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Lifelines: The Resilient Infrastructure Opportunity

Background Paper

Resilient Infrastructure for Thriving Firms

A Review of The Evidence

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Abstract

: This review examines the literature on the role of infrastructure in determining the productivity and competitiveness of firms. It shows that the existing evidence base is clear in concluding that reliable and high-quality infrastructure is a crucial foundation for enabling businesses to thrive. It demonstrates that the provision of electricity, transport, water, and telecommunications systems increases firm-level productivity. It also shows that providing infrastructure per se is not enough to boost productivity, unless it offers reliable service. Disruptions and irregular service have substantial adverse effects on firms, not least due to disrupted supply chains, underutilization of production capacity, and costly adaptation measures.

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Resilient infrastructure for thriving firms: A review of the evidence

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1. Introduction

Infrastructure systems play a crucial role for economic development due to their twofold contribution to supporting well-being: Households rely on essential infrastructure services to meet basic needs and pursue economic activities, while firms rely on infrastructure services as inputs to the production of goods and services, and for the smooth functioning of supply chains.

This review shows that the empirical evidence is clear in concluding that reliable and high-quality infrastructure is a crucial foundation for enabling businesses to thrive. Moreover, it shows that unreliable infrastructure has substantial costs for firms, especially for those engaged in the production of goods. Developing countries in particular tend to suffer from poor reliability and efficiency of their public infrastructure. In these countries, infrastructure users tend to experience frequent disruptions, such as power outages, water supply interruptions, or transport disturbances.

These disruptions can have a range of causes, including sub-standard and malfunctioning equipment, poor management, lacking investment and maintenance, as well as natural stresses and hazards. Without a thorough understanding of the economy-wide costs of infrastructure disruptions, policy makers are ill-equipped for identifying, prioritizing and implementing adequate investments and reforms for enhancing the reliability, quality, and resilience of their infrastructure systems. For as long as infrastructure systems remain disruption-prone, this will have substantial adverse effects on the continuity of business, affecting the smooth functioning of supply chains, diminishing aggregate productivity, and restricting the ability of firms to trade and compete internationally.

This section aims to provide an overview of this relationship by exploring three related, but distinct channels: First, the provision of infrastructure is shown to be crucial for productivity and competitiveness. Second, this review shows that it is not just the availability, but just as much the reliability and quality of infrastructure services that matter to firms. Lastly, the costs of mechanisms that are employed by firms to adapt to unreliable infrastructure are explored.

2. Infrastructure availability is a key driver of productivity and competitiveness

Efficient infrastructure systems are crucial for enabling firms to maximize their productive capacity without investing in expensive back-up or contingency technology. For instance, the ownership of costly diesel-based electricity generators is far less common in countries with reliable electricity supply. In addition, reliable and efficient infrastructure is key to facilitating firms' access to the markets and information that drive their ability to provide goods, services, and jobs.

Infrastructure matters for several key indicators of competitiveness at the country-level

Economists have long studied the factors contributing to firm- and national-level competitiveness and productivity. Their studies have analyzed the role of increased provision of electricity, transport, and information and communication technology infrastructure, focusing on effects at the global, national, and firm levels.

In a prominent paper on the "competitive advantage of nations" Porter (1990) argued that the ability of a country to host high-performing firms is supported by four broad categories of enabling factors: (i) factors of production, (ii) home-market demand conditions, (iii) presence of supply chains, and (iv)

regulation, organization of firms, and domestic rivalry. The study argues that – besides skilled labor – the availability of infrastructure systems is a key factor of production that determines the competitiveness of firms and thus entire economies.

This notion has been confirmed by a wide range of studies focusing on the role of infrastructure: Calderón and Servén (2014) review the literature on infrastructure and economic growth. Overall, both theoretical and empirical literature are concluded to find positive impacts of infrastructure development on growth and even distributive equity. Bom and Ligthart (2014) conduct a meta-regression of 68 quantitative studies that all use a production function approach to quantify the impact of public infrastructure capital on GDP. This review included studies published between 1983 and 2008, predominantly considering developed economies countries. Through a weighted meta-regression, the authors estimate an average elasticity of output with respect to public capital. Their assessment suggests that, on average, a 1% increase in public infrastructure capital is associated with an increase in GDP of 0.1%.

A large body of literature assesses the relationship between infrastructure and economic performance by considering a country's infrastructure stock. In these studies, infrastructure availability is typically assessed in terms of its provided quantity, approximated for example by the total length of paved roads or phone lines in a given country. By considering the variation in infrastructure stocks across countries and time, these studies have shown a significant positive impact of infrastructure availability on various indicators of economic performance.

For instance, Straub and Terada-Hagiwara (2010) conduct an in-depth empirical analysis of infrastructure quality and growth, focusing on developing Asia. For this purpose, they use a range of physical infrastructure stock indicators covering telecommunications, energy, transport, and water for 102 countries, including 23 in South and East Asia, and the Pacific. They find that improvement of a country's infrastructure base correlates significantly with higher economic growth. Similarly, using a large dataset on infrastructure stocks covering 88 developing and industrial countries and the period from 1960 to 2000, Calderón, Moral-Benito, and Servén (2014) show that the output contribution of infrastructure is highly significant. According to their estimates, an increase in infrastructure provision from a typical lower-middle income country (e.g. Bolivia in 2000) to an upper-middle income country (e.g. Uruguay) increases output per worker by 5 percent.

The same positive impact of infrastructure investments is found in studies investigating individual countries at different income levels. A prominent study by Aschauer (1989) finds that public investment in US infrastructure has a significant positive effect on total factor productivity. In particular, investments in 'core' infrastructure such as transport, electricity, gas, water, and sanitation are found to have the strongest explanatory power for productivity. For a 30 year-long panel of South African manufacturing firms, Fedderke and Bogetić (2009) find a positive and significant impact of investments in different types of transport, telecommunication, and power generation infrastructure, on measures on productivity, output, and growth. Similarly, Mitra, Sharma, and Végantonès-Varoudakis (2016) analyze Indian manufacturing firms and find a strong positive impact of the availability of transport, information and communication technology infrastructure on firms' productivity. The size of this effect is larger in industries with greater exposure to foreign competition, thus highlighting the link between competitiveness and infrastructure stocks.

Further studies offer evidence of the economic contribution of specific infrastructure systems, in particular power, transport, ICT, and water.

Electrification increases economic output and employment

Focusing on electricity infrastructure specifically, Rud (2012) investigates the effect of electrification on industrialization in India between 1965–1984. This state-level analysis shows that an increase in electrification of one standard deviation is associated with an increase in manufacturing output of around 14%. In South Africa, electrification has been shown to increase employment in newly-electrified communities between 1996 and 2001, an effect that is especially strong among women. The study suggests that this is mainly driven by an increase in small enterprises and self-employment, rather than larger-scale industrialization of rural regions (Dinkelman, 2011).

Using data on the Indian wholesale electricity trade market, Ryan (2017) simulates the effect of additional transmission infrastructure in regions where limited transmission capacity is obstructing trade and economic activity. He finds that investments in transmission capacity can lead to social benefits (i.e. additional consumer and producer surplus) that exceed the investment costs, especially by facilitating interregional trade, increasing market harmonization, and increasing competition. In other words, new transmission infrastructure can pay for itself by reducing the negative effects of market power. Similarly, in the context of the Indonesian manufacturing sectors between 1990 and 2000, Kassem (2018) demonstrates a link between electrification and industrial development. Electrification is shown to increase the number of firms, employment, competition among firms, and the establishment of firms with higher average productivity in electrified areas.

Transport infrastructure increases productivity and creates jobs

Transport infrastructure has been shown to determine firm productivity through various channels, both at the micro and macro levels. Common links identified in the literature include effects on employment through higher mobility of high-skilled labor, decreased transportation costs and resulting increases in trade and allocative efficiency, reduced transaction costs through lower inventory requirements, increased market entrance of new firms, and agglomeration economies through spill-overs in knowledge and human capital caused by spatial proximity.[1]

A key challenge to the quantification of these relationships is endogeneity. The locations where new roads are built, or existing ones are upgraded, are not randomly chosen. Instead, roads are improved in regions where gains in productivity are expected or likely. Or on the contrary, in other regions a looming decrease in economic activity may cause an increase in infrastructure investments to stimulate growth. Thus, simply evaluating productivity in an area before and after changes to the local transport network does not necessarily allow for the identification of the causal effect of infrastructure investments.

Gibbons et al. (2017) overcome this endogeneity problem by examining areas in the UK not directly affected by, but close enough to new road infrastructure that they profit from increased accessibility. They find that improving accessibility measured through journey times by 1% leads to a 0.3-0.4% increase in overall employment. Interestingly, this increase seems to be largely driven by new firms whereas incumbents register decreases in employment that might be driven by increasing wages and resulting substitution of labor by material inputs. Duranton and Turner (2012) use the location of historic highways and railroads in the USA to assess the effect of interstate highways on the growth of cities. They find that,

[1] For further details refer to a meta-analysis by the Asian Development Bank et al. (2018), which offers a far-ranging discussion and review of the wider economic effects of large transportation infrastructure projects on welfare, social inclusion, inequality, the environment, and economic resilience.

all else being equal, a 10% increase in the initial stock of highways in a city leads to higher employment of 1.5% between 1983 and 2003. A similar analysis for the USA concludes that the construction of interstate highways raises economic growth in counties through which the highway passes, but reduces economic activity in nearby regions, thus leading to an unclear effect on overall economic activity (Chandra and Thompson, 2000).

