The paradox of intelligent infrastructures

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Abstract

There is significant debate [[verify this]] among scholars and policymakers about the size and role of government in a country. In the last few years, due to the economic crisis international organizations are forcing governments to cut their expenses in order to balance their budgets. There are nonetheless some government expenses that are indispensable to a national economy. In this paper we argue that many nations have move beyond the satisfaction of basic infrastructure provision and need to move to the development of intelligent infrastructures through the use of ICTs. We believe that the impact that these technologies can have on the overall wellbeing of a nation are now significantly higher than investment in other infrastructures. This study is a statistical analysis of a panel of approximately 170 countries for a period of 5 years to determine how government expenses affect infrastructures, the type of infrastructures that have the most impact on the well- being of a nation —"beyond GDP"— and how ICTs and infrastructures can further contribute to that well-being.

Keywords: *Infrastructures, ICT, beyond GDP, human development index*

Introduction

President Clinton's Executive Order 13010 (Clinton, 1996), issued on July 15, 1996, established the President's Commission on Critical Infrastructure Protection (PCCIP). As Haimes and Jiang (2001) observe:

America's critical infrastructures underpin every aspect of our lives. They are the foundations of our prosperity, enablers of our defense, and the vanguard of our future. They empower every element of our society. There is no more urgent priority than assuring the security, continuity, and availability of our critical infrastructures..."

The purpose of this paper is to determine the impact of infrastructures and intelligent infrastructures on the well-being of a nation (Human Development Index). We argue that many nations, primarily high-income nations, have moved beyond the satisfaction of basic infrastructure provision and need to invest in the development of intelligent infrastructures through the use of ICTs.

Governments need to think carefully about transitioning into smart infrastructures because of the significant advances that we have made in the provision of services in both the public and private sectors, and the significant increases in commerce that are happening as a result of our information infrastructures.

In addition, the need for intelligent infrastructures has become even more pressing because of the impact that a major malfunction can have on the economy. We have witnessed the huge losses that a country experiences when a blackout happens, a bridge collapses or any other infrastructure service, like water or sanitation, gets disrupted. In addition, cities, towns and nations are interconnected, some even above and beyond national boundaries. The RAND Corporation calculated that it costs companies approximately $100 billion on average, due to outages (Atkinson, Castro, & Ezell, 2009).

Governments need to invest in infrastructure to ensure that they will not fall behind, in a vicious cycle of infrastructure decay. Two important correlations speak to this problem. One is the correlation between perceived infrastructure quality and global competitiveness and the other is that between infrastructures and the impacts of a catastrophic event, which can unleash a cascade of negative effects on other infrastructures.

Regarding infrastructure investment Fay and Estache (2007) indicate that government decisions have been affected by fads. The problem, as they explain it, is that investment is needed constantly and should avoid the ups and downs of high and low investment.

Background

Sanitation and water has been crucial to prevent illnesses that could have deadly consequences, and electricity has become crucial for overall economic activity, from manufacturing to retail to transportation-facilitated and expanded commerce.

Once an infrastructure has been put in place, it has to be maintained. Maintenance happens on two levels. One is the normal upkeep of existing structures, but another is the need for replacement that eventuates because a system is no longer viable and has become dangerous, obsolete and expensive to maintain. These developments entail replacement costs. Moreover, current infrastructures are, for the most part, dumb. They don't generate information that can facilitate decision making regarding maintenance, replacement or upgrades.

As time passes, governments will face additional challenges regarding infrastructures. One is increased use due to population growth and the consequent need for expansion. Infrastructure is one of the areas where the need for investment continues because of population change. Population growth brings with it congestion, which puts pressure on existing structures, and this costs the economy in missed economic activity (Branscomb & Keller, 1996). If, for example, a factory cannot get the power it needs to operate because the system in overloaded, the temporary production stoppage has real economic costs resulting from unrealized product creation and income lost through the interruption of national and international sales.

Population growth in many regions of the world has put great pressure on the infrastructures of affected countries (ADBI, 2009). In Asia, it is believed that population growth could affect competitiveness and become an obstacle to countries' efforts to reduce poverty (ADBI, 2009).

One of the potential risks that countries will face in the absence of investment in high quality infrastructure is that private companies may decide to locate in countries that offer the most reliable infrastructure services, while avoiding countries that are still plagued with outages and subpar service provision. In the absence of private-sector investment in the economy, a country could fall into a vicious cycle that could further weaken its economy.

An overloaded infrastructure could also negatively affect an economy through catastrophes that result from outdated networks (Branscomb & Keller, 1996). The negative effects of poor infrastructure, at least in Asia, have been associated with road accidents, human trafficking, the displacement of people and environmental damage (ADBI, 2009.

Intelligent infrastructures

What is an intelligent infrastructure? An intelligent infrastructure is an infrastructure that uses computing and communication technologies, or other networked devices, to deliver relevant real-time data to authorities in order to optimize its use, minimize costs and prevent failures. Intelligent infrastructures rely on two-way communication sensors and computing power. Real-time data makes possible more dynamic pricing that can reflect the demand and supply conditions of the infrastructure. This data can also be sent to relevant parties and decision makers to facilitate short- and long-term planning, and the implementation of priorities, policies and regulations.

In addition to the long-term benefits for the environment and quality of life, intelligent infrastructures can bring benefits to consumers in the form of greater reliability in the provision of the services, fewer failures and reduced prices.

Today, information and communication technologies can support the development of intelligent infrastructures that can improve the wellbeing of a nation, what scholars have called "beyond GDP" metrics of development.

Developed nations have implemented a certain level of intelligence in their networks. Operators can detect the faults of pre- specified devices by programming them with specified parameters and instructions to set off alarms if they fall outside a certain range of functioning. Infrastructures also are complex, so that smart sensors are being developed that can learn and can identify faults, not only on specific devices, but everywhere in a system.

Today, the operations and the maintenance and replacement schedules of infrastructures can be improved with the use of advanced communications, computers, sensors, satellites and information processing technologies (Branscomb & Keller, 1996). These systems will not only make operations more efficient, but also improve safety.

Highways, for example, can send information about congestion and wear. Electrical power grids can provide information about demand, loads, and outages. Water systems can send alerts about unusual levels of usage and breakdowns.

The pressure to invest in intelligent infrastructures is increasing because of the efforts being made by several nations to reduce their reliance on fossil fuels. For example, European countries are subject to the 20-20-20 targets, which require all countries to increase their energy consumption of renewable energy sources to 20 percent (Lo Schiavo, Delfanti, Fumagalli, & Olivieri, 2011).

