics and on program design. The conference would not have been possible without the logistical support of our conference event team, comprising Brooke Burgess, Sharon Novick, Cindy Moriarty, and Melissa Abraham. Our special thanks go to Emily McKeigue for her overall management of the production of this volume, to Vern Associates for the cover design, and to Nancy Benjamin and Judith Riotto for their tireless and reliable copyediting.

Gregory K. Ingram
Karin L. Brandt

Infrastructure, Land, and Development

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Global Infrastructure: Ongoing Realities and Emerging Challenges

Gregory K. Ingram and Karin L. Brandt

More than 50 percent of the global population resides in urban areas where the interactions between land policy and infrastructure facilitate economic opportunities, affect the quality of life, and condition patterns of urban development. Infrastructure drives economic and social activities and represents the "wheels" of economic activity. Transportation and telecommunications facilitate business and trade, while energy and water are necessities for production processes. Transportation connections within urban areas expand labor markets, and the provision of basic needs to households—water, sanitation, and electricity—prevent the spread of disease and increase life spans. Infrastructure facilities provide the spatial skeleton supporting the location of residences, commerce, industry, and governmental activities. As cities grow, the demands on infrastructure facilities and services that support economic activity increase. For urban areas, the challenges of balancing growth with infrastructure development and maintenance are reflected in debates about infrastructure's finance, regulation, and location and about the sustainable levels of its services.

Infrastructure sectors include energy (electricity and natural gas); telecommunications (fixed phone lines, mobile phone service, and Internet connectivity); transportation (airports, railways, roads, waterways, and seaports); and water supply and sanitation (piped water, irrigation, and sewage collection and treatment). Infrastructure services have technical features such as economies of scale and economic features including externalities and spillovers from users to nonusers that make many of them difficult to provide as a normal private good. Because of these attributes, much infrastructure is either publicly provided or

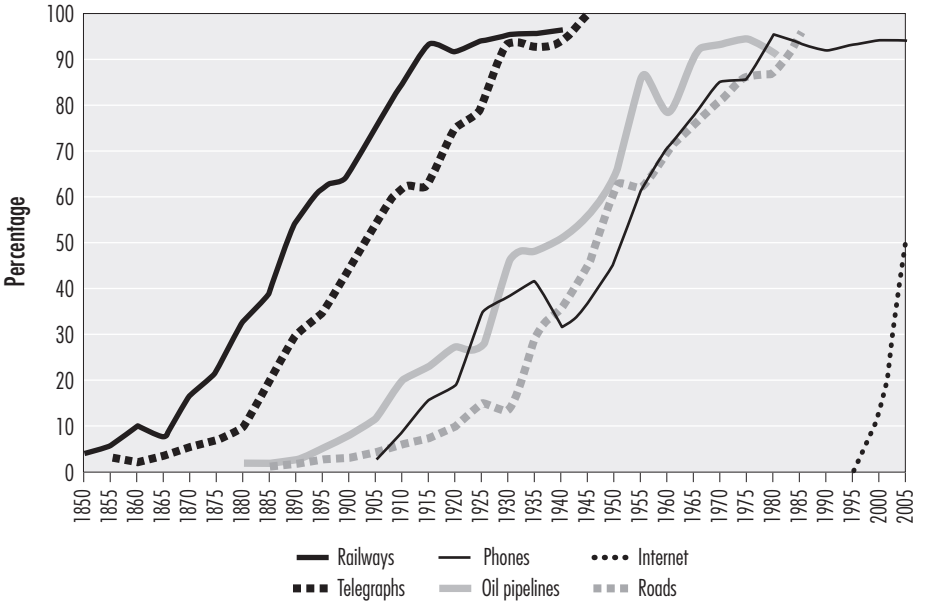
privately provided with regulatory oversight. Infrastructure also delivers economic and poverty-alleviation benefits when it responds to demand and is provided efficiently.

Infrastructure provision is a major determinant of the location of economic activities and of the spatial pattern of development of the built environment. Transport infrastructure in the form of canals, railroads, and highways provides improved access to adjacent land, which in turn is developed by businesses seeking to reduce the costs of shipping inputs to their plants and outputs to their customers. Individuals similarly prefer locations well served by transport in order to widen their labor market opportunities and to ease their shopping and social interactions. Infrastructure services such as energy, water supply, and sanitation make the locations they serve more attractive. Community leaders spend much time devising zoning systems, property taxes, impact fees, and extensions of infrastructure services that strongly affect development patterns in urban areas. In developing countries, the challenge is to provide infrastructure before development occurs because it is much less costly to do so beforehand than to retrofit services in an already developed area.