Road networks also impact regional productivity through changes in transport costs and increased economy-wide allocative efficiency. Faber (2014) investigates the displacement of economic activity caused by increased ease of transport through a 15-year construction program as part of the National Trunk Highway System in China. The study overcomes endogeneity in road placement by considering a hypothetical road network as a benchmark and finds that reduced transport costs lower economic activity in peripheral regions when connected to large centers of production. Baum-Snow et al. (2017) provide somewhat contrasting evidence by showing strong negative relationships between GDP in peripheral regions and the construction of new transport infrastructure in Chinese cities between 1990 and 2010. The results suggest that development of a new radial railroad or ring road displace industrial GDP in the city center by about 20% or 50%, respectively.

It is important to note that these positive or negative changes at the sub-national level do not contradict the national-level gains from better transportation networks found in other studies. Rather, they illustrate the important role of infrastructure systems in distributing and reallocating economic centers across space. This is evident, for example, in studies looking at early infrastructure projects such as the railroad network in colonial India. This transport systems has been shown to have reduced transportation costs, facilitated the harmonization of price levels, and thus increased agricultural income by 16% in the average district (Donaldson, 2018). In current times, Asturias et al. (2015) estimate that the Golden Quadrilateral, a large infrastructure project in India connecting Delhi, Mumbai, Chennai, and Kolkata with highways established from 2001 onwards, lead to real income gains in the manufacturing sector of 2.7%, about 7% of which was caused by gains in allocative efficiency.

In addition to reductions in transport cost, better road infrastructure can also reduce transaction costs for firms. In the US, a marginal dollar invested in highway capital has been estimated to decrease firm-level raw material inventory by seven cents in the 1970s, although the return shrunk to two and 0.3 cents in the 80s and 90s, respectively (Shirley and Winston, 2004). Using the World Bank Enterprise Survey (ES) data for India, Datta (2012) shows that businesses in cities affected by the Golden Quadrilateral project could reduce their average inventory by production inputs worth 6-12 days between 2002 and 2005 and are more likely to have switched their supplier, again hinting at improvements in allocative efficiency. Using firm-level data for Chinese manufacturers, Li and Li (2013) confirm the existence of this effect channel. They find that for every dollar invested in roads, affected firms can reduce their inventory costs by about two cents.

Empirical evidence exists for several other ways in which transport networks can boost productivity. The quality of physical infrastructure has been found to substantially impact the entrance of new firms into the market (Ghani, Kerr and O'Connell, 2014; Ghani, Goswami and Kerr, 2016). Martincus et al. (2017) use the Inca road network to assess changes in road infrastructure in Peru and estimate that 26% of growth in firm exports between 2003 and 2010 can be attributed to upgrades of domestic transport infrastructure. In addition to these direct effects on productivity, Wan and Zhang (2018) identify an indirect effect of infrastructure on firm productivity through agglomeration economies in the Chinese manufacturing sector,

meaning the increased relative proximity of firms allows them to profit from knowledge spillovers and a shared labor pool.

Transport infrastructure can also have positive effects outside the manufacturing industry even though evidence is scarcer for other key economic sectors such as tourism or agriculture. Focusing on the tourism sector, Khadaroo and Seetanah (2008) assess the importance of transport infrastructure in determining the ability of a country to develop as an international tourism destination. Based on a panel data set of bilateral tourism flows among 28 countries over the decade 1990–2000, the study finds that – besides tourism infrastructure and other classical determinants – stocks of transport infrastructure like roads, airport terminals, and ports are indeed significant determinants of tourism inflows.

Information and communication technologies (ICT) infrastructure is associated with increased productivity

Linkages between ICT infrastructure and productivity are well documented at the country-level. Analyzing OECD countries between 1996 and 2007, Czernich et al. (2012) find that a 10 percent increase in broadband penetration increases GDP growth by 0.9 to 1.5 percentage points. Albiman and Sulong (2016) analyze 45 Sub-Saharan African countries from 1990 to 2014 and find that positive effects of ICT infrastructure on economic growth are evident once a penetration rate threshold of about 5 percent has been crossed for mobile phones, internet, and telephone lines.

This positive relationship between ICT infrastructure and performance holds also at the firm level. Paunov and Rallo (2015) use Enterprise Survey data for firms in 117 developing and emerging countries between 2006 and 2011 to quantify the link between ICT and productivity. Overall, an increase in an industry's use of the internet by one standard deviation increases the labor productivity of an average firm in this industry from the 50th to the 55th percentile of the distribution. This effect is heterogeneous amongst firms, with the most productive firms showing three times the increase of the least productive firms. Using the same data, the authors also identify positive effects on innovation activities. An increase in industry internet usage by one standard deviation is associated with an increase in ownership of quality certificates and patents of 3 and 5 percent, respectively (Paunov and Rollo, 2016). In a meta-regression of 70 studies quantifying the relationship between ICT infrastructure and productivity in a production function framework, Polák (2017) finds that an increase in ICT investments of 1% increases productivity by 0.3% on average when controlling for publication bias.

A large fraction of the global economy is dependent on water supply

In addition to the attention given to electricity, transport, and ICT infrastructure, water supply is a further crucial determinant of economic activity. According to one assessment, 42% of the total global active workforce is employed in heavily water-dependent jobs, while a further 36% are moderately water-dependent, meaning that water is a necessary input somewhere in their value chain (United Nations World Water Assessment Programme, 2016). Overall, this amounts to more than three quarters of all jobs on a global level being dependent on water supply. As a result, differences in water availability can explain differences in economic activity between countries. Debaere (2014) exploits cross-sectional variation in 134 countries and over 200 sectors to show that abundant water resources lead to a comparative advantage for countries and to higher exports of water-intensive products, even though this factor is small in comparison to the influence of labor or physical capital. Furthermore, improving water supply infrastructure has impacts on economic growth: According to the United Nations Environment Program, investments in small projects providing safe water supply and basic sanitation in Africa could lead to an

estimated overall economic gain of about US$ 2.84 billion, roughly corresponding to 5% of GDP (United Nations Environment Programme, no date).

3. Infrastructure provision is not enough: Quality and reliability matter

The evidence reviewed in the previous section focuses on infrastructure provision and investments, and thus explores the role of infrastructure availability. However, the *quality and reliability* of infrastructure also plays a key role in all prominent assessments of competitiveness. The Global Competitiveness Report by the World Economic Forum (WEF, 2018), the Doing Business reports and the Enterprise Surveys (ES) by the World Bank (2018a, 2018b), and the Business Environment and Enterprise Performance Survey by the European Bank for Reconstruction and Development and the World Bank (EBRD, 2018) – they all place a strong emphasis on the quality of public infrastructure. In addition to considering a wide range of factors, such as technical capacity, administrative obstacles, regulation, governance, and transparency, these assessments score the reliability and service quality of key infrastructure such as transport, electricity, water, and telecommunications.

Higher infrastructure quality is associated with higher productivity

In a comprehensive review of the literature, Dethier, Hirn, and Straub (2011) examine the impact of business climate on productivity and growth in developing countries. They show that there are several key variables – including infrastructure quality – that have a significant impact on firm performance.

For 26 countries across Africa, Escribano, Guasch, and Pena (2010) assess the impact of infrastructure quality on total factor productivity of manufacturing firms between 1999 and 2005. They focus on the quality of various infrastructure services, including customs clearance, energy, water, sanitation, transportation, telecommunications, and information and communications technology. Overall, they confirm that productivity is, among other factors, determined by infrastructure quality. However, they also show that different infrastructure types matter more in some countries than in others. Low-quality electricity, measured by several power supply and outage frequency indicators, reduces log productivity in Zambia by 34.1% on average, but only by 0.3% in Morocco. This difference is likely driven by a lower overall influence of infrastructure on productivity in the Moroccan economy and a higher reliability of the Moroccan power grid.

Similar effects have been shown for garment and food-processing firms in the Kyrgyz Republic, Moldova, Poland, Tajikistan, and Uzbekistan (Bastos and Nasir, 2004). Using Enterprise Survey data for eight countries in Eastern Europe, Anos-Casero and Udomsaph (2009) show that over the period 2001 to 2004, an increase of one standard deviation in infrastructure quality, measured by an indicator combining information on power and water outages as well as mainline telephone disruptions, raises the total factor productivity of the average firm by 9.8%.

More reliable electricity supply can increase output and productivity

Empirical studies for a large number of countries have shown that power supply irregularity can have substantial adverse impacts on the productivity and sales of firms. These studies are reviewed in this section and are summarized in *Figure 2*. A detailed overview of studies is offered in the Annex, providing the case study country, the type of firms considered in the analysis, details on the power supply quality indicator, methodology, and the estimated effect of power supply irregularity on different indicators of firm performance.