Recent research suggests that up to 20 percent of the energy consumed in a building could be saved by correcting malfunctions and unnecessary operation. Detecting faults and optimizing use can significantly economize on energy costs (Gershenfeld, Samouhos, & Nordman, 2010). Intelligent infrastructures help manage use and deliver service more efficiently by turning off systems when they are not needed, identifying faults, and managing loads. In addition, the emergence of new sources of energy has made critical the need to move from passive to dynamic design and to redesign transportation networks (Lo Schiavo et al., 2011), so that they can accommodate all of these different energy sources as they come to life.

In the US, the government recognizes the need to implement an intelligent infrastructure. In 1995, Harvard University hosted a conference with experts in the area, to determine the most important issues the government would have to address to create an intelligent transportation system (ITS) in conjunction with the development of the National Information Infrastructure (NII). Conference participants identified policy issues, requirements for the integration of ITS with NII goals, technological requirements, a need for collaboration between the public and the private sector, and challenges to implementation, such as privacy issues (Branscomb & Keller, 1996). According Barrett (1990), the US vision for an intelligent network includes three elements: (1) It has to be an intelligent digital network, (2) it has to be broadband with fiber optic transmission, and (3) it has to allow for board interconnections. The benefits from investment in an information technology (IT) infrastructure are expected to be realized in the short term by identifying and supporting projects that have been dubbed "shovel ready."

In transportatton networks, the implementation of ICTs has also led to important safety improvements. In the US, the Department of Transportation has tested a system that forwards information about the arrival of hazardous materials from railroad operators to 911 emergency dispatchers, so that they are prepared and able to respond quickly in the event of an accident.

Infrastructure challenges

There is concern that the greater demands of a growing population on existing infrastructure cannot be resolved with the construction of more or bigger networks, because of the negative environmental impact they can have. There is a danger that in the process of digging and building, we continue to exert pressure on the environment by claiming more space and resources and threatening relatively undisturbed natural regions. There is thus a need to improve the use of existing infrastructures to meet the pressures of demand while preserving fragile ecosystems.

Studies on infrastructure are typically focused on specific types of infrastructures. Transportation papers do not generally talk about the electrical grid, and water studies do not cover air transportation, for example. Studies that analyze infrastructures in combination are difficult to produce, as they must synthesize trends that are occurring in many sectors. There is, nonetheless, evidence that we are going through a major transformation. On power systems, for example, Lo Schiavo et al. (2011) indicate that technology will have profound impacts, and they recommend that regulators invest in in technologically sophisticated grids.

Indirect benefits from smart infrastructures

It is to be expected that investment in infrastructure would lead to direct and indirect job creation. Direct job creation happens from employment generated as a result of spending on infrastructure. This would primarily mean technicians and road workers, for example. Indirect job creation results from employment generated by firms that provide the inputs necessary for infrastructure upgrades. This involves industries such as networking and computing, which are needed to support smart infrastructures. These jobs, a report by Atkinson et al. (2009) indicates, will lead to long-term competitiveness because of the expansion of higher value-added jobs

Population growth, as well as more pressing concerns about the environment, has led governments to seek out alternative energy sources. This means that governments need to think more carefully about how energy is produced and consumed because of the negative impact that its utilization can have on the environment. There is a need for a more efficient use of energy, which will greatly benefit from the use of smart infrastructures that can provide managers and administrators with information about supply and demand, and failures to make decisions that can optimize energy resources.

In the case of the United States, a smart infrastructure would also benefit the provision of services such as healthcare, where one could expect significant cost reductions from fewer administrative errors, and a higher quality of care associated with fewer medical errors. Smart infrastructures make it possible for doctors to identify epidemics much more quickly, spot dangerous side effects from new drugs, and identify promising new treatments (Atkinson et al., 2009).

Atkinson et al. (2009) report that investing in digital infrastructures would positively impact job creation in the short term, and the effect on jobs would be further strengthened by the network effects realized from these investments, which in turn will support higher productivity, competitiveness and quality of life.

In the United States, communities that invested in broadband led to one percentage point more growth in employment compared to communities without it (Atkinson et al., 2009). Thus, if a community created 50,000 jobs, if it had broadband, it would have created an additional 500 jobs.

According to Nordas and Piermartini (2004), an infrastructure that allows for efficient coordination of services can affect trade through the following factors:

• **Monetary inflows**, which can expand due to high quality communications and an air transportation infrastructure that can reduce the costs of general logistics services.

• **Timeliness**, which can be negatively impacted if infrastructure is not adequate.

• **The reduction of risk**, associated with a high-quality infrastructure that can reduce, or even prevent, damage to cargo.

• **Market access and trade opportunities**, which are the results of an extensive and adequate transportation or telecommunication infrastructure that reduces opportunity costs.

• The advantages of a smart infrastructure go beyond the man-made physical assets of the country to benefit education and environment, for example.

Government and infrastructures

During the 1980s, deregulation appeared to be the panacea for investment in infrastructure; governments believed that leaving the responsibility to the private sector would result in expansion and improvements in infrastructure, but this was realized in only a few exceptional cases (Fay & Estache, 2007).

Today, governments, at least the government of the United States, is concerned about rising costs for consumers, while the private sector wants to ensure investment returns. Intelligent infrastructures rely on significant ICT investment, but governments, experiencing both internal and external pressure to cut costs, may be impairing the investment that these intelligent infrastructures require. It is our belief that reducing investment in intelligent infrastructures may incur higher costs down the road and miss the opportunity to improve the country's well-being.

According to Atkinson et al. (2009), during an economic recession, policies that try to foster the economy through consumption, as opposed to investment, will be less beneficial to productivity and innovation in the long term. However, lessons from the 1997-1998 Asian crisis show that the severe reductions in infrastructure investment at that time were painfully difficult to recover from, because of the much greater investment needed later to bring the neglected infrastructure up to its minimal functioning standard. According to an ADBI report (2009), South Korea Malaysia, Indonesia and the Philippines are still suffering from a large infrastructure deficit due to the collapse of investment after the 1997 financial crisis—and "their poor infrastructure has kept growth rates below their potential" (p. 17).

The majority of financing for infrastructure investments has come from government budgets. As much as 90% of water projects have been financed by governments (McCawley, 2010). But there is a recognition that they cannot sustain this level of financing for infrastructure projects. This became apparent during the 1997-1998 Asian crisis, which negatively affected budgets due to higher debt service levels.

It has been shown that investment in infrastructure results in significant returns compared to other forms of capital investment (ADBI, 2009), and intelligent infrastructures are even more still significant. In 2010 Gershenfeld et al. (2010) calculated that it could cost $1,000 to add a $1.00 sensor that requires a skilled technician. However, advances in technology have reduced costs dramatically. According to Branscomb and Keller (1996), making the transportation network smart will cost one twentieth of what it would cost to build a new highway to achieve a similar level of performance.