The historical development of new infrastructure sectors and services has been driven by technological advances that respond to existing needs. Roads and canals are the world's oldest infrastructure sectors. In the nineteenth century, new infrastructure technologies lowered the costs and increased the demand for transportation services. In the United States, extensive networks of canals were constructed in the early nineteenth century, soon to be followed and replaced by railways in the mid-nineteenth century during the Industrial Revolution. The paving material of stone and soil macadam improved road quality, allowing for greater vehicle weights and higher speeds. Around the same time, poor sanitation in cities led to the spread of diseases like cholera. The need in urban areas for fire prevention and household sanitation led to the extension of the water supply and sewer lines. The development in the 1880s of alternating current and long-distance transmission enabled larger generators to take advantage of scale economies, reducing the cost of electricity. Telecommunication expansion saw the spread of the telegraph in the second half of the nineteenth century, the diffusion of the land-line telephone system in the first half of the twentieth century, and now the adoption of mobile phones and the Internet in the past two decades.

Newly introduced infrastructure technologies expand their networks quickly because of their lower costs and often higher-quality service, displacing previous competing services. In the United States, railways and telegraphs quickly expanded their network coverage at a similar rate, achieving their mature size in about 45 years (figure 1.1). Railways were a substitute for canals, and the telegraph was later largely displaced by telephone services. Although the spread of telephone land lines was briefly slowed by the Great Depression, their expansion continued, and their dominance is now being threatened by mobile phones. The success of mobile phones is partly based on service convenience, but cost reductions have also played an important role. For example, the investment cost

Figure 1.1
Growth of U.S. Infrastructure as a Percentage of Maximum Network Size, 1850–2005



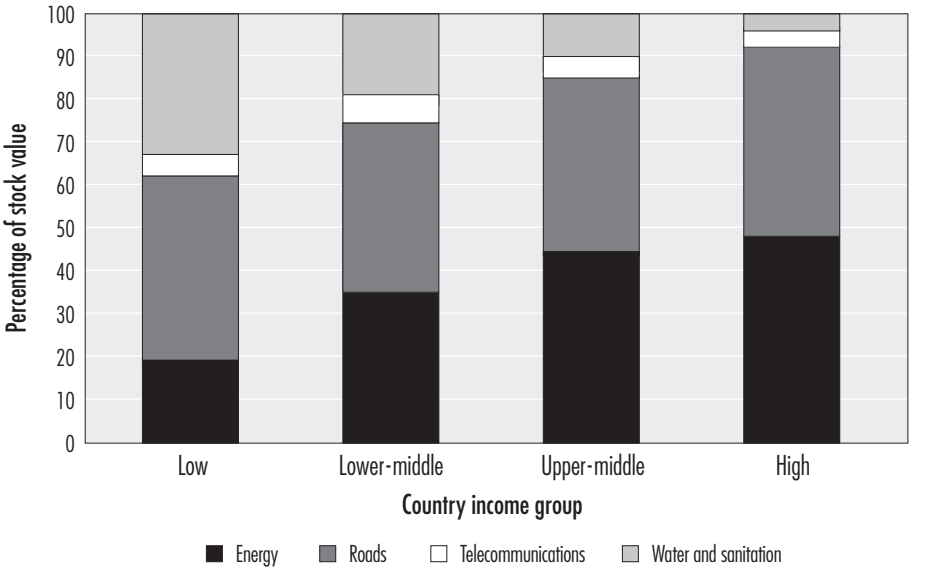
Sources: Grübler (2003); Norris (2002).

associated with a mobile phone subscription fell from around $700 in 2000 to only $100 today (Chatterton and Puerto 2005). Since the mid-1990s, the Internet network has been growing at a faster rate than other recent infrastructure technologies, and its price continues to fall while its service quality increases.

The total value of infrastructure facilities across countries varies proportionally with country incomes. Moreover, the sectoral composition of infrastructure varies significantly across country income groups (figure 1.2). As a result, countries with high economic growth rates need to invest higher shares of country income in infrastructure facilities to maintain the balance between infrastructure and output. Industrialization and income growth increase the demand for energy to support development, and the energy sector grows more rapidly with income than other sectors, such as water and sanitation. Roads make up a fairly constant share of total infrastructure value across all country income groups.

While infrastructure technology continues to advance, many debates about infrastructure also persist. A key debate concerns the extent of infrastructure's impact on economic growth, urban development, and social development. Private investment and development assistance for infrastructure have increased in the past two decades, partly in response to evidence showing high rates of return for

Figure 1.2
Composition of Infrastructure Stock Values Varies with Country Income



Sources: International Telecommunications Union (2010); World Bank (2012).

infrastructure investment. An ongoing debate in the United States concerns the adequacy of infrastructure maintenance and how it should be financed. Debates also continue about other aspects of infrastructure, such as its regulation and taxation. In many countries, the private sector is replacing the public sector in providing infrastructure services. This requires the public sector to take on an explicit regulatory role that often remains implicit when services are publicly provided. In developing countries, private participation in infrastructure (PPI) investment has dramatically increased since 1990, and new sources of finance have become available, especially for well-defined projects such as power-generation facilities or mobile phone franchises. Large infrastructure projects continue to be a challenge for infrastructure provision—with political complications and detrimental social impacts that include involuntary resettlement. Mega-events, such as the Olympic Games, often catalyze large infrastructure investment programs that have had decidedly mixed postevent consequences. Finally, climate change concerns have directed attention to improving the sustainability and efficiency of infrastructure.