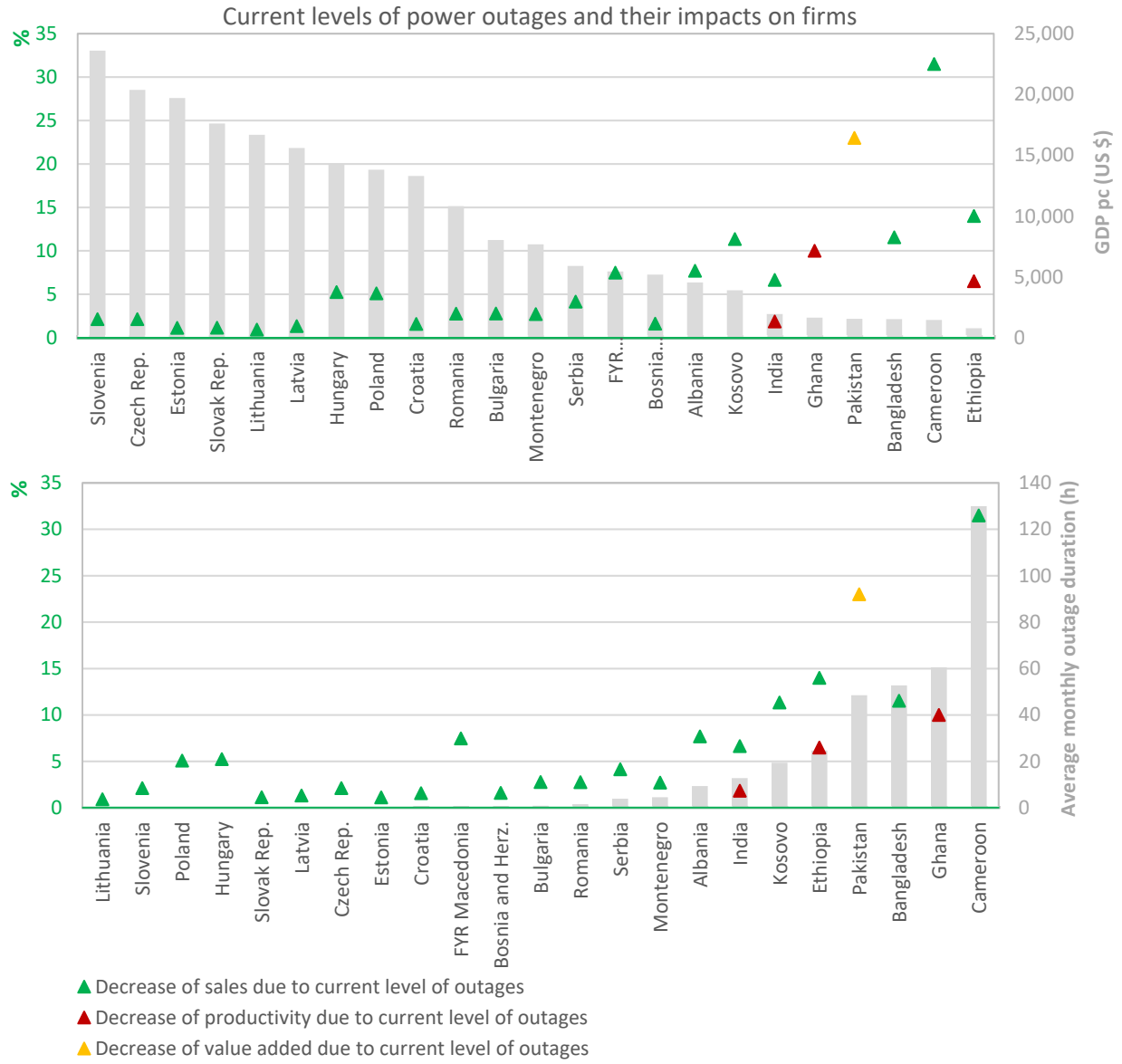

Figure 1: Current level of power outages and their impact on firm performance (left axis), and national level GDP per capita in 2019 USD (upper panel, right axis) and average monthly electricity outage duration (lower panel, right axis) (Source: studies reviewed in this section)

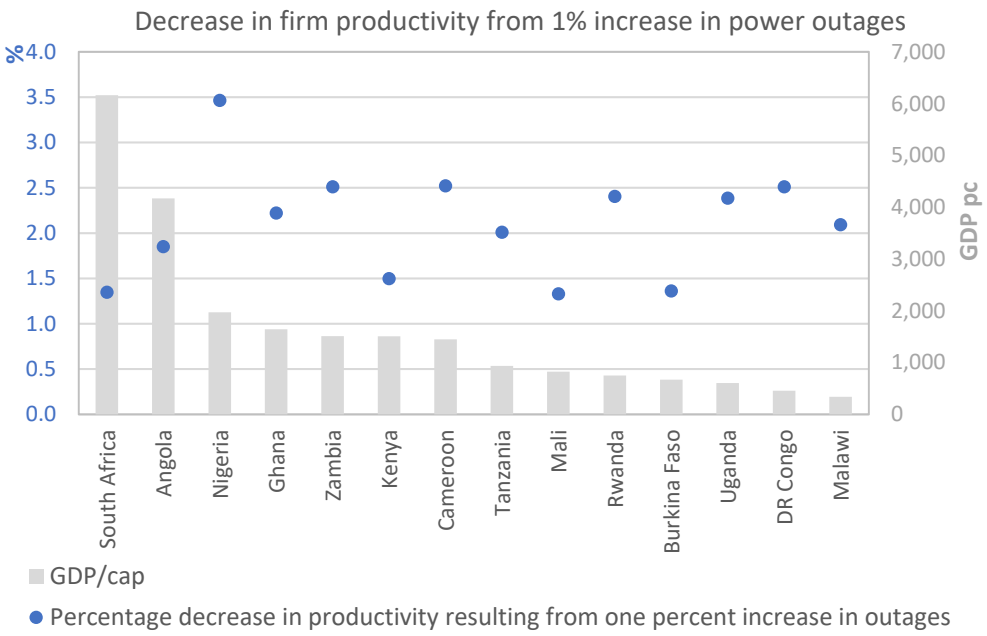

Figure 2: Decrease in firm productivity from 1% increase in power outages (left axis) and national-level GDP per capita in 2019 USD (right axis) (Source: Mensah, 2016)

A meta-review of literature analyzing constraints to growth in developing countries finds that over 40% of such studies classify electricity as a binding constraint (McCulloch and Zileviciute, 2017). Based on the World Bank Enterprise Survey, Bbaale (2018) assesses the impact of electricity outages on manufacturing firms in 26 African countries. The study shows that power outages lead to self-reported losses in sales of 11-12% for small, medium, and non-exporting firms. For large and exporting firms, the study observes that the substitution of grid supplied power with generators tends to increase productivity.

Using Enterprise Survey panel data for 15 Sub-Saharan African countries, Mensah (2016) identifies reductions in firms' productivity by 0.6% to 1.1% for a percentage increase in outage intensity. A similar study based on a panel of 23 African countries estimates that a one percent increase in electricity outages would account for a loss in firms' total factor productivity of 3.5% (Mensah, 2018). Ramachandran et al. (2018) use Enterprise Survey data as well but allow for heterogeneity among firms' experiences of outages. By clustering firms according to their affectedness by outages and their growth behavior, they find a large group of firms seemingly unaffected by outages, a group that seems to be able to cope with outages through the usage of generators, and a group severely affected by power outages that cannot cope even when using generators.

Increasing the reliability of infrastructure services has been found to significantly improve outcomes both at the firm- and macro-economic level. For instance, Ilmi (2011) estimates the marginal impact of electricity reliability on firm costs, using firm-level data collected by the Business Environment and Enterprise Productivity Survey (BEEPS) in 26 countries in Europe and Central Asia. Eliminating all electricity outages would allow firms to reduce costs by about 1.4%, on average. In the Western Balkans, firms loose on average 5.8 percent of their annual sales due to electricity issues, according to the same survey (Kresic, Milatovic and Sanfey, 2017). The losses caused by outages are particularly pronounced in Africa. One study

uses Enterprise Survey observations for 14 countries and hydro-power variation as an instrument to estimate that reducing the outages to a level comparable to that of South Africa would increase sales of firms in Sub-Saharan Africa by 85%, a number that rises to 117% if firms do not own generators (Cole *et al.*, 2018). For 23 countries, a recent study by the World Bank (2019) estimates that a one percentage point increase in power outage frequency reduces firm-level output by 3.3%. Furthermore, the same increase reduces firms' share of sales from exports by 0.12%. Finally, low power reliability makes it impossible for countries to host certain high-growth industries such as large data centers, thus further foregoing economic potential.

As the reliability of electricity supply significantly influences the production possibilities of firms, it also dynamically influences their longer-term choices. Aterido and Hallward-Driemeier (2010) show that for African firms, increased occurrences of power outages have a negative effect on employment growth – especially in the case of large firms. Mensah (2018) finds a negative effect of electricity shortages on employment in 21 countries in Africa that is substantial in size: overall, electricity outages decrease the probability of employment for an individual by 35% to 41%. Impact channels for this link include the discouragement of entrepreneurship by shortages, lower productivity and output by businesses, and reduced international competitiveness of firms. Indeed, a one percentage point increase in outages is estimated to reduce employment by 1.1% in the case of low-skilled workers, and 0.35% for high-skilled workers in a study considering a sample of 23 African countries (World Bank, 2019).

At the country level, Allcott et al. (2016) similarly use hydroelectric power supply as an instrument and estimate that electricity deficits reduce Indian manufacturing firms' revenues by 5% to 10% on average. They do not, however, find that shortages translate into losses in productivity which might be explained by the ability of plants to store inputs for later usage. Looking only at small firms, Zhang (2019) finds that they are disproportionately affected by outages and face production costs that are higher by 0.29% of revenue for every percentage point increase in electricity shortages.

Indeed, firm size is an important factor in determining the ability to cope with outages as confirmed for a set of Indonesian manufacturing firms (Poczter, 2017). In their sample, the negative effect of electricity unreliability on firm productivity is more than 50% larger for smaller than for bigger firms. Further confirming the disproportionate effect on smaller firms, a survey of Ghanaian small- and medium-sized manufacturing firms revealed that major power outages between 2012 and 2015 decreased average monthly productivity by 10% (Abeberese, Ackah and Asuming, 2017). In Bangladesh, Zhang (2019) uses two different sets of firm-level micro data to estimate the productivity impacts of electricity shortages. According to her estimates, a shortage of 10% causes total factor productivity reductions of 3.1% when using a survey of the manufacturing industry or of 4.1% when using Enterprise Survey data.

