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Electricity Reliability and Economic Development in Cities: A Microeconomic Perspective*

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ABSTRACT

In this Energy for Economic Growth ("EEG") state-of-knowledge paper, we review evidence on the causes and consequences of electricity outages, focusing on cities. Studies on the microeconomics of electrification concentrate mainly on the impacts of expanding access to electricity in rural areas. In many cities, the primary issue is the reliability of the electric grid rather than the lack of access to electricity. We discuss supply side, demand side, and political economy factors causing outages, the economic impacts of outages, and how electricity suppliers respond to the prospect of shortages. Finally, we highlight areas that would benefit from further research.

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I. INTRODUCTION

Recent studies on the microeconomics of electrification in developing countries focus primarily on estimating the impacts of providing rural households and communities with access to electricity for the first time.[1] In urban areas, however, many households and firms are already connected to the electric grid. In these settings, the primary issue is the reliability of the grid rather than the lack of access to electricity. Yet few studies analyze the causes and consequences of outages in cities, as well as the ways in which policymakers can address them. In this Energy for Economic Growth ("EEG") state-of-knowledge paper, we review existing empirical evidence on this topic and propose several areas that would benefit from further empirical research.

The remainder of the paper is organized as follows. The next section discusses basic patterns of electricity access and electricity reliability in cities, using existing data sources. The data suggest that reliability remains an issue even in countries that enjoy relatively high rates of access. Moreover, in cities, reliability rates are substantially lower than access rates. Section III presents our conceptual approach to identifying areas for further research. We propose that future work should seek to fill both descriptive gaps in knowledge (e.g., data on the patterns of outages in cities) and causal gaps in knowledge (e.g., analyses on the impacts of interventions to improve reliability).

Section IV summarizes the common supply side, demand side, and political economy factors driving outages in developing countries. Section V reviews the existing literature to describe the potential economic impacts of outages on households and firms, highlighting the outcomes that are particularly relevant in the urban setting. Section VI discusses how energy suppliers respond to outages in the long and short run. In a case study, we then examine historical patterns of load shedding in Dhaka, Bangladesh, which suggest that demand plays a major role in increasing the likelihood of load shedding. For instance, load shedding is more likely on weekdays, in denser areas, and on hotter days.

[1] Studies on the microeconomics of expanding rural access to electricity include Dinkelman (2011), Rud (2012), Lipscomb, Mobarak, and Barham (2013), Grogan and Sadanand (2013), van de Walle et al. (2015), and Chakravorty, Emerick, and Ravago (2016), Burlig and Preonas (2016), and Lee, Miguel, and Wolfram (2016). See Lee, Miguel, and Wolfram (2017), a companion EEG state-of-knowledge paper, for a more detailed discussion on the microeconomic relationship between electricity supply and economic growth.

Finally, Section VII identifies four areas where future research may be particularly valuable. These include: (1) data on the extent to which urban households, firms, and public facilities suffer from unreliable electricity supply; (2) data on the supply side, demand side, and political economy factors causing outages in different settings; (3) estimates of the economic costs of outages; and (4) estimates of the economic impacts of specific policy, technology, and economic interventions that target improvements in electricity reliability in cities.

II. ACCESS TO ELECTRICITY AND ELECTRICITY RELIABILITY

An estimated 1.2 billion people across the world—half of whom are in Sub-Saharan Africa—are currently without access to electricity (IEA 2016). These estimates are often used as motivation for large-scale programs to expand rural electrification and home solar adoption.[2] Less attention is placed on the persistent blackouts that many electricity consumers experience in developing countries. In this section, we use existing data sources to summarize what is known about relative rates of electricity access and reliability in cities across the world.

Reliability is a problem in many countries, including those that enjoy relatively high rates of access. The World Bank Doing Business ("WBDB") project reports System Average Interruption Duration Index ("SAIDI") and System Average Interruption Frequency Index ("SAIFI") estimates for the main city in each country for a large sample of countries.[3] Using these data, Figure 1 compares access rates (at the country-level) to SAIDI and SAIFI rates (at the city-level).[4] In our sample, high-income (i.e., OECD) countries are characterized by high access rates and low SAIDI and SAIFI rates. In contrast, developing countries are characterized by much lower access rates and much higher outage rates. This pattern holds even in countries with high rates of access like Pakistan (represented by Lahore and Karachi in Figure 1). A key takeaway from this comparison is that reliability may remain an issue in many countries, even after the

[2] Examples include the US Agency for International Development (USAID) *Power Africa* initiative and the UK Department for International Development (DFID) *Energy Africa* campaign.
[3] The WBDB measures of SAIDI and SAIFI include all planned interruptions (including load shedding) and all unplanned interruptions that are reported to the utilities. Outages lasting less than five minutes are typically not included.
[4] For national electrification rates, we use 2012 data from the World Bank Databank.

access gap is largely addressed. Yet if electricity is unreliable, the gains from expanding access will be limited.