Infrastructure, Land, and Development

Infrastructure looms large in terms of a country's share of annual investment, its share of the total stock of capital in an economy, its contribution to economic

growth, its effect on human welfare, and its influence on spatial development patterns. Annual investment in infrastructure ranges across countries from a low of around 2 percent of gross domestic product (GDP) up to 8 percent—or even higher in rapidly growing economies. The public sector plays a large role as a direct provider of investment, as a provider of services, and as a regulator of services provided by itself and others. At the same time, the share of private investment in infrastructure can be large, ranging up to half or more of annual infrastructure investment in some countries. The value of cumulative infrastructure investment—the physical stock of all existing infrastructure—is also large, with its value averaging around 60 percent of GDP across countries (Ingram, Liu, and Brandt 2013).

Infrastructure services increase economic productivity by offering firms and households efficient and inexpensive services that enable them to reduce their transportation, energy, water, sanitation, and communication costs. Lower transportation costs reduce price differences over space and underpin some of the earliest theories about the distribution of land use and agriculture around urban centers (von Thünen 1966). Adequate infrastructure is seen as a key determinant of international competitiveness because it can reduce production costs, ease international transportation, and even facilitate the availability of labor and specialized services to firms.

Economists use several approaches to measure the productivity impacts of infrastructure. At the microeconomic level, infrastructure project rates of return are often substantial and higher than those in other sectors such as agriculture and human services (World Bank 1994). At the macroeconomic level, production functions, cost functions, and cross country studies are the main approaches used to estimate the productivity of infrastructure. Production functions estimate the contribution of infrastructure to national output, such as GDP, typically in a single country over time. The results are often summarized in terms of the percentage increase in national output that is associated with a 1 percent increase in the amount of infrastructure (the elasticity of output with respect to infrastructure). The amount of infrastructure is measured either by constructing a perpetual inventory (adding up depreciated annual investment amounts from the past) or by using current data on physical quantities of infrastructure, such as miles of paved road or installed generating capacity, multiplied by their unit cost. Data for the perpetual inventory approach are not as widely available as data on physical quantities of infrastructure, and private investment is particularly elusive, so the production function approach tends to focus on public investment. Some analysts argue that the costs of public infrastructure investment may include extra expenditures for inefficiencies such as overcapacity or side payments and therefore are biased upward (Pritchett 2000). Cost functions explore the extent to which infrastructure reduces costs at the firm level, and these are also usually estimated based on data from a single country over time. Cross country studies relate national amounts of infrastructure (typically using physical quantities) to national outputs, usually at a single point in time.

Table 1.1
A Majority of Studies Find That Infrastructure Increases Productivity

	Infrastructure Effect (% of studies)			Number of Studies
	Negative	None	Positive	
Overall results	5.7	31.4	62.9	140
By infrastructure proximity				
Public capital	10.8	40.0	49.2	65
Physical indicator	1.3	24.0	74.7	75
By approach				
Production function	2.9	36.2	60.9	69
Cost function	7.7	15.4	76.9	13
Cross country regression	13.8	37.9	48.3	29

Source: Straub (2008).

Straub (2008), who reviewed and summarized 140 empirical studies examining the effect of infrastructure on productivity, reported that nearly two-thirds of the studies found a positive relation (table 1.1). Studies using physical measures of infrastructure were more likely to find positive effects than those based on accumulated past investment. Typical results using production functions and physical measures report elasticities of output with respect to infrastructure around 0.1 (Calderon, Moral-Benito, and Serven 2011). This indicates that the rate of return to infrastructure investment is around 16 percent if infrastructure stocks average 60 percent of GDP, meaning an investment that increased infrastructure stocks by 1 percent would cost 0.6 percent of GDP and increase output by 0.1 percent of GDP.

Most analyses of returns to infrastructure focus on countries, and few estimate returns to metropolitan areas. However, investment data are available for two unique metropolitan areas: the special administrative region of Hong Kong and the city-state of Singapore. Their average economic growth rates from 2000 to 2010 are 4.4 percent and 5.9 percent, respectively. Between 2007 and 2010, Hong Kong's infrastructure expenditure averaged 2.56 percent of its GDP, and Singapore's averaged 6.44 percent, supporting the view that higher growth rates are associated with higher infrastructure expenditures (albeit over a short period of time in these cases). As Yan Song points out in chapter 2, China—which has one of the most rapidly growing economies—proposes to invest around US$1.03 trillion on urban infrastructure during its 12th Five-Year Plan from 2011 to 2015. This is slightly more than 3 percent of its total GDP projected

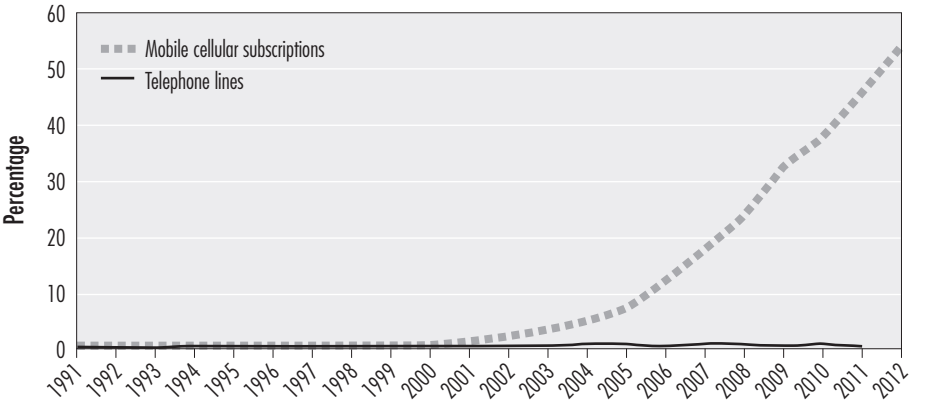
over the five-year period—a share larger than many countries routinely invest in all national infrastructure needs.