While investment will be necessary, the savings that accrue can pay for such upgra des. According to (Branscomb & Keller, 1996), the inclusion of ICTs in transportation has led to important benefits to communities. In Minnesota, a smart network has increased traffic speeds at rush hour by 35 percent and capacity by 22 percent, while in California a similar system has reduced work commutes by 15 percent and vehicle stops by 35 percent. This also reduces the amount of pollution that these cars emit every minute they are on the road. In Oklahoma, the state has reduced the costs of operating a toll highway lane by 91 percent.

While it is true that the private sector could be the one in charge of upgrading infrastructures, it is also the case that these infrastructures, being national networks, require standardization of technology to facilitate communication across infrastructures and the coordination of agencies that can increase the benefits from smart infrastructures, which can relay information to relevant authorities.

Government intervention is necessary because of the existence of both private and public infrastructures. In the absence of government intervention, private companies have little incentive to cooperate. The private sector does not have incentives to invest in smart infrastructures because they do not benefit directly from the additional intelligence that these networks will provide. If, for example, sensors determine that there is high load on a certain bridge, the authorities may reroute traffic to a bridge belonging to another company, and thus cause a revenue loss for the first company.

Similarly, the private sector has not involved itself in infrastructure projects, with the exception of telecommunications. The reluctance of the private sector to invest in infrastructure has been attributed to unclear and uncertain regulation, which results from both political and social pressure, to traditional price suppression and to subsidies for infrastructure (McCawley, 2010) that have tended to benefit the middle class, because the poor often do not even have access (McIntosh, 2003).

McCawley (2010) also indicates that in the private sector, telecommunications is the exception to a lack of infrastructure investment because the electricity, water, road and transportation industries have been reluctant to support large projects unless they get support from the government. This gives us some hope regarding partnerships between communication operators and other infrastructure companies, which could partner to find ways to improve and upgrade, and invest in other infrastructures. The argument from sectors that are reluctant to invest is that prices for infrastructure are kept low, and in many cases, they are fraught with uncertainty as the different agendas of government officials come and go.

In addition, McCawley (2010) indicates that a lot of the financial support that came from international development banks has moved from infrastructure into education, health and governance. This trend fails to recognize that infrastructures support all three of these activities and can, in fact, enhance them if the infrastructures are managed well.

Evidence of the effectiveness of more intelligent infrastructures comes from informal markets that emerge due to an inadequate supply of services. A study by ADB (1994) calculated that the price of water in informal markets in Manila was 20 to 30 times more than the fixed priced offer by the government. The same phenomenon was observed in Karachi, Dhaka, Surabaya, and Istanbul, where informal vendors charge up to 12 times the cost of the city's water. In addition, the prices fluctuated according to demand and supply conditions. This indicates that more dynamic pricing through the monitoring of supply and demand forces, based on information technology, can lead to more accurate pricing and more efficient usage of public services.

The lack of private investment does not mean that the government has to be the one who engages in the modernization of these networks, but it would require public-sector incentives for the private sector to take action (Atkinson et al., 2009). Therefore, as Lo Schiavo et al. (2011) indicate, government regulation is going to be a key element in the successful implementation of an intelligent infrastructure. In the words of Barrett (1990): words:

> Upgrading this nation's publicly available telecommunications infrastructure to meet the increasingly sophisticated needs and demands of the future requires a deliberate and well-reasoned regulatory response. It seems to me that this vitally important issue is one of the most complex issues facing regulators and industry leaders as this nation enters the 1990's. The implications are wide ranging. Indeed, one must consider the ramifications for such things as national productivity, our ability to compete internationally, world leadership in telecommunications, world trade, social equity, and our overall quality of life. (Barrett, 1990)

McCawley (2010) argues that governments recognize the need for infrastructure improvements and, in the process, they need to select appropriate projects and determine how they are going to be financed, priced and accessed. They also need to set up appropriate policies and regulations to support projects, and ensure that they are managed properly. In this paper, we argue that intelligent infrastructures make it possible for countries to reduce their maintenance and operational costs, while improving the quality of services.

It is clear that the amount of investment for any given country will depend on the current state of its infrastructure. If the infrastructure is still inadequate and in a critical condition, the government will need to spend more. If, on the other hand, the infrastructure has been maintained regularly, investment may require only minor upgrades.

Infrastructure interconnections

When infrastructures were originally designed and implemented, they were isolated. Today, however, there are linkages among them, which means that a failure in one could render another inoperable, or partially so. "Inoperability of a system is defined as the inability of the system to perform its intended functions" (Santos & Haimes, 2004, p. 2). Therefore, the effects of the state of a country's infrastructure on its the economy, positive or negative, will depend to a certain extent on the levels of interdependency among its infrastructures.

Because of the connections among different sectors of an economy, it is important for a government to carefully decide which infrastructures are likely to have the greatest impact, giving specific economic and infrastructure conditions. Focusing on critical sectors can also help to make operations less vulnerable, due to the intelligence built into them.

Santos and Haimes (2004), for example, A paper by for example calculated that a 10 percent demand reduction in air transportation due to terrorism, for example, will have an effect on petroleum refining, food and drinking services, telecommunications, financial services and power generation and supply (p. 1444). This does not take into account additional losses to sectors that are indirectly related to transportation.

The electrical and transportation infrastructures will become even more closely linked, due to plug-in electric vehicles (PEVs), full-electric vehicles (EVs) and extended-range plug-in hybrid electric vehicles (PHEVs), which will increase the demand for energy, in a trend thatLo Schiavo et al. (2011) call electromobility.

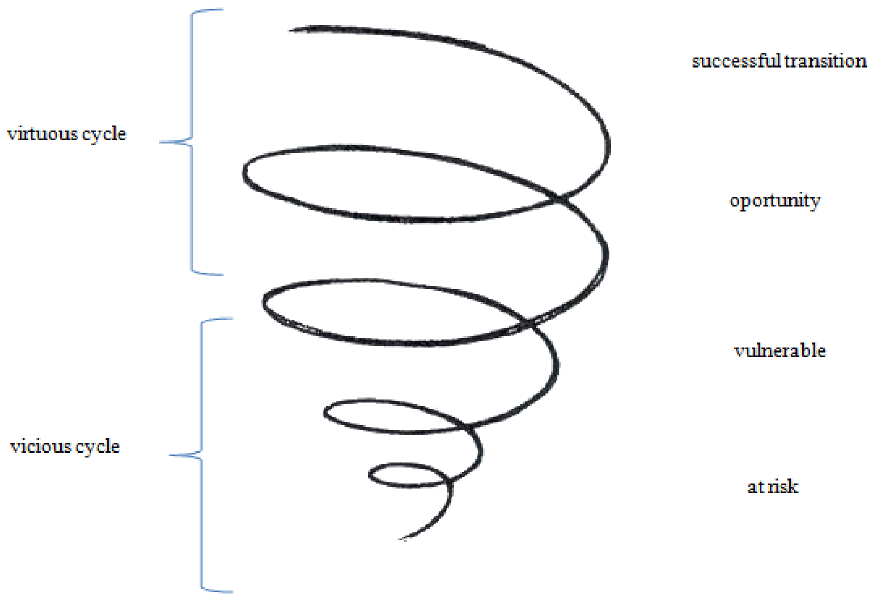
The incorporation of smart technologies will present challenges to infrastructure regulation. For example, the moment a country begins to construct electric car refueling stations, the Department of Transportation will need to coordinate its efforts with energy regulators, who, in turn, will have to take into consideration telecom regulations, given that all these infrastructures will eventually be connected to the internet, so that consumers can monitor their consumption and potentially alter their demand patterns, based on real-time pricing data.