A problem related to, but distinct from power outages are so called brownouts, which refer to fluctuations in the voltage provided by the electrical grid. According to one study, one third of enterprises surveyed in Tanzania experienced damage to their appliances resulting from brownouts (Bensch et al., 2017).

The relationship between power outages and foregone economic activity is not only visible at the firm-level, but also on a country-wide scale. Andersen and Dalgaard (2013) estimate the impact of power outages on economic growth at the country-level for Sub-Saharan African countries. Using nightlight brightness and lightning strikes as control variables, they estimate that an increase in outages by one percent reduces GDP per capita in the long run by 2.86%.

The link between unreliable electricity and output losses varies between countries and industries

Aside from econometric estimation, losses can also be quantified using specifically designed surveys. In Bangladesh, about 14% of industrial sector electricity demand could not be met between 2001 and 2003, with 94% of outages being unplanned according to a survey conducted by Wijayatunga and Jayaleth (2008). In 2001, this is estimated to have translated into damages equivalent to 1.72% of Bangladesh's GDP. A survey conducted with Pakistani industrial firms in 2008 finds that, on average, firms suffer losses of 23% of value added as a result of unserved electricity (Siddiqui *et al.*, 2008). A newer study of Pakistani manufacturing firms finds that an increase in average daily power outages by one hour causes a reduction in value added of 1.26% (Zhang, 2019). In Cameroon, about 80% of industrial firms experience output losses of between 16% and 50% due to power outages, according to one survey. Costs of outages are found to increase with outage duration and decrease if advance notice is given (Diboma and Tamo Tatietse, 2013).

In Ethiopia, power supply disruptions result in productivity losses of about 4% to 10% among manufacturing firms, according to census data. Disaggregating the impact shows that firms with very low and very high power usage intensities suffer the most productivity losses from electricity disruptions. Intuitively, firms with low electricity intensity adopt costly coping mechanisms to a lesser degree and are therefore hit harder by disruptions, whereas firms with high power intensity do invest in adaptation measures, but are also most affected by the high costs of self-generation, thus incurring greater losses (Gurara and Tessema, 2018).

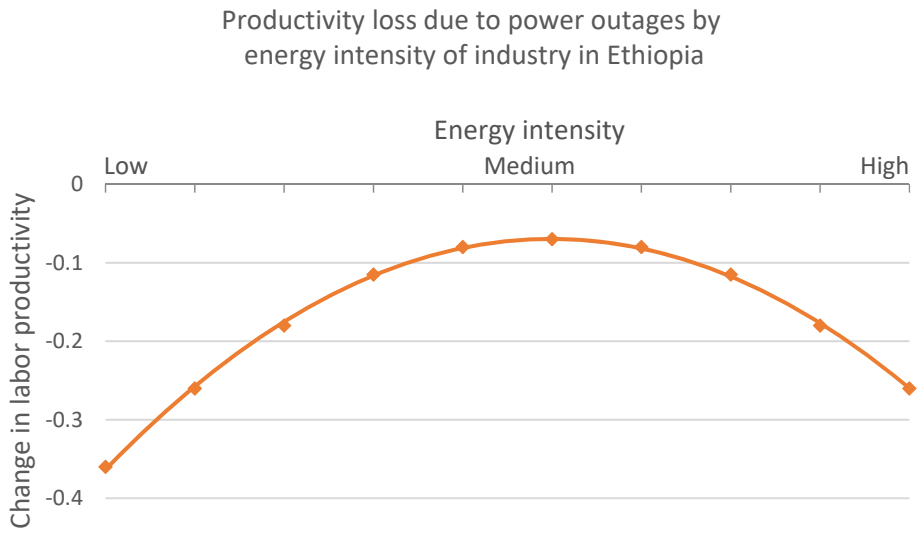

Figure 3 Power supply disruptions in Ethiopia cause the highest productivity losses among firms with very low or very high power use intensity in production (difference in labor productivity due to power supply disruptions on the y-axis, energy intensity on the x-axis) (Reproduced from Gurara and Tessem, 2018)

For manufacturing firms in Indonesia, Rentschler and Kornejew (2017) show that lacking access to reliable electricity can cause firms to switch towards polluting and less efficient fuels. This reduces their profitability and causes them to pass on higher prices down their supply chains. Stated preference valuation methods can be used to quantify the direct and indirect cost of unreliable electricity infrastructure by asking businesses for their willingness to pay for improved service. According to one survey, small Indian manufacturing firms face on average outages of between two (winter, monsoon

season) and six hours a day (summer) and would be prepared to pay 0.018 to 0.031 US$/kWh for uninterrupted power supply, or 20% more than the actual prices (Ghosh *et al.*, 2017).

In Ethiopia, manufacturing firms of comparable size are willing to pay US$ 0.0046 per kWh to reduce the monthly number of outages by one, which corresponds to 16% of the current kWh electricity price. In order to decrease average outage duration by one hour, firms would be prepared to pay US$ 0.0092 per kWh. From these numbers, the authors infer that firms' compensating variation for a scenario without power outages would be about three times the current cost of electricity (Carlsson, Demeke and Martinsson, 2018). In Ghana, firms affected by significant power rationing between 2012 and 2015 were estimated to be willing to pay a 16% higher monthly electricity bill to avert future power outages (Abeberese, Ackah and Asuming, 2017). These results further illustrate the substantive differences in power supply quality across countries and the heterogeneity in firms' vulnerability to power outages.

Higher-quality water infrastructure matters for firms' production and productivity

While the better availability of data has caused studies to focus on the effects of unreliable electricity supply, water supply infrastructure also plays an important role for production. In agriculture, the relationship between water availability – determined by weather and irrigation technology – and agricultural production has been clearly established (Damania *et al.*, 2017).

Looking beyond the agricultural sector, Iimi (2011) finds that if all water supply disruptions could be removed in Europe and Central Asia, firms would on average be able to reduce their costs by 0.5%. This effect can be expected to be significantly larger in developing countries with less reliable water infrastructure.

Indeed, Islam and Hyland (2018) use Enterprise Survey data for 103 countries and analyze the effects of water supply disruptions on firms separately for low and lower-middle income and for upper-middle and higher income countries. They find a significant effect only for the poorer of the two groups; here, an additional water outage incident in a day would lead to sales losses of about 8.2% for the average manufacturing firm. Described as an elasticity, a 1% increase in daily water shortages causes a sales decline of 0.002%. While the ES includes only formally registered firms, similar results also hold in a survey of informal firms in 12 developing countries. For these, an increase of the monthly duration of water shortages by one standard deviation causes annual losses of about 15% of the monthly sales per worker (Islam, 2018).

Such clear relationships, however, are not present in all studies. Using multivariate analyses on ES data for firms from 100 countries, Bhat (2015) does not find a link between water scarcity problems and firms' labor productivity. This result, however, does not imply that there is no causal link. Instead it may also indicate that firms account for unreliable water supply and choose less water intensive activities.

Traffic congestion disturbs economic activity in metropolitan areas

In addition, inefficient transport infrastructure can further affect firm productivity – especially through traffic congestion in urban areas. The negative impacts of congestion on economic growth have been shown in a number of case studies, which have been reviewed by Sweet (2011). The evidence suggests that firms that are reliant on high-skilled labor, specialized inputs, and geographically distributed markets are especially sensitive to congestion, as it obstructs their access to these factors (Weisbrod, Vary and Treyz, 2003). Sweet (2013) uses panel data from 2001 to 2007 and 88 metropolitan areas in the US and finds that, amongst effects on economic growth, a one percent increase in congestion – measured by daily

traffic per freeway lane – leads to a decrease in productivity growth per worker of up to 0.033%. With a panel of similar geographical scope, Jin and Rafferty (2017) show that an increase in congestion growth by one percent – measured by an index of traffic delays – furthermore causes a decrease in employment growth of 0.08%.

Traffic disruptions and congestion have been shown to have negative productivity effects in developing countries too. Based on a survey with commuters in Kumasi, Ghana, congestion has been estimated to result in an average loss of daily productive hours of 9% per worker (Harriet et al. 2013). In the Greater Cairo Metropolitan Area in Egypt, traffic congestions cause direct costs of US$ 5.1 billion annually as of 2010, an amount that is only expected to increase (World Bank, 2013). The upside to these numbers is that addressing congestion does not have to be costly. A recent modeling study in Grand Casablanca, Morocco, finds that a combination of demand-side instruments – a fuel tax, a parking fee, and a bus fare – increases income by 0.8% through decreasing travel times and thus freeing up travelers' time for other activities. These gains can be further increased by adding bus services or constructing new roads (Anas, De Sarkar and Timilsina, 2018).

4. Firms adapt to unreliable infrastructure – often at considerable cost

As infrastructure directly affects firms' productivity, firms take infrastructure quality into account when making business decisions. Through adaptation measures, firms can influence to what degree they will be affected by disruptions.

This can be illustrated when considering the effects of a large shock, such as an earthquake. Figure 4 plots the recovery of a directly affected firm's production capacity. The recovery from damages to the firm's productive assets is slowed down by the loss of electricity, water, and gas supply (subsumed under 'lifelines'). Here, two factors determine the impact of the infrastructure disruptions; it is influenced by both speedier service restoration (i.e. when the upward steps appear in the fat black line) and a firm's resilience to infrastructure disruptions (i.e. the size of the vertical difference between the fat black line and the thin black line). Through adaptation measures, firms can increase their resilience and decrease the negative impact of the loss of infrastructure services (Kajitani and Tatano, 2014).