In addition to increasing economic productivity, infrastructure promotes human welfare by reducing the cost of accessing markets: helping farmers get their crops to market and workers get to jobs. Infrastructure investment also shapes urban growth patterns, which are linked to transportation networks that serve local demand and connect cities to expand labor markets and increase incomes. In developing countries, rural roads also allow easier access to health care and education, facilitating human capital formation. Adequate infrastructure can reduce consumption costs for households. For example, the cost of piped water in underserved informal settlements is a fraction of the cost of trucked-in water, and for illumination, electric lights cost much less than candles. Household consumption of infrastructure services improves household productivity, but measuring this productivity increase is difficult because household production is not included in standard measures of national product. Thus, increases in household productivity are not normally included in estimates of the productivity impacts of infrastructure, such as those summarized in table 1.1.

Infrastructure is likely to have collateral benefits that may be of particular importance to the poor. Improved infrastructure may benefit the poor by increasing the value of their assets. For example, improved rural transportation can increase the value of agricultural land in rural areas, much of which may be owned by low-income households. Better and safer roads raise school attendance; access to electricity allows more time to study and makes computer use possible; and improved water and sanitation reduce child mortality. Empirical work is finding that infrastructure development is associated with reduced income inequality (Calderon and Serven 2008; Lopez 2004). Infrastructure improvements may not only increase output, but may also provide a host of benefits to low-income households.

For example, infrastructure services create developmental and social impacts at the individual level. Clean water and sanitation service have improved the health and extended the life expectancies of urban residents, while social relationships have been transformed by telecommunications, particularly mobile phones in developing countries. Communication in rural areas in the global south is changing rapidly as mobile phones supplant fixed phone lines. This change is most notable in sub-Saharan Africa (figure 1.3). The revolution in mobile telephony that is sweeping through Africa has made it much easier for residents in rural areas and small towns to become knowledgeable about market prices, to learn of opportunities in other locations, and to keep in touch with distant relatives and friends. The mobile technology itself creates new jobs: running charging stations where electricity is not readily available, selling mobile credit for minutes, and repairing mobile phones. This transformation is changing relationships as people once spatially isolated become connected through mobile communication. In chapter 3 Mirjam de Bruijn illustrates this impact with anthropological case studies in four sub-Saharan African countries.

Figure 1.3
Mobile Cellular Subscriptions Bypass Telephone Lines in Sub-Saharan Africa, 1991–2011



Source: World Bank (2012).

Finance, Regulation, and Taxation

The economic and social benefits of infrastructure are great, but so are the costs of developing and maintaining infrastructure. Governments continue to experiment with various financing mechanisms, including fee-for-service pricing arrangements and related revenue-collection schemes. Finance methods vary widely across infrastructure sectors and countries, although user charges, subsidies from general funds, and borrowing are the primary sources used to pay for operating costs and investment. User fees are common in many sectors, including telephone use, power consumption, transit fares, and travel on toll roads. Examples of indirect cost recovery include fuel taxes, vehicle registration fees, some property taxes, and land-based revenues. Borrowing from public and private lenders is advantageous given the long life of many infrastructure facilities. Industrialized countries have long used sovereign bond finance to fund hydroelectric dams and road systems, and municipal bonds to finance local infrastructure. These practices are being adapted to the needs of developing countries. For example, Johannesburg's "Jozi bonds" support the provision of infrastructure services in poorly serviced townships that were incorporated into municipalities following the end of apartheid.

The need for innovative financing schemes to support rapid growth has drawn attention to the use of land-based finance. Land value capture—the practice of using land value increases associated with service provision to finance infrastructure—was the subject of the Lincoln Institute's previous Land Policy