Reliability may be a relatively more important issue in cities, compared to rural areas, for two reasons. First, population density is much higher in cities. As a result, the marginal cost of connecting a new user is lower; it may be easier to connect to the grid illegally; and there may be more opportunities to share electricity connections with neighbors. This suggests that access rates are probably already much higher in cities compared to rural areas. At the same time, reliability rates may be low in cities due to the issues like overcrowding and electricity theft. Second, urban production tends to be concentrated in manufacturing and services, rather than agriculture, which is the principal activity in rural areas. Since electricity is a critical input in most manufacturing activities, the opportunity costs associated with outages are probably higher in cities.[5]

In Figure 2, we use data from the Afrobarometer survey to compare access and reliability rates in a sample of major cities in Sub-Saharan Africa.[6] For each city, we plot access rates (Panel A), and the proportion of connected households with reliable electricity connections, where a reliable connection is defined as one that works "most of the time" or "all of the time" (Panel B). Reliability rates are substantially lower than access rates, and appear to fall with population size. These patterns suggest that in cities, failures in the provision of electricity mostly take the form of inadequate, intermittent, and unreliable power supply.

Although Figure 2 presents just a simple descriptive pattern based on a small sample, one can imagine a relationship in which urbanization and rapid population growth lead to an unanticipated increase in the demand for electricity, resulting in a less reliable supply of power. This hypothesis, along with many others concerning the linkages between reliability and economic growth, remain largely unexplored. Yet the

[5] Although irrigation requires electricity, its use is uncommon in many developing countries outside of South Asia. In Sub-Saharan Africa, only 4 percent of land is irrigated (Burney, Naylor, and Postel 2013). Small-scale milling is another energy-intensive agricultural activity that is common in many developing countries. In Kenya, however, Lee et al. (2016) note that only 13.3 percent of observed small-scale cornmeal "posho" mills are visibly connected to electricity.

[6] We use Round 6 Afrobarometer data, which were collected in 2015, covering roughly 32,000 households from 21 countries in Sub-Saharan Africa. In order to isolate city-level access and reliability rates, we limit the data to the subset of cities that can be identified by their county or district name. In Kenya, for instance, household surveys corresponding to Nairobi can be identified because Nairobi County is coterminous with the city of Nairobi.

majority of the world's population growth is expected to be concentrated in cities in developing countries (Cohen 2006), and nearly all of the growth in energy demand over the next 25 to 30 years is forecast to come from the developing world (Wolfram, Shelef, and Gertler 2012). The goal of this paper is to propose a research agenda on this increasingly important topic.

III. Conceptual approach

In Figure 3, we present a simple path diagram illustrating our conceptual approach to setting a research agenda. The sequence of boxes in the center of the diagram represents the main pathway from energy to economic growth. Energy is generated, distributed, and consumed by public, industrial, commercial, and residential users before it is finally reflected in measures of economic growth. We are interested in the quality of the electricity supply that is generated and distributed through this main pathway. Surrounding this pathway are examples of various policy, technology, and economic interventions that can potentially improve reliability.

Future research should seek to fill two knowledge gaps. First, focusing on the main pathway, we need descriptive data and evidence on the causes of poor service quality and the impacts of leaving them unaddressed. Second, focusing on the goal of increasing economic development, we need causal evidence on the impacts of specific interventions to improve reliability. In Figure 3, we highlight some of the possible interventions, including supply side investments to expand generation capacity and demand side interventions to encourage the adoption of energy efficient appliances.

IV. Causes of outages

What are the causes of electricity outages and what can be done about them? Outages can be described in a number of ways. They may be planned or unplanned, and may vary in terms of their frequency and duration. Sudden equipment failures, for example, are unplanned and result in continuous blackouts, lasting hours and sometimes days. Load shedding incidents, in contrast, are planned and occur somewhat predictably, with power being available a few hours each day. Planned outages may also differ in terms of whether they are communicated to consumers in advance.