Virtuous and vicious cycles in infrastructures

The main premise of virtuous and vicious cycles is that when things go well, they strengthen the positive elements of the system, so that it continues to grow satisfactorily. The opposite is also the case: in a vicious cycle, negative elements reinforce a downward spiral. These cycles can operate within countries. Positive elements will launch a period of growth and wellbeing, while negative elements can lead to the devastation of an economy.

The processes of virtuous and vicious cycles are important in the context of this research because of the transition period that we are going through in regard to technologies and infrastructures. We are at a point when governments need to make decisions about their existing infrastructures. Many nations need to replace or significantly upgrade their aging infrastructures. This is happening at a time when technology can be an asset to the process and alleviate some of the stress that these services are under due to population growth and aging facilities.

However, this transition is also happening at a time when many of the world's economies are struggling with economic problems. The 2008 mortgage crisis, which affected many countries, is still being felt today, and there is a call from policymakers to shrink government costs in attempts to reduce their national debts. This means that some of the funding needed for smart infrastructures will not be available, which could



lead a country into a vicious cycle and negatively affect the economy in the long term.

Figure 1 shows a graphical representation of the framework we wish to test in this paper.

Figure 1. A graphical representation of vicious and virtuous cycles.

The need for infrastructure improvement is urgent. A report by the UN Economic and Social Commission for Asia and the Pacific (ESCAP, 2006) calculated that an investment of at least US $228 billion per year would be needed in the 2006-2010 period. Similarly Romp and de Haan (2005) calculated that US $200 billion per year would be necessary, while the ADB- ADBI report on Infrastructure for a Seamless Asia (ADBI, 2009) calculated a need of US $750 billion per year during the 2010-2020 period. According to McCawley (2010), the region needs to invest between 20 and 25 percent of GDP, while it is actually investing 6 to 7 percent of GDP, a quarter of the minimum desirable.

It is common sense to assume that modern economies cannot work without efficient and adequate infrastructures, although the academic literature has found contradictory evidence regarding the relationship between infrastructure and growth (Briceño, 2004; Gramlich, 1994; Romp & de Haan, 2005; Straub, 2006) and detailed research shows that the impact is greater for lower-income countries.

McCawley (2010) indicates that we have not yet developed techniques that can give us some guidance regarding the optimal levels of infrastructure for any given country. We believe, in this respect, that a minimum of infrastructure is necessary to prevent a country from falling into a vicious cycle that could lead to significant degradation of its citizens' wellbeing.

Failing to invest in infrastructure can severely affect the wellbeing of a nation, because it then risks falling behind other nations. A poor infrastructure makes it difficult to conduct business and as a result, reduces, or even eliminates, incentives for companies, both foreign and national, to do business in the country, which has a negative impact on job creation.

The state of infrastructures around the world

In regard to infrastructure, we still see significant differences between developed and developing countries. According to Tendler (1968), there is strong political pressure on governments to guarantee elite goods like airline travel in preference to mass-based infrastructures such as roads and railroads. Alternatively McCawley (2010c) hypothesizes that multinational corporations puts pressure on national governments to improve infrastructures that will allow the transportation of goods.

Methodology

data on infrastructures are deficient. In Fay and Estache (2007) words "the information gap the infrastructure sector faces is huge and shows no sign of narrowing… The problems with the monitoring of access rates may surprise many. Even more surprising is the failure to monitor progress in the affordability and quality of these services – dimensions that should be part of the baseline needed to track progress… As to data on public spending on infrastructure, they are largely non-existent" (pp.4-5).

Data

The number of countries in the sample is 197, because we eliminated entries associated with listings that do not have full- country status, such as territories or protectorates. It is common with international datasets to have missing data. To solve this problem, scholars have devised techniques to calculate missing values from regression techniques. In this paper, we used multiple imputation (MI), which is a simulation method-based approach for analyzing incomplete data. MI replaces the missing values with multiple sets of simulated values and then applies standard analyses to each completed dataset, and adjusts the parameter estimates to minimize missing-data uncertainty Rubin, 1987 #76. The objective is not to predict missing values that are close to the true ones, but to calculate missing data in a way that is valid for making statistical inferences. The method accounts for missing-data uncertainty and, thus, does not underestimate the variance of estimates, as single-imputation methods do. Table 1 presents the summary statistics of the data included in the model.

Code	Variable Description	Mean	Standard Deviation	Total
hdi	Human Development Index (HDI) value	0.6469268	0.1774531	1394
ggfce	General government final consumption expenditure (% of GDP)	15.17598	5.485986	2040
fbiphp	Fixed broadband Internet subscribers (per 100 people)	4.931373	6.789933	2040
mcsphp	Mobile cellular subscrip-tions (per 100 people)	48.78922	40.40611	2040
pcphp	Personal computers (per 100 people)	57.52941	8.493896	2040
hpc	Percentage of households with a computer	25.44804	21.84032	2040
sis	Secure Internet servers (per 1 million people)	123.6191	270.8595	2040
dnphp	Daily newspapers (per 1,000 people)	134.6833	58.86563	2040
cgd	Central government debt, total (% of GDP)	52.34705	32.21907	654

ate	Access to electricity (% of population)	67.90308	32.29615	98
taxr	Tax revenue (% of GDP)	16.70596	7.178197	1265
iws	Investment in water and sanitation with private participation (current US$)	536000000	1090000000	204
isf	Improved sanitation facilities (% of population with access)	69.13711	30.16382	1974
airp	Air transport, passengers carried	52600000	191000000	1689
airregister	Air transport, registered carrier departures worldwide	631943.1	2329654	1688
roaddensity	Road density (km of road per 100 sq. km of land area)	70.8216	98.7649	822
pseduc	Public spending on education, total (% of GDP)	4.633023	1.795453	1310
iwsource	Improved water sources (% of population with access)	84.7673	16.97167	1981