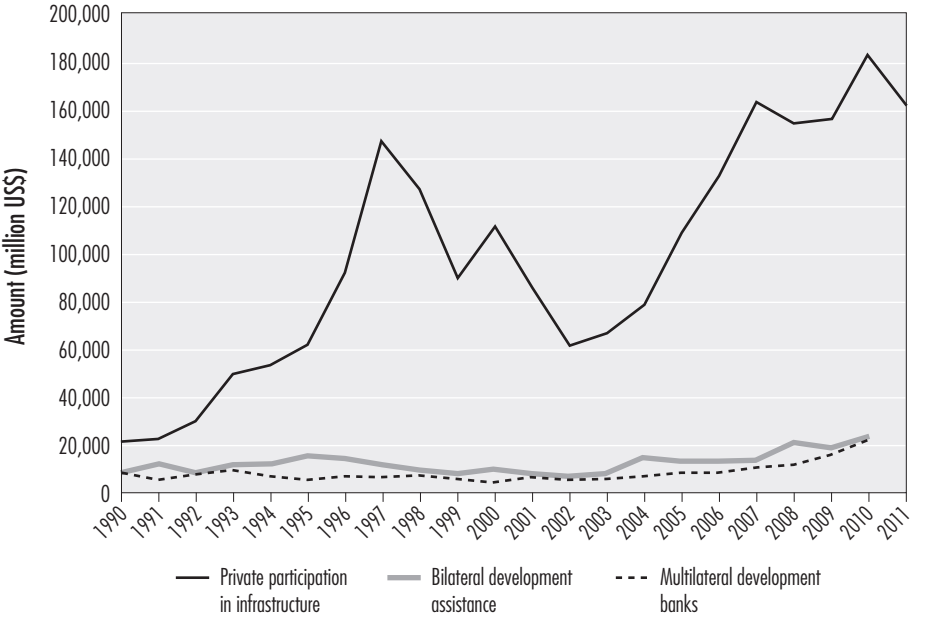
Series volume.[1] Value capture is a common practice in Latin America, and variations of this method are used in other countries. In Bogotá, Colombia, betterment levies have supported infrastructure development since the 1930s, including roads, water and sewer, and more recently sidewalks and public parks (Borrero et al. 2011). Transit companies in Hong Kong and Tokyo used value capture to finance transit projects with revenue from the codevelopment of residential and commercial areas served by transit, and Ahmedabad, India, is known for its Town Planning Scheme, which uses a land readjustment process to finance infrastructure for newly urbanized land (Ingram and Hong 2012). Proceeds from the sale of urban land is a major revenue source used to fund infrastructure in China, and the sale of development rights is a growing source of revenue in Brazil.

While high- and middle-income countries are more concerned with financing infrastructure maintenance or infrastructure that supports growth, many low-income countries face large infrastructure needs. In developing countries, the projected annual cost of infrastructure investment (US$450 billion) and maintenance needs (US$305 billion) totals US$755 billion, which is nearly 5 percent of the countries' aggregate GDP (Ingram, Liu, and Brandt 2013). External funding commitments for infrastructure have grown substantially and now cover about 46 percent of projected investment in developing countries. This total comprises bilateral development assistance (US$22 billion in 2010); regular and concessional financing from multilateral development banks (US$23.7 billion in 2010); and private participation in infrastructure (US$161.7 billion in 2011) (figure 1.4). Some developing countries are now investing in infrastructure in other developing countries. This so-called south-south financing has been growing, as enterprises in one country invest in those in other countries, a practice that has been under way for some time in Latin America. More recently, some developing countries, especially China, have been investing in infrastructure projects in sub-Saharan Africa, often in arrangements where loans are repaid with commodity exports (figure 1.5).

The movement in developing countries toward greater private sector involvement in infrastructure development is not unprecedented. Private finance and ownership of infrastructure—including railroads, transit, and canals—were common in the nineteenth century. Much infrastructure finance shifted to public sources in the mid-twentieth century and then back to public-private partnerships starting in the 1980s. In Europe, power and telephone services were largely publicly provided, whereas they have been privately provided in the United States and regulated in terms of service quality, universal service obligations, and price (usually based on the utility's rate of return). The United States has more than 100 years of experience with the regulation of utility infrastructure, as Janice A.

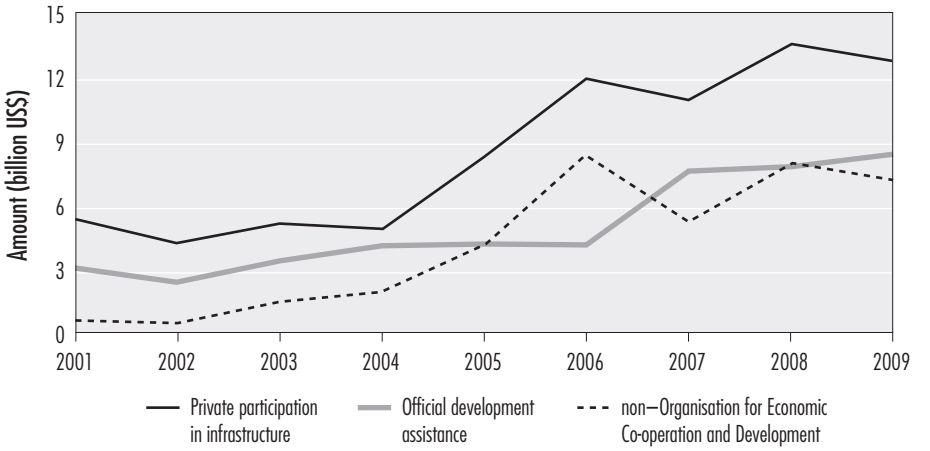
1. See the sixth volume in the Land Policy Series, *Value Capture and Land Policies*, ed. Gregory K. Ingram and Yu-Hung Hong (Cambridge, MA: Lincoln Institute of Land Policy, 2012).