The set of factors causing outages is likely to be the same in cities as in rural areas. Insufficient electricity generation, for instance, is an issue affecting both urban and rural consumers. In comparison, capacity overloads may occur more frequently in cities where there is greater demand. In developing countries, outages are not always caused by shortages in electricity. In some cases, they are caused by poor quality wiring at the point of use. In others, they are caused by maintenance requirements, or because a utility staff member is seeking a bribe.

In this section, we describe common causes of outages, categorizing them into supply side factors, demand side factors, and political economy factors.[7] Although most outages are rooted in a constraint on the supply side, it is useful to classify them in this way because each of the three categories points to a different set of technological, economic, or political solutions that can potentially improve reliability. In the future, research estimating the impacts of these various solutions will be especially valuable.

A. Supply side factors

Supply side factors causing outages include insufficient electricity generation, network fragility, and scheduled maintenance. These issues are related to the basic capacity and quality of the electricity system. Insufficient electricity generation, for instance, is a persistent problem in India, where utilities regularly fail to meet peak demand loads, and investors and state governments have been unsuccessful in meeting their investment targets (Alam 2013; Allcott, Collard-Wexler, and O'Connell 2016). Even if the installed capacity base is sufficiently large, utilization rates may still be low due to poor utility performance, or because the mix of power generation sources is undiversified and there is a shortage in one of the key inputs.[8]

Network fragility can lead to breakdowns along transmission and distribution lines, and in transformers and other equipment. In certain cases, the breakdowns are completely exogenous. Unexpected lightning strikes, for example, have been blamed for

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[7] In this paper, we focus on describing the causes of blackouts and permanent faults, rather than brownouts and voltage fluctuations.

[8] For example, coal shortages impact the supply of electricity in India since a large share of electricity is generated using coal. In Kenya, shortages in river flow similarly impact the supply of hydroelectric power.

over-voltage damage to networks in Sub-Saharan Africa.[9] In other cases, the breakdowns are caused by equipment failures, which are sometimes exogenous. In 2008, a rupture in an underwater cable resulted in a month-long blackout on the island of Zanzibar.[10] Breakdowns can also be endogenous to the performance of local utilities and their commitment to regular maintenance, or to the socio-economic characteristics of the underlying neighborhood. For example, vandalism and theft of grid components, including copper and transformer oil, may occur more frequently in poorer neighborhoods with less security.

Scheduled maintenance is another cause of outages. Maintenance work is required to upgrade power lines and equipment, connect new customers, and relocate network infrastructure. These types of outages are common in rapidly developing countries, and particularly in urban areas where there is a constant stream of construction. In the long run, more maintenance should result in higher service qualities. However, if maintenance more favorably targets certain neighborhoods, there may eventually be inequalities in the quality of power supply.

Outages caused by supply side factors can be solved in various ways. Insufficient generation capacity and network fragility, for example, can be addressed through investments to expand or upgrade the electricity system. The impact of maintenance-related outages can be reduced by notifying consumers about upcoming blackouts, or by improving the maintenance capabilities of the electric utilities.

B. Demand side factors

Outages occur when the peak demand for electricity exceeds the total amount of electricity that the system can supply. This inequality may be the result of transitory factors or longer-term trends. An example of a transitory factor is a surge in demand due to extreme weather. The 2012 India blackouts, for instance, affected hundreds of millions of people and were attributed in part to an extremely hot summer. These types of events

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[9] Anderson and Dalgaard (2013) employ lightning density as an instrument for power outages to study the impacts of blackouts on economic growth in Sub-Saharan Africa.

[10] Burlando (2014) studies the impacts of the 2008 Zanzibar blackout on health and other outcomes.

can present opportunities to measure the economic costs of outages.[11] Identifying solutions to these causes, however, is more challenging. Potential responses include upgrading infrastructure on the supply side, investing in private generators on the demand side, and implementing time-varying electricity pricing to curb excess demand during peak hours.

A longer-term trend that can lead to an imbalance in supply and demand is economic growth accompanied by an unanticipated increase in energy demand. Wolfram, Shelef, and Gertler (2012) point out that demand forecasts in the developing world fail to capture increases along the extensive, pro-poor margin. If infrastructure investments are determined based on understated forecasts, supply will potentially lag demand, leading to a higher incidence of outages. This issue highlights the need for better data, and more specifically, improvements in the way we measure and forecast electricity access and energy consumption.