As such adaptation measures protect firms from losses, the real impact of infrastructure disruptions on firms is difficult to estimate. They require consideration of the costs of adaptation investments along with the cost of the disruption. This section discusses various measures that firms implement to cope with unreliable infrastructure. It includes the costly location choices by firms in response to infrastructure constraints, the increase in inventory to cope with unreliable transportation systems, the direct cost of backup self-generation incurred by firms, and the dynamic consequences of unreliable electricity supply on industry composition.

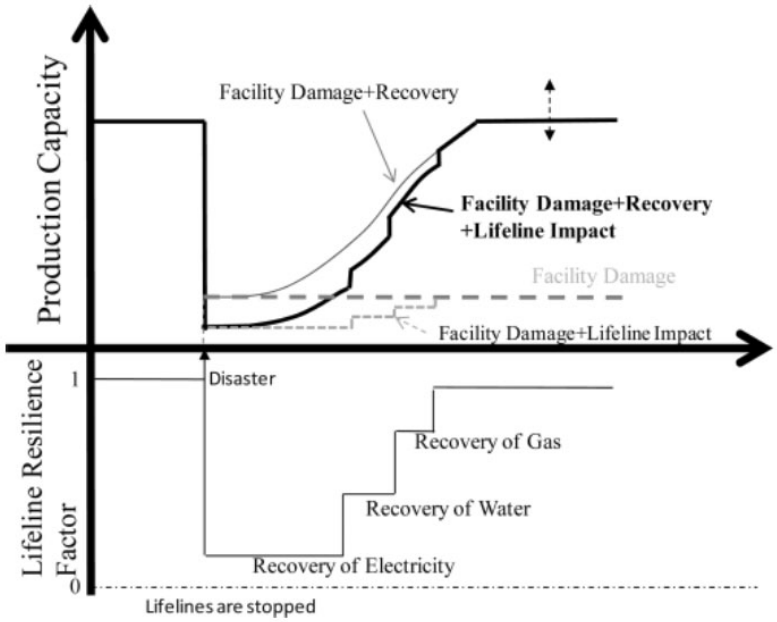

Figure 4: Recovery of production capacity after a shock that damages a firm's productive assets and cuts off infrastructure services ('lifelines'). Figure from (Kajitani and Tatano, 2014).

In their location choices, firms consider the availability of transport and ICT infrastructure

In a large number of empirical analyses in various countries, transport infrastructure has been shown to have a significant impact on firms' location choices (see Arauzo-Carod, Liviano-Solis, and Manjón-Antolín, 2010 for a review). In Indonesia, for example, road improvements in the 1990s lead to a diffusion of manufacturing activity away from industrial centers as lower transport costs and better access to labor increased the set of feasible firm locations (Rothenberg, 2011). Similar results also hold for other types of infrastructure – Kim and Cho (2017) find that the availability of broadband connectivity significantly increases the chance that a firm chooses a certain location in the rural US. While such location decisions do not necessarily impose greater costs on firms, regions with poor infrastructure quality are bound to be less attractive to businesses which has implications for local economic activity and employment outcomes.

Firms increase inventories to deal with low-quality infrastructure

Guasch and Kogan (2003) detail another channel through which infrastructure quality impacts firms by investigating the determinants of firm inventories in a cross-country analysis. While they do not find an impact of road infrastructure provision, a country-level indicator of infrastructure quality has a significant impact on average inventories held by firms in a developing country. If infrastructure quality were to decrease by one standard deviation, raw material inventories increase by 11-37%. The importance of this effect is also visible at the firm-level in East-Africa. An analysis of firms in Burundi, Kenya, Rwanda, Tanzania, and Uganda finds that inventories would decrease significantly with reduced transportation costs (Iimi, Humphrey and Melibaeva, 2015). This adaptation measure to unreliable transport infrastructure comes with significant costs in the form of opportunity costs of capital bound in the inventory, costs of storage, and possible depreciation of stored goods.

Unreliable electricity can force firms to invest in back-up generators and pay extra for used power

As relocation may not always be feasible, firms can also opt for other measures to decrease the adverse effects of lacking infrastructure services. In the case of electricity supply, the most commonly employed

strategy is the purchase of diesel-powered back-up generators that mitigate outages and ensure continued business operations. This, of course, comes at a cost to firms. Using Enterprise Survey data for 25 African countries between 2002 and 2006, Steinbuks and Foster (2010) find that self-generated electricity is on average three times more expensive than if purchased from the grid. This number is in line with findings based on a 1998 survey in the Nigerian manufacturing sector (Adenikinju, 2003).

In a more recent study, Farquharson et al. (2018) also estimate the additional costs of self-generated electricity in 15 Sub-Saharan African countries. This study shows that self-generation is substantially more expensive than grid electricity. The net cost of backup power generation (i.e. cost of backup generation minus hypothetical cost of grid electricity for the same amount) varies substantially across countries, with Senegal carrying additional annual costs of US$ 4 million, corresponding to 0.03% of GDP, and Nigeria incurring additional annual cost of US$ 1.6 billion, or 0.28% of GDP (see Figure 5). Overall, Nigerian backup generation produces electricity corresponding to roughly 25% of grid electricity generation. Moreover, the authors also demonstrate that backup generation using diesel generators significantly increases emissions of air pollutants such as PM2.5 and greenhouse gases like CO2, thus causing substantial indirect costs in the form of health impacts or climate change (Farquharson, Jaramillo and Samaras, 2018; World Bank, 2018c).

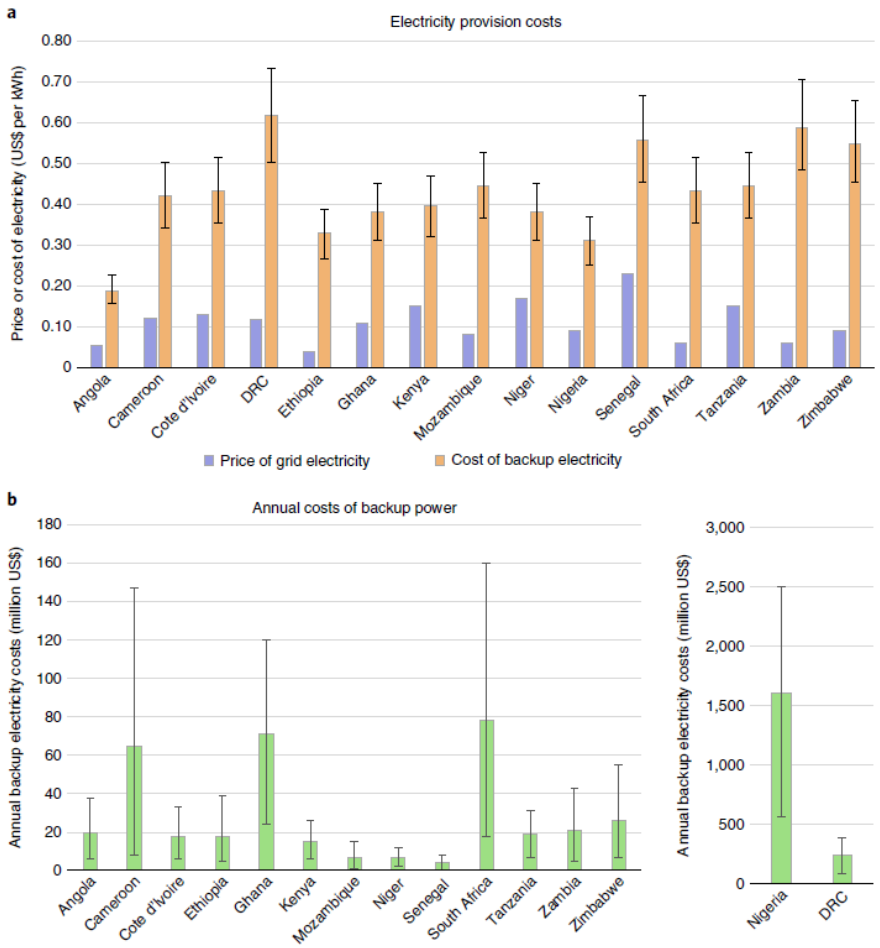

Figure 5: Back-up electricity comes with an extra cost. Panel a: Blue bars display grid electricity prices (US$ kWh-1) and orange bars display backup electricity costs. Panel b: Annual costs consumers incur for backup power with. Figure from (Farquharson, Jaramillo and Samaras, 2018)

Generators can mitigate short-term losses but reduce other investments

Using a set of Enterprise Survey observations restricted to eight Sub-Saharan African countries in 2007, Oseni and Pollitt (2015) show unmitigated losses due to outages range between US$ 2-24 per kWh for firms possessing generators and US$ 1.5-32 per kWh for firms without generators. These figures, however, do not reveal all differences between the two sets of firms as those owning generators are also more likely to be exposed to outages and more reliant on electricity. And while generators can prove to be effective in mitigating short term losses, they are also linked to lower longer-term productivity due to higher marginal costs, thus limiting investments into other input factors (Mensah, 2016). Furthermore, scarcity in electricity supply has been found to increase production cost via spending on alternative inputs and even lead to the outsourcing of production to firms with reliable electricity supply in a large panel of Chinese firms (Fisher-Vanden, Mansur and Wang, 2015).