Figure 1.4
Private Participation in Infrastructure Versus Development Assistance, 1990–2011



Sources: OECD (2012); World Bank (2012); World Bank and Public-Private Infrastructure Advisory Facility (2011).

Figure 1.5
South-South Non-OECD Investment Growth in Sub-Saharan African Infrastructure, 2001–2009



Sources: Foster et al. (2008); World Bank (2012); World Bank and Public-Private Infrastructure Advisory Facility (2011).

Beecher points out in chapter 4. The first U.S. regulatory agency for infrastructure was the Interstate Commerce Commission (ICC), which was established in 1887 to address railway price discrimination. Other regulatory agencies then followed to control monopoly power and pricing. Technological advances and the advent of competing services (e.g., trucking that competes with rail) have led to deregulation. Thus, the ICC was abolished in 1995, and deregulation has advanced in telecommunication, trucking, and air travel in the United States.

Privately owned infrastructure service providers in the United States, such as airlines, gas and electric utilities, railroads, water companies, and telecommunications firms, are typically subject to property taxation, often at rates that are much higher than residential rates. This is an often-overlooked topic in property taxation, and most service users are unaware that their utility bills cover such taxes. This tax base is of great importance to any local government that hosts utility plants and equipment. Utility property is generally assessed by state agencies using methods that differ markedly from those employed by local assessors, with results that are often controversial and complex, as noted by Gary C. Cornia, David J. Crapo, and Lawrence C. Walters in chapter 5. Some utilities pay a substantial portion of their revenues in property taxes, such as Consolidated Edison Co. of New York, which pays 12 percent of its gross operating revenues in property taxes.

Just as physical infrastructure affects urban development patterns, the taxation of motor vehicle use and the pricing of road infrastructure shape land policy by affecting location choices and land values. Researchers and planners have debated the impact of tolls, congestion charges, and gasoline taxes on metropolitan development patterns. The locational setting and spatial coverage of toll systems, congestion pricing, or fuel and vehicle taxes have implications for residential and employment location. In theory, congestion charges focused on central locations could either attract jobs and residents to these areas or displace them. Careful simulations by Alex Anas in chapter 6 suggest that congestion tolls in central areas are likely to move jobs and residents to suburban areas, whereas a metropolitan-wide gasoline tax is likely to cause both jobs and residents to concentrate in the city.

The Challenges of Large Projects

Extremely large infrastructure projects, such as a new airport, subway system, or ring road, can produce large changes in land values, location decisions, and development patterns. The United States has seen many such projects in recent decades, including the Washington, DC, Metro, the Denver airport, and Boston's depression of the Central Artery ("the Big Dig"). These were all multibillion-dollar projects whose spatial impacts are still under way long after their completion. For example, the construction of residential, commercial, and office space and the general concentration of economic activity around Metro stations in Washington is still ongoing, 25 years after the bulk of the Metro system was opened.

In addition, infrastructure megaprojects are frequently well over budget. The new Denver airport's final cost was nearly three times its original cost estimate of $1.7 billion, and the Big Dig's cost of $14.6 billion was three and a half times its original cost estimate (all in 2003 dollars). Because megaprojects take a long time to build and their construction spans several terms of governors, mayors, or department secretaries, they inevitably become steeped in political lore.

Most megaprojects are long-lived after they begin operation, and their public and private financing and operation take many forms, as facilities can be transferred back and forth between public and private operators. A common public-private instrument is the flexible build-operate-transfer (BOT) scheme. For example, Kuala Lumpur, Malaysia, has developed three urban rail lines, each with varying BOT agreements and government guarantees for domestic debt. While the financing instrument is important, the outcome of such projects is dependent on numerous factors, many related to the political environment, which facilitate or hinder implementation. In recent years large public facilities have been sold to private firms, a transfer often motivated by government's need for funds. In chapter 7 Louise Nelson Dyble examines the history of political leadership throughout the Chicago Skyway's development as a public project and assesses the lessons from its eventual privatization.

Like megaprojects, mega-events such as the Olympics or the World Cup are associated with large infrastructure investments and promises of high economic returns. However, the evidence from host economies shows that these sporting events typically bring high costs with low rewards, as Victor A. Matheson notes in chapter 8. For the London 2012 Summer Games, a fifth of the total budgeted cost for the new Wembley Soccer Stadium was for infrastructure improvements, including new roads and a renovated transit station to accommodate Olympic traffic. Mega-event facilities may even serve one event's single purpose and not be suitable for other regular events. For the Beijing 2008 Summer Games, the National Aquatic Center, or "Water Cube," opened for public swimming after the Olympics and was later transformed into a large and extraordinarily expensive water park. Some cities have reused sports infrastructure by modifying them to serve universities or professional teams. Nonetheless, the high costs of these short-term mega-events raise questions of economic feasibility for host cities in developing countries.