One reason why demand forecasts may be understated is that in many countries, a significant portion of electricity is consumed through illegal connections. These are often difficult to detect and measure at scale. Electricity theft can lead to more outages by increasing inefficient uses of electricity (Jamil 2013). There are few incentives to conserve power if it can be consumed for free. Anecdotally, theft is most common in the slums and informal settlements surrounding city centers. In these areas, there is often low willingness to pay for improved public services, and general investment inertia due to the lack of property rights and the informal nature of housing, which precludes many structures from urban planning and public upgrading initiatives (see, e.g., Duflo, Galiani, and Mobarak 2012; Marx, Stoker, and Suri 2013). In addition, in these areas, there is a higher chance that attempts to pay for electricity upgrades will be captured by third parties. One way to address illegal connections and improve revenue recovery is to offer users with an illegal connection a formal meter at a heavily subsidized price.[12] Electricity theft, however, is a complex issue, and efforts to upgrade illegal connections in Latin America have at times been met with violent resistance (McRae 2015).

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[11] Fisher-Vanden, Mansur, and Wang (2015), for example, study the impacts of outages on Chinese firms caused in part by demand surges due to unusually hot summers, cold winters, and other extreme weather during the early-2000s.

[12] Examples of such programs include the Global Partnership on Output Based Aid (GPOBA) slum electrification projects in Kenya and India.

When there is excess demand due to transitory shocks or longer-term trends, there is an increased risk of capacity overloads. An overload occurs when users attempt to draw too much electricity from the grid causing components of the distribution network to break down. This issue typically occurs at a local level, such as a secondary distribution transformer, which converts high voltage electricity into low voltage electricity. Capacity overloads can be addressed on the supply side, possibly by upgrading local transformers and other distribution equipment. Alternatively, they can be addressed through demand side interventions to encourage the local adoption energy efficient appliances.[13] Carranza and Meeks (2016), for example, use a field experiment in Kyrgyzstan to show that when compact fluorescent lightbulbs (CFLs) are adopted at a high enough intensity, there can be local aggregate reliability effects in the form of fewer days without electricity due to outages at the transformer level.

C. Political economy factors

Access to electricity is increasingly viewed as a basic right across the developing world and concerns about the affordability and reliability of electricity appear with regular frequency in national newspapers and policy discussions.[14] Like the supply of other necessities such as water and fuel, the supply of electricity is a political issue. As a result, governments play a central role in the electricity sector, either through ownership or regulation of utilities, or through the provision of subsidies. We now discuss how outages can be caused by a number of political economy factors, including subsidies, political priorities and manipulation, and petty corruption.

Electricity subsidies are common in many countries. In a study of 39 countries in Sub-Saharan Africa, Trimble et al. (2016) note that only two countries (the Seychelles and Uganda) have electricity sectors that collect enough cash to cover the capital and operating costs of supplying electricity. Many of the remaining countries rely heavily on government subsidies in order to bridge the funding gap. Electricity subsidies can take many forms. Consumer subsidies, for example, may involve payments from the

[13] See Fowlie and Phadke (2017), a companion EEG state-of-knowledge paper, for a more detailed discussion on energy efficiency in the developing world.

[14] In 2015, the United Nations declared "secure access to affordable, reliable, sustainable and modern energy for all by 2030" as one of seventeen Sustainable Development Goals.

government to the utility as compensation for setting a low tariff, or for providing services to low-income communities that would otherwise remain without power.

Yet these types of subsidies can have the unintended consequence of discouraging investment in infrastructure, trapping consumers into a nonpaying, low-quality equilibrium (McRae 2015). Consumers in informal settlements often suffer from dangerous and highly unreliable electricity connections that allow them to access power for free. At the same time, governments provide utilities with subsidies to encourage them to maintain service to these areas. A trap may occur because subsidies are provided regardless of consumption, which is unobserved; consumers tolerate an unreliable supply of power because it is free; and politicians continue to offer subsidies in order to maintain political support.