TABLE 1. Descriptive Statistics

	Access to electricity (% of population) ate	Investment in water and sanitation with private participation (current US$) iws	Improved sanitation facilities (% of population with access) isf	Air transport, passengers carried airp	Road density (km of road per 100 sq. km of land area) roaddensity	Improved water sources (% of population with access) iwsource
ate	**1.0000**					
iws	**0.5614**	**1.0000**				
	0.1476					

isf	**0.8509**	**-0.0919**	**1.0000**			
	0.0000	0.2027				
airp	**0.1660**	**0.6756**	**0.1065**	**1.0000**		
	0.1360	0.0000	0.0000			
roaddensity	**0.2311**	**-0.1040**	**0.3943**	**-0.0718**	**1.0000**	
	0.1027	0.2956	0.0000	0.0538		
iwsource	**0.8051**	**0.0048**	**0.8159**	**0.1304**	**0.3648**	**1.0000**
	0.0000	0.9473	0.0000	0.0000	0.0000	

Table 2 shows the correlation coefficients for the infrastructure variables. A number of infrastructure variables (e.g., access to electricity, improved sanitation facilities and improved water sources) are highly correlated (>.5) and will have to be combined for the regression analysis to avoid multi-collinearity problems.

Table 2. A Correlation Coefficients For Infrastructure Variables (Prais-Winsten Estimation; P Values Are Shown Below Each Coefficient)

Table 3 shows the correlation coefficients for the governance and economic indica-

	General government final consumption expenditure (% of GDP)	Central government debt, total (% of GDP)	Tax revenue (% of GDP)	Public spending on education, total (% of GDP)
	Ggfce	**cgd**	**Taxr**	**Pseduc**
ggfce	**1.0000**			
cgd	**0.1146**	**1.0000**		
	0.0051			
taxr	**0.4729**	**0.2623**	**1.0000**	
	0.0000	0.0000		
pseduc	**0.5501**	**0.0359**	**0.6305**	**1.0000**
	0.0000	0.4265	0.0000	

tors; the results show a high correlation between "general government final consumption" and "public spending on education." This is not surprising, given that public spending on education reflects, to a certain extent, an element of governance expenditure. Also "tax revenue as a percent of gross domestic product" is highly correlated with "public spending on education." This result is normal because governments finance their expenditures with taxes.

Table 3. Correlation Coefficients For Government And Economic Variables (Prais-Winsten Estima

	Fixed broadband Internet subscribers (per 100 people) fbiphp	Mobile cellular subscriptions (per 100 people) mcsphp	Personal computers (per 100 people) pcphp	Percentage of households with a computer hpc	Secure Internet servers (per 1 million people) sis
fbiphp	**1.0000**				
mcsphp	**0.5353**	**1.0000**			
	0.0000				
pcphp	**0.4464**	**0.1289**	**1.0000**		
	0.0000	0.0000			
hpc	**0.7430**	**0.6260**	**0.3491**	**1.0000**	
	0.0000	0.0000	0.0000		
sis	**0.5588**	**0.2340**	**0.3398**	**0.4702**	**1.0000**
	0.0000	0.0000	0.0000	0.0000	

tion; P Values Are Shown Below Each Coefficient)

Table 4 shows the correlation coefficients of the technological variables. Here we find a high correlation between the two ICT variables "broadband" and "mobile subscriptions," and then between "mobile cellular subscriptions" with "percentage of households with a computer."

Table 4. Correlation Coefficients For Technological Variables (Prais-Winsten Estimation; P Values Are Shown Below Each Coefficient)

The high correlations among all variables required us to explore potential multicollinearity problems. To test for this, we calculated the variance inflation factor (VIF), which quantifies the severity of multicollinearity. We adjusted the model based on these results.

The regression model

In this study, we used a fixed-effects and instrumental variable (IV) analysis of panel data. The purpose was to estimate not only the effect of intelligent infrastructures on the human development index (HDI), but also the effect of government debt on infrastructure investment. Because of the many types of infrastructures, we had to develop an infrastructure index before we were able to run the final regression model.

$$Infrastructure\ index = \frac{Actual\ value - Minimun\ Value}{Maximum\ value - Minimum\ value} \quad (1)$$

In both the index and the final regression, the sample of countries is represented by the subscript i {i = 1,2,3 ... 197}, and {t = 2000, 2001, ..., 2011} is the time dimension of our

$$I_{i,t} = \sqrt[3]{(\prod_{i=1}^{n} I_i)^n}$$

$$I_{i,t} = \sqrt[2]{(RD_{i,t} * EPC_{i,t} * ISF_{i,t})^3} \quad (2)$$

data set. To develop our infrastructure index, the first step was to identify which infrastructures are significant in a standardized model where the dependent variable is the HDI. The next step was to determine the minimum and maximum values of each variable to transform the indicators into indices with values between 0 and 1. With these values, we then calculated sub-indexes, as follows:

The result of this equation for each of the infrastructure variables allowed us to obtain an index of the significant infrastructure variables, which is calculated like a geometric mean, as follows.

where

$RD_{i't}$:	Road density as a km of road per 100 sq. km of land area
$EPC_{i't}$:	Electricity power consumption (KWH per capita)
$ISF_{i't}$:	Improved sanitation facilities (% of population with access).

$$\overline{\mathrm{HDI}_{i,t}} = \vartheta_0 + \sum_{i=1}^{k} \vartheta_k \overline{\mathrm{I}_{k,,t}} + \varepsilon_{i,t} \quad (3)$$

$$\overline{\mathrm{HDI}_{i,t}} = \frac{\mathrm{HDI}_{i,t} - \sum_{i=1}^{n} \frac{HDI_{i,t}}{n}}{\sigma_{\mathrm{HDI}_{i,t}}}$$

To capture the impact of each infrastructure into the human development index we run a standardize model. This regression replaces the original unit of measurement

$$\sum_{i=1}^{n} \frac{HDI_{i,t}}{n}$$

of the variables with a standardized unit. This will allows to compare directly the relative effects of predictors The standardization of the coefficients was calculated as expressed

$$\overline{\mathrm{I}_{K,t}} = \frac{\mathrm{I}_{i,t} - \sum_{i=1}^{n} \frac{\mathrm{I}_{i,t}}{n}}{\sigma_{\mathrm{I}_{i,t}}};$$

in equation (3).

where
where
is the standardized variable for the Human Development Index, and here

denotes the median, and crHDii,t is the standard deviation;

calculates the standardized coefficient of the infrastructure index.