A perennial issue with megaprojects and mega-events is the involuntary resettlement and forced displacement that are often associated with infrastructure development. Mega-events involve large stadium and transportation projects to support an influx of visitors, and they often cause the displacement of local, low-income residents. An estimated 720,000 low-income workers, renters, and squatters were forcibly evicted to make room for the 1988 Olympic Games in Seoul, South Korea (Davis 2007). In Atlanta, Georgia, the controversial demolition of Techwood Homes, one of the first U.S. public housing projects, located between the Olympic venue and the Georgia Institute of Technology campus, displaced all

of its residents. Similarly, with mega-projects, particularly dams, the objectives of infrastructure development and human development frequently collide, as Robert Picciotto notes in chapter 9. For example, Ghana's Akosombo Hydroelectric Project created the world's largest artificial lake, Lake Volta, which covers nearly 4 percent of the country's land and displaced 80,000 people, nearly 1 percent of the population. The dam provides a substantial amount of electric power to the West African nation and its neighbors, Togo and Benin. The reservoir behind the Three Gorges Dam in China displaced over a million people as of 2008. Differences between resettlement standards promulgated by international agencies and the practices applied by many governments remain unresolved.

Improving Sustainability and Efficiency

Infrastructure facilities and their services produce a variety of spillovers and externalities for nearby activities, for metropolitan areas, and for the environment. Electric power and transportation are energy-intensive sectors that produce emissions that have local consequences (particulates and smog) and global consequences (greenhouse gases). Because of the large scale of emissions, infrastructure will bear a major burden when it comes to reducing emissions, but this burden can become an asset when credits are granted for emission reductions—an outcome that is being realized in some countries. Infrastructure also produces spatial externalities because its location often helps determine the location of residential, commercial, and industrial activities. Accordingly, locating infrastructure is an instrument that can be used to affect spatial development patterns in both urban and rural areas. Infrastructure also has fiscal externalities because its influence on the location of economic activities has consequences for local employment and tax revenues. Finally, because most infrastructure facilities have long lives, the management and stewardship of infrastructure assets are a critical determinant of their efficient use.

Sustainability increasingly affects infrastructure investment patterns, particularly in cities in developing countries where urban populations will more than double—increasing by 2.6 billion people—by 2050. Some governments provide economic incentives to support long-term investments in sanitation and drainage systems that include green infrastructure such as green roofs, rain gardens, and permeable pavements. Energy-efficient power generation from wind, solar, and water sources is growing, and improved technology will decrease prices. Institutional partnerships are critical in creating finance strategies for sustainable infrastructure in cities, as illustrated by Katherine Sierra in chapter 10 with three case studies of cities facing climate change challenges. The regulation of carbon emissions has created a market for financing sustainable energy and transportation infrastructure in developing countries with carbon credits—payments for activities that sequester carbon or reduce emissions. Uganda's West Nile Electrification Project (WNEP) is the World Bank's first sub-Saharan project

to issue carbon credits. The WNEP includes a 3.5-megawatt hydroelectric power plant and a 1.5-megawatt heavy fuel oil–fired power plant that issued more than 20,000 carbon credits. Other strategies identify environmental needs and form responsive public-private partnerships such as the Arab Financing Facility for Infrastructure (AFFI). The Middle East and North Africa region historically receives the smallest share of private participation in infrastructure, and the AFFI seeks to address the pressing needs of rapid population growth and unmet investment needs by supporting public infrastructure services and public-private partnerships that follow Islamic-compliant financing.

Analyzing the economic and environmental impacts of urban infrastructure—whether its contribution to productivity or its generation of greenhouse gas emissions—is very challenging because urban or metropolitan infrastructure is seldom self-contained. Cities almost always import infrastructure services (e.g., power and water) from outside their boundaries, and allocating the costs and benefits of intercity transportation to specific cities is a difficult accounting problem. Accounting for emissions from industrial production and household consumption raises the issue of how to assign the carbon emissions of intermediate inputs and final production goods that originate outside the city. Promising approaches that address this problem specify a boundary around the city or metropolitan area and carefully analyze all transboundary flows of goods and services to analyze both infrastructure and all other movements, as noted by Anu Ramaswami in chapter 11. Results indicate that improvements in energy efficiency and reductions in greenhouse gas emissions will be achieved more readily for buildings (responsible for nearly half of urban greenhouse gas emissions) than for transportation (responsible for nearly a quarter of greenhouse gas emissions).

The location of infrastructure has a major influence on the location of residential, commercial, and industrial activity. In the United States, much has been written about the relationship between highway networks and the spread of low-density residential and commercial development. Less obvious is the major role that infrastructure has played in the location decisions of industrial firms. The growth of trucking and the spread of highway facilities in the United States unmoored many industrial firms from locations next to rail sidings or port facilities. The growing use of assembly lines and related production processes that work best in a one-story rather than a multistory building increased the land area required for many manufacturing facilities. Accordingly, the use of trucking and the need for larger sites stimulated industrial firms to move to suburban and even exurban locations along interstate highways. This move has reduced city tax revenue and employment in many cities as industrial enterprises and their associated suppliers relocated. Some analysts think that a trend toward a third industrial revolution, based on smart manufacturing, will provide incentives for smaller industrial firms to relocate to developed urban areas and that cities need to plan for this possibility by preserving areas for future industrial development,

as Nancey Green Leigh notes in chapter 12. If cities fail to do this, they will have little success in attracting these new smart manufacturing firms and their associated jobs.