The "infrastructure quality and subsidy trap" is one way in which electricity supply varies across different groups of users. Prices can also vary due to cross-subsidization, a system in which one sector faces higher prices to offset the lower prices faced by a different sector. India, for example, has historically cross-subsidized agriculture, providing agricultural consumers with flat or unmetered prices, even when using agricultural pump-sets, which require large amounts of electricity. As a result, Indian utilities have faced both power deficits and financial losses, which has incentivized them to ration power more often to rural areas (Harish, Morgan, and Subrahmanian 2014).

Outages can also be caused by political priorities and manipulation. Political priorities, for instance, determine the extent to which government investments target expanding electricity supply along the extensive margin versus the intensive margin. Extensive margin investments include projects to increase access to electricity, such as grid extensions to remote public facilities and mass connection subsidies for under grid households and firms. Intensive margin investments include new generation facilities and network upgrades. Many factors influence how governments set their relative priorities. Politicians may prioritize increasing access to electricity, even if it results in a less-reliable power supply, because it appeals to a larger number of voters.

Politicians may also manipulate the power supply in order to influence elections. In India, Min and Golden (2014) highlight a series of patterns supporting the hypothesis that incumbent politicians in Uttar Pradesh allow more theft to occur in order to boost their chances of reelection. Baskaran, Min, and Uppal (2015) find similar evidence in India, showing that between 1992 and 2009, there were positive shocks to the electricity supply in constituencies holding unexpected elections, particularly when those elections were tightly contested or the government held just a small majority.

Corruption may also play an important role. In Nigeria, the state utility is known to respond slowly to maintenance problems; demand bribes in exchange for basic services; and shut down the power supply in order to blackmail specific neighborhoods (Olukoju 2004).[15] Both of these issues can be addressed through interventions to improve monitoring and accountability.

The results in Trimble et al. (2016) suggest that improving revenue recovery will be a key priority in the future. This might be done in several ways. Utilities can focus on improving the performance of their individual meter readers, or more closely monitoring their staff to ensure that bribes are not being demanded. Alternatively, utilities can introduce new technologies to encourage bill payments through mobile money systems, or promote prepaid electricity meters. These technologies can reduce the transaction costs associated with paying bills and eliminate the risk of nonpayment by forcing consumers to pay in advance.[16] There may, however, be unexpected tradeoffs. Jack and Smith (2016) study the impact of prepaid meters on electricity consumption in Cape Town, South Africa, and find that while revenue recovery rates improved, consumption declined.

V. IMPACTS OF OUTAGES

In order to identify effective solutions to the various causes of outages described above, we need evidence on the economic costs of outages in different settings. In this

[15] In some countries, corruption can also affect access to electricity. In a field experiment randomizing grid connections in rural Kenya, Lee, Miguel, and Wolfram (2016) note that construction delays were at times caused by expectations that bribes would be paid to utility staff members. Corruption also contributes to electricity theft. Kojima, Bacon, and Trimble (2014) note that large consumers sometimes steal electricity by colluding directly with utility staff.

[16] Smart meters, which allow utilities to monitor consumption at high frequency intervals, may also be helpful in detecting theft and allowing utilities to rapidly respond to any problems.

section, we review the existing literature on the impacts of outages, keeping in mind the firm, household, and public facility outcomes that are relevant to the urban setting.

A. Macroeconomic impacts

There is a large macroeconomic literature exploring the relationship between electricity consumption and economic growth. Econometric identification is often challenging due to the possibility of omitted variables bias and potential reverse causality.[17] Nevertheless, there is consensus that energy consumption is highly linked to economic growth. Fried and Lagakos (2016), for example, develop a structural model suggesting that investments in energy systems in Sub-Saharan Africa have been responsible for one third of total economic growth since 2000. In India, Hulten, Bennathan, and Srinivasan (2006) attribute large gains in manufacturing productivity between 1972 and 1992 to investments in roads and electricity infrastructure.

Reliability is also believed to play an important role in economic growth, although there is much less evidence in this area. Anderson and Dalgaard (2013), for instance, use lightning density as an instrument for electricity shortages in Sub-Saharan Africa and find that, between 1995 and 1997, a one percent increase in outages reduced long run GDP per capita by 2.86 percent.[18]

B. Household impacts

When individuals face economic shocks, including changes in the price and availability of electricity, they adjust their behavior to minimize the negative impacts. The impacts of outages will largely depend on the types of coping mechanisms that are adopted by different users. During blackouts, users may turn on their back-up generators or delay all electricity-intensive activities until power returns.