The high cost of generators changes industry composition in power-intensive sectors and disadvantages small firms

Aside from increased operational costs, unreliable power networks can drastically increase the initial investments required to start a business. In Nigeria, small firms have to spend between 10 and 30 percent of their start-up cost on technologies for self-generation (Adenikinju, 2003, 2008). In industries that require a large amount of electricity for production, small firms might be unable to finance such investments and thus be shut out of the market, leading to overall efficiency losses. Indeed, Alby et al. (2013) use Enterprise Survey data for 77 countries to show that energy-intensive sectors (e.g. chemical and textile industries) have a significantly lower share of small firms in countries with frequent outages. In these circumstances, large firms are more likely to be able to mobilize sufficient funds for investing in generators, while smaller firms are pushed out of the market. And unreliable electricity supply also affects entrepreneurship. An analysis of Enterprise Survey data for 23 African countries finds that, power outages diminish the probability that individuals start their own business by 32%, an effect that even rises to 44% when considering only the non-farm sector (Mensah, 2018).

5. Conclusion

The literature reviewed in this section demonstrates the positive effects of provision of electricity, water, transportation, and ICT infrastructure on economic development. It stresses the crucial role that infrastructure quality plays in increasing the productivity of firms, even though further research is needed assessing the impacts of ICT quality upgrades, such as improving internet speeds.

At the same time, there is ample evidence how infrastructure disruptions hurt firms. In analyzing the consequences of infrastructure disruptions, most of the literature focusses on direct effects such as foregone production. Indirect effects have been quantified to a lesser degree. This does not, however, mean that they are less important. Disruptions such as power outages reduce investment through several channels; firm-level adaptation measures such as procurement of self-generating capacity crowd out investments that would increase the productivity of capital, and investment in infrastructure-dependent sectors is more likely to flow to regions with fewer disruptions. Outages also distort the sectoral allocation of firms, leading, for example, to macroeconomic efficiency losses due to a lack of small firms in energy-intensive sectors.

The total effect of these and other indirect impacts of infrastructure disruptions on economic growth is unknown. In the long term, they may even exceed the short-term direct impacts and lead to costs that

are substantially higher than immediately evident from analyzing foregone economic output from halted production. Reducing the prevalence of disruptions by increasing the resilience of infrastructure therefore provides a powerful tool to increase longer-term capital investments and entrepreneurship and can lead to sustainable economic benefits far exceeding the primary effects of avoided disruptions (Tanner *et al.*, 2015).

References

Abeberese, A. B., Ackah, C. G. and Asuming, P. O. (2017) *How did the 2012-2015 power crisis affect small and medium manufacturing firms in Ghana?* 33305.

Adenikinju, A. F. (2003) 'Electric infrastructure failures in Nigeria: a survey-based analysis of the costs and adjustment responses', *Energy Policy*, 31(14), pp. 1519–1530. doi: https://doi.org/10.1016/S0301-4215(02)00208-2.

Adenikinju, A. F. (2008) *Efficiency of the Energy Sector and its Impact on the Competitiveness of the Nigerian Economy*, *Fourth Quarter*.

Albiman, M. M. and Sulong, Z. (2016) 'The role of ICT use to the economic growth in Sub Saharan African region (SSA)', *Journal of Science and Technology Policy Management*, 7(3), pp. 306–329. doi: 10.1108/JSTPM-06-2016-0010.

Alby, P., Dethier, J.-J. and Straub, S. (2013) 'Firms Operating under Electricity Constraints in Developing Countries', *The World Bank Economic Review*, 27(1), pp. 109–132. doi: 10.1093/wber/lhs018.

Allcott, H., Collard-Wexler, A. and O'Connell, S. D. (2016) 'How Do Electricity Shortages Affect Industry? Evidence from India', *American Economic Review*, 106(3), pp. 587–624. Available at: http://www.aeaweb.org/articles?id=10.1257/aer.20140389.

Anas, A., De Sarkar, S. and Timilsina, G. (2018) *The Optimal Mix of Pricing and Infrastructure Expansions to Alleviate Traffic Congestion and In-Bus Crowding in Grand Casablanca*. 8501.

Andersen, T. B. and Dalgaard, C.-J. (2013) 'Power outages and economic growth in Africa', *Energy Economics*, 38, pp. 19–23. doi: https://doi.org/10.1016/j.eneco.2013.02.016.

Anos-Casero, P. and Udomsaph, C. (2009) 'What Drives Firm Productivity Growth?', *World Bank Policy Research Working Papers*, 4841.

Arauzo-Carod, J.-M., Liviano-Solis, D. and Manjón-Antolín, M. (2010) 'Empirical Studies in Industrial Location: An Assessment of Their Methods and Results', *Journal of Regional Science*, 50(3), pp. 685–711. doi: 10.1111/j.1467-9787.2009.00625.x.

Aschauer, D. A. (1989) 'Is public expenditure productive?', *Journal of Monetary Economics*. North-Holland, 23(2), pp. 177–200. doi: 10.1016/0304-3932(89)90047-0.

Asian Development Bank *et al.* (2018) *The WEB of Transport Corridors in South Asia*. The World Bank. doi: 10.1596/978-1-4648-1215-6.

Asturias, J., García-santana, M. and Ramos, R. (2018) *Competition and the welfare gains from transportation infrastructure: Evidence from the Golden Quadrilateral of India*. 1816.

Aterido, R. and Hallward-Driemeier, M. (2010) 'The Impact of the Investment Climate on Employment Growth Does Sub-Saharan Africa Mirror Other Low-Income Regions?', *The World Bank Policy Research Working Paper*, pp. 1–42. Available at: http://documents.worldbank.org/curated/en/965531468192859171/pdf/WPS5218.pdf.

Bastos, F. and Nasir, J. (2004) 'Productivity and the Investment Climate : What Matters Most ?', *World Bank Policy Research Working Paper*, pp. 1–30. doi: 10.1596/1813-9450-3335.

Baum-Snow, N. *et al.* (2017) 'Roads, Railroads, and Decentralization of Chinese Cities', *The Review of Economics and Statistics*, 99(3), pp. 435–448. doi: 10.1162/REST_a_00660.

Bbaale, E. (2018) 'Infrastructure quality and firm productivity in Africa', *World Journal of Entrepreneurship, Management and Sustainable Development*, 14(4), pp. 367–384. doi: 10.1108/WJEMSD-11-2017-

0091.
Bensch, G. *et al.* (2017) *The Status of Energy Access in Three Regions of Tanzania: Baseline report for an urban grid upgrading*. Essen, Germany. doi: 10.1075/eurosla.10.04reg.
Bhat, V. N. (2015) 'Water and Its Effect on Business Productivity: A Cross-Country Analysis', *Water Resources Management*, 29(11), pp. 4007–4020. doi: 10.1007/s11269-015-1042-7.
Bom, P. R. D. and Ligthart, J. E. (2014) 'What have we learned from three decades of research on the productivity of public capital?', *Journal of Economic Surveys*. John Wiley & Sons, Ltd (10.1111), 28(5), pp. 889–916. doi: 10.1111/joes.12037.
Calderón, C., Moral-Benito, E. and Servén, L. (2014) 'Is infrastructure capital productive? A dynamic heterogeneous approach', *Journal of Applied Econometrics*. John Wiley & Sons, Ltd, 30(2), pp. 177–198. doi: 10.1002/jae.2373.
Calderón, C. and Servén, L. (2014) *Infrastructure, Growth, and Inequality: An Overview*, *Policy Research Working Paper, World Bank Group*. doi: 10.1596/1813-9450-7034.
Carlsson, F., Demeke, E. and Martinsson, P. (2018) *Cost of Power Outages for Manufacturing Firms in Ethiopia : A Stated Preference Study*. 731.
Chandra, A. and Thompson, E. (2000) 'Does public infrastructure affect economic activity?: Evidence from the rural interstate highway system', *Regional Science and Urban Economics*, 30(4), pp. 457–490. doi: https://doi.org/10.1016/S0166-0462(00)00040-5.
Cole, M. A. *et al.* (2018) 'Power outages and firm performance in Sub-Saharan Africa', *Journal of Development Economics*, 134, pp. 150–159. doi: https://doi.org/10.1016/j.jdeveco.2018.05.003.
Czernich, N. *et al.* (2012) 'Broadband Infrastructure and Economic Growth*', *The Economic Journal*, 121(552), pp. 505–532. doi: 10.1111/j.1468-0297.2011.02420.x.
Damania, R. *et al.* (2017) *Uncharted Waters: The New Economics of Water Scarcity and Variability*. Washington DC. doi: 10.1596/978-1-4648-1179-1.
Datta, S. (2012) 'The impact of improved highways on Indian firms', *Journal of Development Economics*, 99(1), pp. 46–57. doi: 10.1016/j.jdeveco.2011.08.005.
Debaere, P. (2014) 'The Global Economics of Water: Is Water a Source of Comparative Advantage?', *American Economic Journal: Applied Economics*, 6(2), pp. 32–48. doi: 10.1257/app.6.2.32.
Dethier, J.-J., Hirn, M. and Straub, S. (2011) 'Explaining enterprise performance in developing countries with business climate survey data', *The World Bank Research Observer*, 26(2), pp. 258–309.
Diboma, B. S. and Tamo Tatietse, T. (2013) 'Power interruption costs to industries in Cameroon', *Energy Policy*, 62, pp. 582–592. doi: https://doi.org/10.1016/j.enpol.2013.07.014.
Dinkelman, T. (2011) 'The Effects of Rural Electrification on Employment: New Evidence from South Africa', *American Economic Review*, 101(7), pp. 3078–3108. doi: 10.1257/aer.101.7.3078.
Donaldson, D. (2018) 'Railroads of the Raj: Estimating the Impact of Transportation Infrastructure', *American Economic Review*, 108(4–5), pp. 899–934. doi: 10.1257/aer.20101199.
Duranton, G. and Turner, M. A. (2012) 'Urban growth and transportation', *Review of Economic Studies*, 79(4), pp. 1407–1440. doi: 10.1093/restud/rds010.
EBRD (2018) *Business Environment and Enterprise Performance Survey (BEEPS)*.
Escribano, A., Guasch, J. L. and Pena, J. (2010) 'Assessing the Impact of Infrastructure Quality on Firm Productivity in Africa : Cross-Country Comparisons Based on Investment Climate Surveys from 1999 to 2005', *World Bank Policy Research Working Papers*, 5191.
Faber, B. (2014) 'Trade Integration, Market Size, and Industrialization: Evidence from China's National Trunk Highway System', *The Review of Economic Studies*, 81(3), pp. 1046–1070. doi: 10.1093/restud/rdu010.
Farquharson, D., Jaramillo, P. and Samaras, C. (2018) 'Sustainability implications of electricity outages in sub-Saharan Africa', *Nature Sustainability*, 1(10), pp. 589–597. doi: 10.1038/s41893-018-0151-8.
Fedderke, J. W. and Bogetić, Ž. (2009) 'Infrastructure and Growth in South Africa: Direct and Indirect