First stage: infrastructure model with instrumental variables

The relation between infrastructure and the Human Development Index may suffer from an endogeneity bias. The concern is over reverse causality, where human development may depend on infrastructure enhancers, and vice versa. Infrastructure could be endogenous because the welfare of a nation depends on infrastructure, and therefore, more and better infrastructures improve the Human Development Index. Similarly, in wealthy countries, the population may demand better living conditions and conveniences, which can then drive investments in infrastructure. If we do not take in consideration this reverse

$$I_{i,t} = \gamma_0 + \gamma_1 I_{i,t-1} + \gamma_2 \mathrm{DebtService}_{i,t} + \gamma_3 ggfce_{i,t} + \gamma_4 Governance_{i,t} + \gamma_5\, Effgov_{i,t} + \gamma_6 Poptot_{i,t} + \gamma_7 Pitlcpup_{i,t} \qquad (4)$$

where

$I_{i,t}$: the Infrastructure Index

$I_{i,t-1}$:	one year lag of infrastructure
$DebtService_{i,t}$:	total debt service as a percent of gross national income
$ggfce_{i,t}$:	general government final consumption expenditure as a percent of GDP
$Governance_{i,t}$:	the vector of variables relating to the government; the governance indicators that we used in this study try to capture what is known as second-level regulatory institutions (Estrin & Mickiewicz, 2011), which can influence relate the day-to-day effectiveness of the government apparatus.
$Effgov_{i,t}$:	the interaction variable between government final consumption and the governance indicator
$Poptot_{i,t}$:	total population
$Pitlcpup_{i,t}$:	population in the largest city (% of urban population).

causality, the estimated coefficients are not consistent. In reality, it is likely that causality goes in both directions, and therefore, this should be considered in the empirical model using instrumental variables.

To address the endogeneity problem between human development and infrastructure, we assumed that infrastructure is determined by information and communication variables, government debt, taxes, total population, the population of the largest city, and governance effectiveness, as specified in equation (4):

$$\boldsymbol{Ln(HDI_{i,t})} = \boldsymbol{\gamma_0 + \sum_{k=1}^{K} \beta_k \hat{I}_{i,t} + \sum_{k=1}^{K} \gamma_k Educ_{i,t} + \sum_{k=1}^{K} \theta_K Governance_{i,t} + \sum_{k=1}^{K} \delta_k (GovInteligence)_{i,t} + \varepsilon_{i,t}} \quad (5)$$

Here:

$HDI_{i,t}$: is the Human Development Index;

$\hat{I}_{i,t}$: is an estimation of infrastructure index (first step of the instrumental variable approach);

$Educ_{i,t}$: corresponds to public spending on education (as a percent of GDP)

$Governance_{i,t}$: is the vector of variables relating the government;

$(GovInteligence)_{i,t}$: is an interaction term between governance indicator and broadband penetration;

$\varepsilon_{i,t} = \mu_i + v_{i,t}$: represents unobservable effects that differ across countries but not in time, which is usually associated with the ability of each country to promote development $v_{i,t}$ represents a purely random error (i.e., a distributed with zero mean and constant variance, formally: $\varepsilon_{i,t} \sim N(0, \sigma^2$These effects are time-invariant.

Second stage: final model

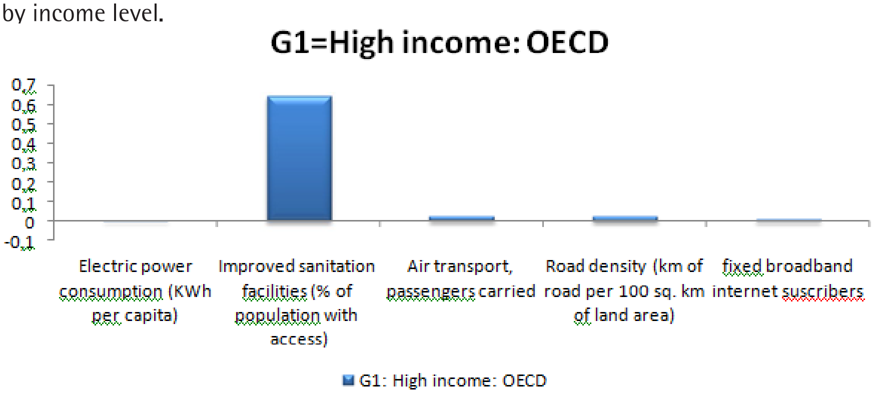
Equation (5) provides our main HDI specification. All regressions use fixed effects, with heteroskedasticity- consistent standard errors

Regression results: Infrastructure impacts on the human development model

As we conducted this study, we realized that infrastructure development varied considerably across countries. Because of these differences and our interest to provide recommendations regarding infrastructure investment, we felt compelled to divide the results by income level.

Variable	G1: High income: OECD	G2: High income: nonOECD	G3=Low income	G4 Lower-middle income	G5 Upper-middle income	Aggregate
Electricity power consumption	-0.00399	0.02506	0.18885**	0.29886***	0.38469***	0.09718**
	(0.03657)	(0.03172)	(0.08118)	(0.07734)	(0.05211)	(0.04485)
Improve sanitation facilities	0.64542***	0.50778***	0.32094***	0.34299***	0.49022***	0.46733***
	(0.08691)	(0.14531)	(0.08447)	(0.05864)	(0.09495)	(0.04417)
Air Passengers	0.02552*	0.08901	0.00077	0.02375	0.01129	0.01460
	(0.01393)	(0.05348)	(0.00833)	(0.04147)	(0.02945)	(0.00888)
Road Densit	0.02889	-0.00361	0.08615**	0.13719***	0.05598**	0.04299***
	(0.01759)	(0.01230)	(0.03317)	(0.03621)	(0.02757)	(0.01317)
Fixed Broadband Suscribers	0.01299***	0.01666***	-0.00299	-0.00204	0.02795***	0.01331***
	(0. 00211)	(0.00443)	(0.00729)	(0.00716)	(0.00375)	(0.00183)
Number of obs	372	180	408	552	564	2076
R-sq Within	0.4083	0.4228	0.1442	0.2696	0.3662	0.2514
R-sq between	0.5561	0.9246	0.7401	0.8056	0.6031	0.9294
R-Overall	0.4609	0.6909	0.6135	0.7084	0.4927	0.8829

All variables are standardizing. Standard errors are in parentheses (delta method) ***p<0.01. **p<0.05. *p<0.1