For households, the reliability of the grid may influence decisions to invest in complementary electrical appliances. This could have important effects on the benefits of rural electrification. Dinkelman (2011) finds that household electrification results in a

[17] Studies on the causal effect of electricity consumption on economic growth have found contradictory results, depending on the datasets, methodologies, and time periods examined (Khanna and Rao 2009).
[18] See Stern (2017), a companion EEG state-of-knowledge paper, for a more detailed discussion on the macroeconomic relationship between electricity supply and economic growth.

large gain in female employment, supporting the hypothesis that household electrification operates as a labor saving technology shock to home production, allowing women to allocate more time towards market work. These gains, however, may not materialize if households choose not to invest in labor saving appliances because the reliability of the grid is so poor.

Outages can also result in differential gender effects due to intra-household bargaining. In settings where women have less control over household spending decisions, they may be less likely to turn on back-up generators during blackouts despite spending most of their time on household work. In this case, the negative productivity impacts may be higher for women.

There is currently very little evidence on the impacts of outages on individual and household outcomes, and more research is needed in this area. In India, Chakravorty, Pelli, and Marchand (2014) find that the impacts of household electrification on non-agricultural income are much higher for households with more reliable connections. Productivity is a major outcome, but there are other outcomes of interest as well, such as health and education. Burlando (2014), for instance, estimates that the 2008 blackout in Zanzibar resulted not only in substantial income losses to households using electricity for productive purposes, but also in a higher number of children born nine months after the blackout, and lower birth weights amongst children exposed in utero to the blackout.

C. Firm impacts

For firms, electricity outages impact the cost of production. Much of the existing literature focuses on the impacts of outages on firm productivity. Firms respond to outages in several ways. First, they may invest in back-up generators as a substitute for grid electricity. This explains why privately owned generators account for six percent of total installed generation capacity in Sub-Saharan Africa (Steinbuks and Foster 2010). However, back-up generators are more costly to use. In Nigeria, the average cost of back-up electricity is three times the cost of publicly supplied electricity (Adenikinju 2003). For this reason, investing in generators results in “second-best” capital investments and input choices that are less productive than what would be used if grid electricity were more reliable (Reinikka and Svensson 2002). Second, firms may outsource their electricity-intensive activities, substituting electricity inputs with other types of intermediate inputs. Fisher-Vanden, Mansur, and Wang (2015) study the impacts of shortages on Chinese firms and find evidence that firms re-optimize inputs and shift from "making" to "buying" intermediate inputs to production. Third, firms may adjust their production technologies and schedules, for example, by switching to more electricity-efficient technologies during blackouts. Alam (2013) examines the impacts of outages on Indian steel and rice mills, and points out that since rice mills have the option of switching to more electricity-efficient technologies, they are less impacted by them. Impacts therefore vary substantially across industries.

In the short run, there is evidence that the negative impacts of outages are somewhat reduced by the coping mechanisms adopted by firms. Allcott, Collard-Wexler, and O'Connell (2016), for example, study how electricity shortages affect manufacturing firms in India. They conclude that when firms are equipped with generators, shortages act like a time-varying input tax, increasing the cost of electricity. When firms are not equipped with generators, the primary productivity loss is the waste of non-flexible inputs. However, since most inputs can be stored, average productivity losses are limited.

In the long run, the impacts may be more significant. Industries in which firms are more sensitive to shortages may develop at slower rates, particularly if it is necessary to incur the cost of a back-up generator in order to be competitive. In countries with frequent shortages, sectors that are relatively electricity-intensive are characterized by a smaller number of small firms (Alby, Dethier, and Straub 2012; Allcott, Collard-Wexler, and O'Connell 2016). This is consistent with the idea that outages act as a significant barrier to entry. Poor reliability can therefore affect the long run structure of the economy by causing firms to enter and exit industries at different rates.

D. Impacts on urban outcomes

There is almost no evidence on the impacts of outages on urban outcomes, such as rural-urban migration patterns, agglomeration effects, safety, transportation, and pollution. Reliability may affect urban outcomes in several ways. For example, a more reliable grid can enhance the benefits of agglomeration. Local businesses and households become more productive, which in turn encourages the in-migration of firms and workers, labor specialization, and knowledge spillovers. Reliable street lighting makes neighborhoods much safer, and there are less frequent interruptions to key urban services, like hospitals and water.