Productivity Impacts of 19 Infrastructure Measures', *World Development*. Pergamon, 37(9), pp. 1522–1539. doi: 10.1016/J.WORLDDEV.2009.01.008.

Fisher-Vanden, K., Mansur, E. T. and Wang, Q. (Juliana) (2015) 'Electricity shortages and firm productivity: Evidence from China's industrial firms', *Journal of Development Economics*. North-Holland, 114, pp. 172–188. doi: 10.1016/J.JDEVECO.2015.01.002.

Ghani, E., Goswami, A. G. and Kerr, W. R. (2016) 'Highway to Success: The Impact of the Golden Quadrilateral Project for the Location and Performance of Indian Manufacturing', *The Economic Journal*, 126(591), pp. 317–357. doi: 10.1111/ecoj.12207.

Ghani, E., Kerr, W. R. and O'Connell, S. (2014) 'Spatial Determinants of Entrepreneurship in India', *Regional Studies*. Routledge, 48(6), pp. 1071–1089. doi: 10.1080/00343404.2013.839869.

Ghosh, R. *et al.* (2017) 'Are small firms willing to pay for improved power supply? Evidence from a contingent valuation study in India', *Energy Policy*, 109, pp. 659–665. doi: https://doi.org/10.1016/j.enpol.2017.07.046.

Gibbons, S. *et al.* (2017) *New Road Infrastructure : The Effects on Firms*.

Guasch, J. L. and Kogan, J. (2003) *Just-in-Case Inventories : A Cross-Country Analysis*. 3012.

Gurara, D. and Tessema, D. (2018) 'Losing to Blackouts : Evidence from Firm Level Data', *IMF Working Paper*, 18(159). doi: 10.1177/0022034574053006100l.

Harriet, T., Poku, K. and Emmanuel, A. K. (2013) 'An Assessment of Traffic Congestion and Its Effect on Productivity in Urban Ghana', *International Journal of Business and Social Science*, 4(3).

Iimi, A. (2011) 'Effects of Improving Infrastructure Quality on Business Costs: Evidence from Firm-Level Data in Eastern Europe and Central Asia', *The Developing Economies*, 49(2), pp. 121–147. doi: 10.1111/j.1746-1049.2011.00126.x.

Iimi, A., Humphrey, R. M. and Melibaeva, S. (2015) *Firm Inventory Behavior in East Africa*. The World Bank (Policy Research Working Papers). doi: 10.1596/1813-9450-7280.

Islam, A. (2018) *The Burden of Water Shortages on Informal Firms*. 8457.

Islam, A. and Hyland, M. (2018) *The Drivers and Impacts of Water Infrastructure Reliability A Global Analysis of Manufacturing Firms*. Available at: http://www.worldbank.org/research. (Accessed: 5 February 2019).

Jin, J. and Rafferty, P. (2017) 'Does congestion negatively affect income growth and employment growth? Empirical evidence from US metropolitan regions', *Transport Policy*, 55, pp. 1–8. doi: https://doi.org/10.1016/j.tranpol.2016.12.003.

Kajitani, Y. and Tatano, H. (2014) 'Estimation of Production Capacity Loss Rate after the Great East Japan Earthquake and Tsunami in 2011', *Economic Systems Research*. Routledge, 26(1), pp. 13–38. doi: 10.1080/09535314.2013.872081.

Kassem, D. (2018) 'Does Electrification Cause Industrial Development ? Grid Expansion and Firm Turnover in Indonesia Job Market Paper Click here for recent version', *Job Market Paper*, (August).

Khadaroo, J. and Seetanah, B. (2008) 'The role of transport infrastructure in international tourism development: A gravity model approach', *Tourism Management*. Pergamon, 29(5), pp. 831–840. doi: 10.1016/J.TOURMAN.2007.09.005.

Kim, K. and Cho, Y. (2017) 'Estimation of power outage costs in the industrial sector of South Korea', *Energy Policy*. Elsevier, 101, pp. 236–245. doi: 10.1016/J.ENPOL.2016.11.048.

Kresic, A., Milatovic, J. and Sanfey, P. (2017) *Firm Performance and Obstacles to Doing Business in the Western Balkans: Evidence from the BEEPS*, *European Bank for Reconstruction and Development*. doi: 10.2139/ssrn.3119154.

Li, H. and Li, Z. (2013) 'Road investments and inventory reduction: Firm level evidence from China', *Journal of Urban Economics*, 76, pp. 43–52. doi: https://doi.org/10.1016/j.jue.2013.02.002.

Martincus, C. V., Carballo, J. and Cusolito, A. (2017) 'Roads, exports and employment: Evidence from a developing country', *Journal of Development Economics*, 125, pp. 21–39. doi:

https://doi.org/10.1016/j.jdeveco.2016.10.002.
McCulloch, N. and Zileviciute, D. (2017) *Is Electricity Supply a Binding Constraint to Economic Growth in Developing Countries?* 1.3.
Mensah, J. T. (2016) 'Bring Back our Light: Power Outages and Industrial Performance in Sub-Saharan Africa', in *Agricultural and Applied Economics Association Annual Meeting*.
Mensah, J. T. (2018) *Jobs ! Electricity Shortages and Unemployment in Africa*.
Mitra, A., Sharma, C. and Véganzonès-Varoudakis, M.-A. (2016) 'Infrastructure, information & communication technology and firms' productive performance of the Indian manufacturing', *Journal of Policy Modeling*, 38(2), pp. 353–371. doi: https://doi.org/10.1016/j.jpolmod.2016.02.013.
Oseni, M. O. and Pollitt, M. G. (2015) 'A firm-level analysis of outage loss differentials and self-generation: Evidence from African business enterprises', *Energy Economics*, 52, pp. 277–286. doi: https://doi.org/10.1016/j.eneco.2015.11.008.
Paunov, C. and Rollo, V. (2015) 'Overcoming Obstacles: The Internet's Contribution to Firm Development', *The World Bank Economic Review*, 29, pp. S192–S204. doi: 10.1093/wber/lhv010.
Paunov, C. and Rollo, V. (2016) 'Has the Internet Fostered Inclusive Innovation in the Developing World?', *World Development*, 78, pp. 587–609. doi: https://doi.org/10.1016/j.worlddev.2015.10.029.
Poczter, S. (2017) 'You Can't Count on Me: The Impact of Electricity Unreliability on Productivity', *Agricultural and Resource Economics Review*. Cambridge University Press, 46(3), pp. 579–602. doi: 10.1017/age.2016.38.
Polák, P. (2017) 'The productivity paradox: A meta-analysis', *Information Economics and Policy*, 38, pp. 38–54. doi: https://doi.org/10.1016/j.infoecopol.2016.11.003.
Porter, M. E. (1990) 'The Competitive Advantage of Nations', *Harvard Business Review*, (March-April).
Ramachandran, V., Shah, M. K. and Moss, T. (2018) *How Do African Firms Respond to Unreliable Power? Exploring Firm Heterogeneity Using K-Means Clustering*. 493. London. Available at: https://www.cgdev.org/publication/how-do-african-firms-respond-unreliable-power-exploring-firm-heterogeneity-using-k-means.
Rentschler, J. and Kornejew, M. (2017) 'Energy price variation and competitiveness: Firm level evidence from Indonesia', *Energy Economics*, 67, pp. 242–254. doi: https://doi.org/10.1016/j.eneco.2017.08.015.
Rothenberg, A. D. (2011) *Transport Infrastructure and Firm Location Choice in Equilibirum: Evidence from Indonesia's Highways*.
Rud, J. P. (2012) 'Electricity provision and industrial development: Evidence from India', *Journal of Development Economics*. North-Holland, 97(2), pp. 352–367. doi: 10.1016/J.JDEVECO.2011.06.010.
Ryan, N. (2017) *The Competitive Effects of Transmission Infrastructure in the Indian Electricity Market*. doi: 10.3386/w23106.
Shirley, C. and Winston, C. (2004) 'Firm inventory behavior and the returns from highway infrastructure investments', *Journal of Urban Economics*, 55(2), pp. 398–415. doi: https://doi.org/10.1016/j.jue.2003.11.001.
Siddiqui, R. *et al.* (2008) 'The Cost of Unserved Energy: Evidence from Selected Industrial Cities of Pakistan', *The Pakistan Development Review*. Pakistan Institute of Development Economics, Islamabad, 47(3), pp. 227–246. Available at: http://www.jstor.org/stable/23234709.
Steinbuks, J. and Foster, V. (2010) 'When do firms generate? Evidence on in-house electricity supply in Africa', *Energy Economics*, 32(3), pp. 505–514. doi: https://doi.org/10.1016/j.eneco.2009.10.012.
Straub, S. and Terada-Hagiwara, A. (2010) 'Infrastructure and Growth in Developing Asia', *ADB Economics Working Paper Series*. Manila, 231.
Sweet, M. (2011) 'Does Traffic Congestion Slow the Economy?', *Journal of Planning Literature*. SAGE Publications Inc, 26(4), pp. 391–404. doi: 10.1177/0885412211409754.
Sweet, M. (2013) 'Traffic Congestion's Economic Impacts: Evidence from US Metropolitan Regions', *Urban*