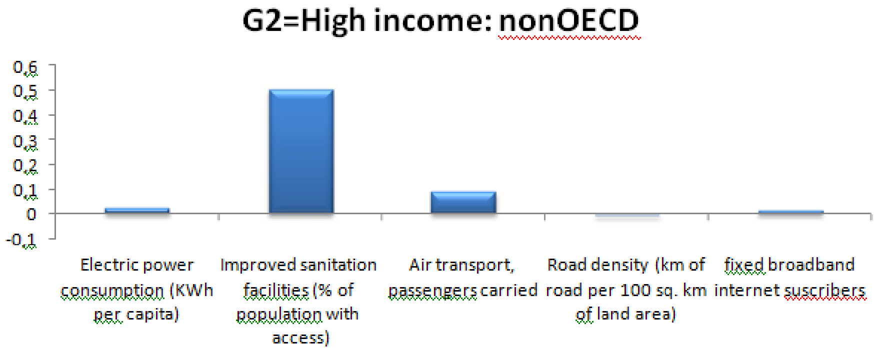
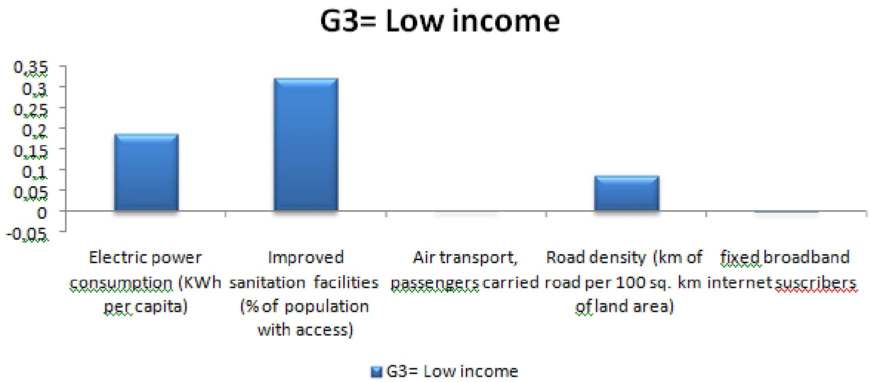
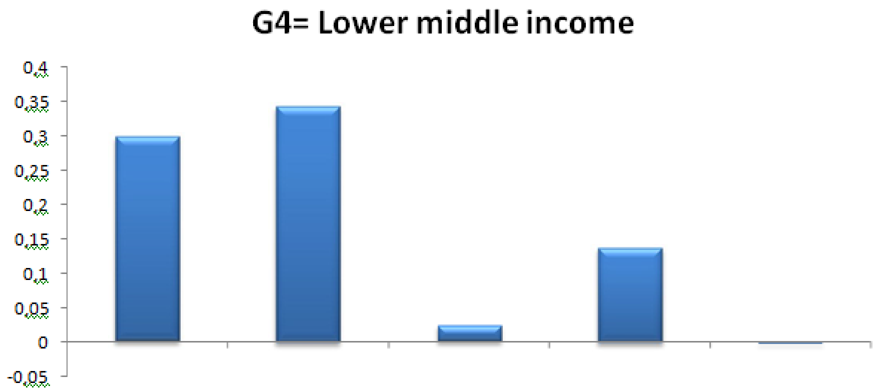
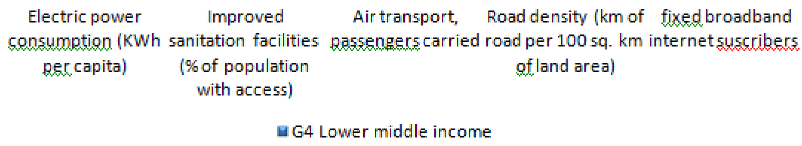


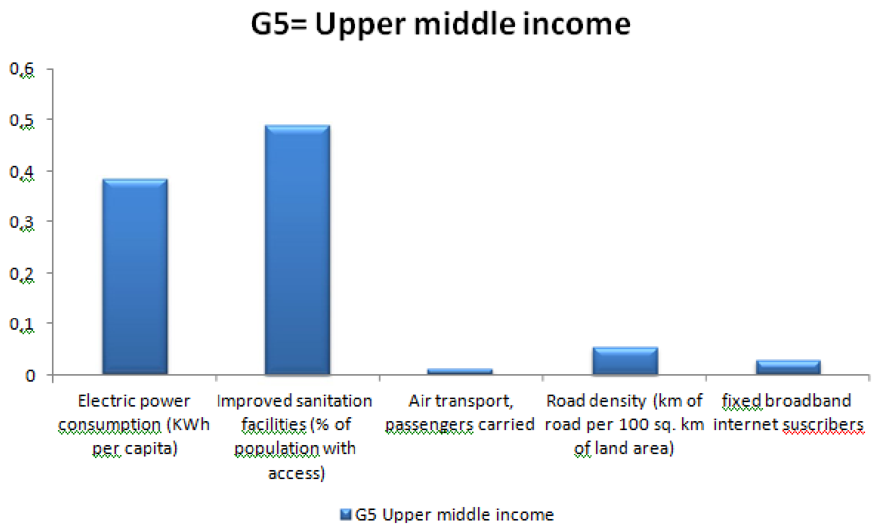
Table 5 shows the output of the model that captures the beta coefficients of all infrastructures by income level. “Electricity power consumption” and “road density” were significant

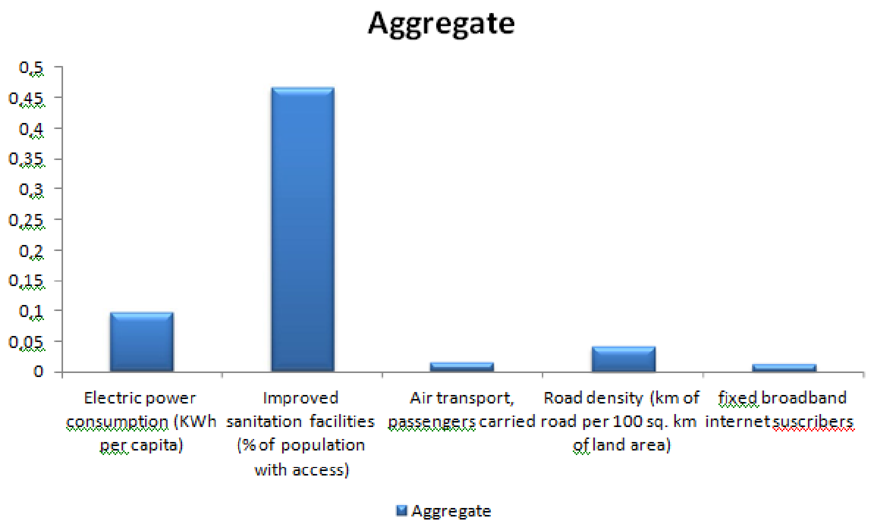


for low, lower-middle and upper-middle income. On the other hand, “improved sanitation




Electric power consumption (KWh per capita)
Improved sanitation facilities (% of population with access)
Air transport, passengers carried
Road density (km of road per 100 sq. km of land area)
fixed broadband internet suscribers
G4 Lower middle income


G5= Upper middle income
0,6
0,5
0,4
0,3
0,2
0,1
0
Electric power consumption (KWh per capita)
Improved sanitation facilities (% of population with access)
Air transport, passengers carried
Road density (km of road per 100 sq. km of land area)
fixed broadband internet suscribers
G5 Upper middle income


Aggregate
0,5
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
Electric power consumption (KWh per capita)
Improved sanitation facilities (% of population with access)
Air transport, passengers carried
Road density (km of road per 100 sq. km of land area)
fixed broadband internet suscribers
Aggregate

facilities" was significant for all income levels. "Air passengers" was not significant. For ICT, we included "broadband subscribers." This variable was significant for high-income and upper-middle income levels.