To increase productivity and to achieve related environmental goals, infrastructure facilities must produce high-quality services efficiently. This means that the facilities must be maintained so that they achieve their planned useful lives and targeted operating costs. But adequate maintenance faces many challenges, particularly in the United States. Maintenance has large economic returns and reduces long-term investment requirements and consumer costs, but it is often undervalued by revenue-constrained governments. The most recent annual infrastructure "report card" from the American Society of Civil Engineers (2009) issued an overall grade of D for delayed maintenance and underfunding in many categories and estimated that poor road conditions impose costs of $67 billion annually on U.S. motorists. Moreover, repairing neglected roads is two to three times more costly than performing appropriate ongoing maintenance. In chapter 13 Felix Rioja reviews research findings and empirical studies that indicate that optimal levels of maintenance expenditures can increase a country's growth rate and have significant and positive effects on productivity. He also sheds light on why industrialized and developing governments neglect maintenance despite its positive effects.

While research offers some promising insights about how to improve maintenance and the overall performance of infrastructure provision, countries may be able to learn from one another how to improve performance or may even be able to transfer lessons from their strongly performing infrastructure sectors to those with weaker performance. As noted earlier, the value of infrastructure stocks across countries is closely associated with country incomes. However, the performance of the various infrastructure sectors is not strongly associated with country incomes. This is not because some countries are just better at managing infrastructure than others. It is because the performance across infrastructure sectors varies greatly within countries. The low correlation of performance within countries means that if a country is performing well in one sector, such as electric power, it tells one very little about how well it is performing in another sector, such as providing telephone service. Table 1.2 uses data from 83 countries to show that infrastructure stock levels are highly correlated across sectors, but performance in one sector is weakly correlated with, and is a poor predictor of, performance in other sectors within countries. In chapter 14 George R. G. Clarke explores some reasons for this lack of correlation of performance across sectors, and he also assesses which sector's performance is most important to private firms.

Table 1.2
Stock Levels Are Highly Correlated, But Performance Varies Within Countries

Correlation Matrices

Performance Levels (average correlation = 0.34)

	Phone-Line Faults	Electric Loss	Unpaved Roads	Lack of Cell Service
Phone-line faults	1.00			
Electric loss	0.01	1.00		
Unpaved road share	0.22	0.42	1.00	
Lack of cell service	0.75	0.22	0.44	1.00

Stock Levels (average correlation = 0.79)

	Phone Lines	Generating Capacity	Paved Road Share	Mobile Subscriptions
Phone lines	1.00			
Generating capacity	0.86	1.00		
Paved road share	0.83	0.81	1.00	
Mobile subscriptions	0.82	0.75	0.66	1.00

Source: Authors' calculations.

Conclusions

Infrastructure, characterized by Jawaharlal Nehru as a principal element of the commanding heights of the economy, continues to have a key role in economic development. The value of infrastructure facilities increases in step with national income, which is now growing more rapidly in developing countries than in industrial countries. The unprecedented expansion of the urban population of developing countries will require substantial investments in the infrastructure of cities for the next 40 years. At the same time, there may be surprises that stem from technological change, such as when a new technology displaces or reduces the prominence of another. For example, in the past two decades we have witnessed the explosive growth of mobile phones relative to fixed-line telephony. Compelling evidence indicates that infrastructure investment often increases economic productivity, although this is not true for poorly conceived projects, such as bridges to nowhere.

Growing cities in the United States that face demands on infrastructure facilities and services can use land policy to increase density and make use of economies of scale. Infrastructure, particularly transit, has a strong relationship with density, and reports show that cost-effective transit requires density levels of 15 people

per hectare (Angel 2012). In the United States the development of highways promoted density reductions of households (Alonso 1964) and of industrial firms (Moses and Williamson 1967). This pattern of urban development has generated ongoing challenges to modify existing zoning, taxation, and fee structure systems that support low-density development, though some U.S. cities are now gradually increasing density levels. The lesson for cities in developing countries is to build infrastructure and implement land policy that support dense patterns of urban development, a point highlighted in chapter 2's case study of Chinese cities.

More recent research is finding that inadequate infrastructure is associated with income inequality. This is likely linked to the benefits that good infrastructure services deliver to households in the form of direct health benefits, improved access to education, and enhanced economic opportunities. Because much infrastructure is energy intensive, efforts to reduce greenhouse gas emissions will need to address infrastructure, particularly electric power and transport. It is difficult to foresee what impacts policies to reduce greenhouse gas emissions will have on these sectors, but they could have large effects on households and firms. Bringing the management of infrastructure up to levels of good practice has a large economic payoff, and performance levels vary dramatically between and within countries. Conveying the large economic returns from improving infrastructure performance, and particularly maintenance, to policy makers and voters is a necessary, but so far unmet, challenge.

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