Studies. SAGE Publications Ltd, 51(10), pp. 2088–2110. doi: 10.1177/0042098013505883.
Tanner, T. *et al.* (2015) *The Triple Dividend of resilience - Realising development goals through the multiple benefits of disaster risk management.* London & Washington, DC.
United Nations Environment Programme (no date) 'Water In the Transition to a Green Economy: A UNEP Brief'.
United Nations World Water Assessment Programme (2016) *The United Nations World Water Development Report 2016: Water and Jobs*. Paris: UNESCO. doi: ISBN 978-92-3-100146-8.
Wan, G. and Zhang, Y. (2018) 'The direct and indirect effects of infrastructure on firm productivity: Evidence from Chinese manufacturing', *China Economic Review*, 49, pp. 143–153. doi: https://doi.org/10.1016/j.chieco.2017.04.010.
WEF (2018) *The Global Competitiveness Report 2017-2018*. Cologny: World Economic Forum.
Weisbrod, G., Vary, D. and Treyz, G. (2003) *Measuring Economic Costs of Urban Traffic Congestion to Business*, *Transportation Research Record*. doi: 10.3141/1839-10.
Wijayatunga, P. D. C. and Jayalath, M. S. (2008) 'Economic impact of electricity supply interruptions on the industrial sector of Bangladesh', *Energy for Sustainable Development*, 12(3), pp. 5–12. doi: https://doi.org/10.1016/S0973-0826(08)60433-0.
World Bank (2013) *Cairo Traffic Congestion Study: Final Report*. Washington DC.
World Bank (2018a) *Doing Business 2018 - Reforming to Create Jobs*. Washington DC: The World Bank.
World Bank (2018b) *Enterprise Surveys*.
World Bank (2018c) 'National Accounts Data'. Available at: https://data.worldbank.org/indicator/ny.gdp.mktp.cd?end=2014&start=2013.
World Bank (2019) 'Electricity Uptake for Economic Transformation in Sub-Saharan Africa'.
Zhang, F. (2019) *In the dark: How Much Do Power Sector Distortions Cost South Asia?* Washington, DC. doi: doi:10.1596/978-1-4648-1154-8.

6. Annex

a. Impact of the current level of power supply quality on firm productivity

Country	Type of firms	Power supply quality variable	Method	Effect of low electricity supply quality on firms	Source
Ghana	Small and medium-sized manufacturing firms	Number of days with power outage	Regression	Major power outages in Ghana between 2012 and 2015 decreased firms' average monthly productivity by 10 percent	(Abeberese, Ackah and Asuming, 2017)
Ethiopia	Manufacturing firms	Are power disruptions major obstacle to firm (binary)	Quantile regressions	Power disruptions result in total factor productivity losses of about 4–9 percent on average	(Gurara and Tessema, 2018)
India	Manufacturing firms	Percent of electricity demand in state/year that is unmet	IV regression, simulations	Electricity deficits decrease total factor productivity losses by 1.5-2.2 percent on average (2.6 for firms w/o generator)	(Allcott, Collard-Wexler and O'Connell, 2016)

b. Impact of the current level of power supply quality on firm revenue, output, or costs

Country	Type of firms	Power supply quality variable	Method	Effect of low electricity supply quality on firms	Source
26 transition economies in Eastern Europe and Central Asia	Business Environment and Enterprise Performance Survey	Frequency and duration of electricity outages	Estimation of firms' cost function	The removal of all existing electricity outages would enable cost reductions of 1.3-1.4% by firms	(Iimi, 2011)
Albania, Bosnia and Herzegovina, Macedonia, Kosovo, Montenegro and Serbia	Business Environment and Enterprise Performance Survey	Percent of annual revenue lost due to power outages	Descriptive statistics from firm survey	On average, firms lose 5.8 percent of their annual sales due to electricity issues (Kosovo 11.3%, FYR Macedonia 7.5%, Albania 7.7%, Montenegro 2.7%, Serbia 4.0, Bosnia & Herz. 3.7%)	(Kresic, Milatovic and Sanfey, 2017)
Hungary, Poland, Bulgaria, Romania, Czech Republic, Slovak Republic, Croatia, Lithuania, Slovenia, Latvia, Estonia	Business Environment and Enterprise Performance Survey	Percent of annual revenue lost due to power outages	Descriptive statistics from firm survey	On average, firms lose 2.4 percent of their annual sales due to electricity issues (Hungary 5.2%, Poland 5.1%, Bulgaria 2.8%, Romania 2.8%, Czech Republic 2.1%, Slovak Republic 1.1%, Croatia 1.6%, Lithuania 0.9%, Slovenia 2.1%, Latvia 1.3%, Estonia 1.1%	(Kresic, Milatovic and Sanfey, 2017)
India	Manufacturing firms	Percent of electricity demand in state/year that is unmet	IV regression, simulations	Electricity deficits decrease Indian manufacturing firms' revenues by 5.6-7.7 percent on average (10 for firms w/o generator)	(Allcott, Collard-Wexler and O'Connell, 2016)
Bangladesh	Industrial firms	All power outages	Descriptive statistics from firm survey	Planned and unplanned outages translate into unmet industrial demand amounting to 11.54% of the industrial sector GDP or 1.72 % of Bangladesh's GDP in 2000-01	(Wijayatunga and Jayalath, 2008)
Pakistan	Industrial firms	Unserved energy demand	Calculations based on firm survey	Firms suffer losses of 23% of value added as a consequence of unserved electricity	(Siddiqui *et al.*, 2008)
Ethiopia	Small and medium-sized manufacturing firms	Power outages	Descriptive statistics from firm survey	Firms lose 14 percent of their monthly sales due to outages	(Carlsson, Demeke and Martinsson, 2018)
Bangladesh	Manufacturing firms; World Bank Enterprise Survey	Power outages and load shedding	Calculations based on firm survey	Firms experience annual output losses of US$ 1.1 billion or 0.5 percent of GDP due to power outages and load shedding	(Zhang, 2019)
India	Micro, Small, and Medium Enterprises	Power outages and load shedding	Calculations based on firm survey	Firms experience annual output losses of 1.09 percent of GDP due to power outages and load shedding	(Zhang, 2019)

Pakistan	Manufacturing firms	Power outages and load shedding	Calculations based on firm survey	Firms experience annual output losses of US$ 8.4 billion or 3.1 percent of GDP due to power outages and load shedding	(Zhang, 2019)
Cameroon	Industrial firms	Power outages	Descriptive statistics from firm survey	Firms on average experience total output losses of at least about 31 percent due to power outages	(Diboma and Tamo Tatietse, 2013), own calculation of average

c. Elasticity of firm productivity with respect to power supply quality

Country	Type of firms	Power supply quality variable	Method	Effect of low electricity supply quality on firms	Source
26 African countries	World Bank Enterprise survey	Number of power outages in a typical month	Regression	An increase in the number of power outages in a typical month by one reduces productivity by 0.1–0.2 percentage points	(Bbaale, 2018)
15 Sub-Saharan African countries	World Bank Enterprise survey	Outage frequency	IV regression	A one percentage increase in outage frequency is associated with a decline in firms' productivity by between 0.6% and 1.1 percent (Angola 1.85%, Burkina Faso 1,36%, Cameroon 2,52%, DR Congo 2,51%, Ghana 2,22%, Kenya 1,50%, Mali 1,33%, Malawi 2,09%, Nigeria 3,46%, South Africa 1,35%, Rwanda 2,40%, Tanzania 2,01, Uganda 2,38%, Zambia 2,51%	(Mensah, 2016)
23 African countries	World Bank Enterprise survey	Outage frequency per month	IV regression	A one percent increase in outages leads to a 3.5 percent loss in firms' total factor productivity	(Mensah, 2018)

d. Elasticity of firm production with respect to power supply quality

Country	Type of firms	Power supply quality variable	Method	Effect of low electricity supply quality on firms	Source
23 African countries	World Bank Enterprise survey	Outage frequency per month	IV regression	A one percentage point increase in the frequency of power outages decreases firm-level output by 3.3 percent; this increase in outage frequency also results in a 2.7 percent loss in firm revenue	(Mensah, 2018)
India	Micro, Small, and Medium Enterprises	Power outages and load shedding	IV regression	A one percentage point increase in shortages increases production costs of	(Zhang, 2019)

				small firms by 0.29 percent of revenue	
Pakistan	Manufacturing firms	Power outages	Calculations based on firm survey	An increase in average daily power outages by one hour causes a reduction in value added of 1.26 percent	(Zhang, 2019)