Table 5. Regression results for the infrastructure model

	Variables	*Human development Index* Coef
Infrastructureindex	Infrastructure index estimated in first stage.	0.57494*** (0.0813834)
Intelgov	Government Intelligence	0.00261*** (0.0004171)
Pseduc	Public spending on education, total (% of GDP)	0.01355*** (0.0024277)
Governance	Governance Indicator	0.00684** (0.0039092)
Cons	Constant	-0.54920*** (0.0139876)
R-sq: within	0.0881	
between	0.3813	
overall	0.3713	
F test that all u_i=0:	F(163, 1292)= 5.23 Prob > F = 0.0000	
Number of obs	1465	
Number of groups	164	

The dependent variable corresponds to the human development indicator in logarithmic. Standard errors are in parentheses (delta method) ***p<0.01. **p≤0.05. *p≤0.1. Regression coefficients are robust to heteroskedasticity.

The HDI, intelligent infrastructures and government debt

This final model includes two additional government variables: the governance variable and an intelligence government variable, which we created from the interaction between ICTs, broadband and government. Both government variables were significant, as well as public spending on education, which was included in the model as a control.

Regarding technological factors, we included broadband, which is significant. We find that increases in broadband increase the HDI. The infrastructure variable had the greatest impact on human development.

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Appendix 1. Data descriptions

Variable	Definition
Human Development Index (HDI) value	The *Human Development Index (HDI) value* is a summary measure of human development. It measures the average achievements in a country in three basic dimensions of human development: a long and healthy life (health), access to knowledge (education) and a decent standard of living (income). Data availability determines HDI country coverage. To enable cross-country comparisons, the HDI was calculated, to the extent possible, based on data from leading international data agencies and other credible data sources available at the time of writing. The HDI sets a minimum and a maximum for each dimension, called goalposts, and then shows where each country stands in relation to these goalposts, expressed as a value between 0 and 1.
General government final consumption expenditure (% of GDP)	*General government final consumption expenditure* (formerly *general government consumption*) includes all current government expenditures for purchases of goods and services (including compensation of employees). It also includes most expenditures on national defense and security, but excludes government military expenditures that are part of government capital formation.
Fixed broadband internet subscribers (per 100 people)	*Fixed broadband Internet subscribers* describes the number of broadband subscribers with a digital subscriber line, a cable modem, or other high-speed technology.
Mobile cellular subscriptions (per 100 people)	*Mobile cellular subscriptions* are subscriptions to a public mobile telephone service using cellular technology, which provide access to a public switched telephone network. Post-paid and prepaid subscriptions are included.
Personal computers (per 100 people)	*Personal computers* are self-contained computers designed to be used by single individuals.
Percentage of households with a computer	*Percentage of households with a computer* is the total number of computers available in the country's households.
Secure Internet servers (per 1 million people)	*Secure internet servers* are servers using encryption technology in Internet transactions.
Daily newspapers (per 1,000 people)	*Daily newspapers* refers to newspapers published at least four times a week and is calculated as average circulation (or copies printed) per 1,000 people.
Central government debt, total (% of GDP)	*Central government debt* is the entire stock of direct government fixed-term contractual obligations to others outstanding on a particular date. It includes domestic and foreign liabilities, such as currency and money deposits, securities other than shares, and loans. It is the gross amount of government liabilities reduced by the amount of equity and financial derivatives held by the government. Because debt is a stock rather than a flow, it is measured as of a given date, usually the last day of the fiscal year.
Access to electricity (% of population)	*Access to electricity* is the percentage of population with access to electricity. Electrification data are collected from industry, national surveys and international sources.
Tax revenue (% of GDP)	*Tax revenue* refers to compulsory transfers to the central government for public purposes. Certain compulsory transfers, such as fines, penalties, and most social security contributions, are excluded. Refunds and corrections of erroneously collected tax revenue are treated as negative revenue.
Improved sanitation facilities (% of population with access)	*Improved sanitation facilities* refers to the percentage of the population with at least adequate access to excreta disposal facilities that can effectively prevent human, animal, and insect contact with excreta. Improved facilities range from simple but protected pit latrines to flush toilets with a sewerage connection. To be effective, facilities must be correctly constructed and properly maintained.
Air transport, passengers carried	*Air passengers carried* includes both domestic and international aircraft passengers of air carriers registered in the country.

Road density (km of road per 100 sq. km of land area)	*Road density* is the ratio of the length of the country's total road network to the country's land area. The road network includes all roads in the country: motorways, highways, main or national roads, secondary or regional roads, and other urban and rural roads.
Public spending on education, total (% of GDP)	*Public expenditure on education, total* as % of GDP is the total public expenditure (current and capital) on education, expressed as a percentage of the gross domestic product (GDP) in a given year. Public expenditure on education includes government spending on educational institutions (both public and private), education administration, and transfers/subsidies for private entities (students/households and other privates entities).
Governance	*Governance* captures perceptions of the extent to which agents have confidence in, and abide by, the rules of society, and in particular estimates the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence. Also, the indicator captures the quality of public services, voice and accountability, political stability and absence of violence/terrorism, and the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. The estimate gives the country's score as an aggregate indicator, in units of a standard normal distribution, i.e., ranging from approximately -2.5 to 2.5.
Population in the largest city	*Population in the largest city* is the percentage of a country's urban population living in that country's largest metropolitan area.

Appendix 2. Regression results for the infrastructure model

	Variables	*Infrastructure* **Coef**
intelgov	Intelligence of government	-0.00209*** (0.00018)
pseduc	Public spending on education, total (% of GDP)	0.00394*** (0.00112)
governance	Governance Indicator	0.00868* (0.00447)
laginfrasindex	One lag of infrastructure variable	0.38727*** (0.05274)
tdspgni	Total debt service (% of GNI)	0.00358*** (0.00015)
ggfce	General government final consumption expenditure (% of GDP)	-0.00291*** (0.00037)
effgov		-0.00047* (0.00029)
Poptot	Population, total	0.00001*** (0.00001)
pitlcpup	Population in the largest city (% of urban population)	0.00112*** (0.00012)
cons		-0.01118 (0.01044)
R-sq: within	0.4365	
between	0.2649	
overall	0.2642	
F test that all u_i=0:	F(163, 1292) = 5.23 Prob > F = 0.0000	
Number of obs	1465	
Number of groups	164	

The dependent variable corresponds to the infrastructure index. Standard errors are in parentheses (delta method) ***p<0.01 **p<0.05. *p<0.1. Regression coefficients are robust to heteroskedasticity.