In contrast, a more reliable grid can result in congestion due to higher levels of in-migration. This can lead to the overcrowding of complementary infrastructure, such as roads and sanitation, and additional pollution. Dinkelman and Schulhofer-Wohl (2015) show that a place-based program such as rural electrification can induce a migration response that results in the overcrowding of inelastically supplied local public goods. Increased in-migration can also lead to lower reliability levels, particularly if the number of illegal connections also rises.

There are other reasons why reliability may be important in the urban context. In order to sustain economic growth, cities must be able to attract and retain the most productive workers. One way to do this is to provide a variety of critical urban services, such as water and sanitation, transportation, and public safety, all of which require a reliable supply of electricity.

VI. Energy supplier responses

In this section, we describe some of the ways in which governments and utilities, which we refer to collectively as the "energy supplier," respond when faced with the prospect of electricity shortages.

A. Potential responses

The energy supplier can choose to implement both long run and short run actions. In the long run, the energy supplier can invest in expanding generation capacity, improving the quality of the transmission and distribution network, and implementing institutional reforms. In the latter case, vertically integrated public monopolies may be broken up in order to encourage competition through deconsolidation and deregulation.[19]

[19] Since the 1990s, a large proportion of developing countries have reformed their power markets in order to improve the performance of their electricity sectors. The results, in terms of increasing service quality for consumers and widening access to electricity, have been mixed (Besant-Jones 2006). See Eberhard (2017), a companion EEG state-of-knowledge paper, for a more detailed discussion on the political economy of power sector reforms in the developing world.

In the short run, there are a number of options. For example, the energy supplier can turn its focus away from the grid and facilitate access to self-generation through subsidies, particularly for large firms that might be able to resell electricity to smaller firms in surrounding areas (Alby, Dethier, and Straub 2013).

Alternatively, the energy supplier can manage supply and demand by influencing the price of electricity and the quantity of electricity supplied. During periods of peak demand, the energy supplier can increase the price of electricity to shift consumption towards users with the highest marginal benefits, essentially pricing out users with the lowest marginal benefits. Similarly, the energy supplier can offer interruptible electricity contracts, providing rebates to users that choose to accept outages during periods of peak demand. Allcott, Collard-Wexler, and O'Connell (2016) argue that if firms were given the choice between uninterruptible and interruptible contracts, they would be able to sort into their preferred contract, effectively allocating outages towards the firms that are least affected by them.

Instead of altering prices, the energy supplier can ration quantities through load shedding, a system in which power supply is interrupted to different areas for non-overlapping periods of time. In a standard load shedding incident, power is cut off to an entire 11kVA feeder line, potentially impacting thousands of electricity consumers. In the Section VI.B, we analyze patterns of load shedding in Dhaka, Bangladesh.

There are many other ways in which the energy supplier can address the causes of outages summarized in Section IV. Some of the political economy factors, for example, can be addressed with better monitoring and governance. All of the potential energy supplier responses would benefit from higher quality data and improved methods of forecasting long run demand and peak loads.

B. Load shedding in Dhaka, Bangladesh

Although load shedding (i.e., rolling blackouts) is common in many countries, there is limited data on the basic correlates of load shedding in cities. There is some evidence that load shedding is unevenly allocated across regions. Harish and Tongia (2014), for instance, find that in Karnataka, India, rural and non-urban feeders experience more load shedding than urban feeders serving cities like Bangalore, the state capital.

Even within the same city, different groups of users may be rationed different amounts of power. Utilities may provide higher service levels to feeders serving embassies, hospitals, and districts with a high number of commercial and industrial establishments. There may be political, ethical, or commercial reasons for distributing blackouts in this way. There may also be areas that receive better service due to political connections and bribes.

Many of these questions remain unanswered, due to a lack of data. In this section, we examine data from Dhaka, Bangladesh to explore basic patterns of load shedding in a major urban center. In Bangladesh, per capita electricity consumption is among the lowest in the world and the electricity sector has historically struggled with poor management and high system losses. There are two major utilities in Dhaka: Dhaka Power Distribution Company (DPDC) and Dhaka Electric Supply Company (DESCO). Most of the country's electricity is generated using natural gas, diesel, and coal. Electricity is heavily subsidized, and this is one reason why DPDC and DESCO need to ration power.[20]

The dataset, which is obtained from DPDC and DESCO, includes administrative records of each load shedding incident between September 2012 and September 2014.[21] Each incident, which is recorded at the feeder level, involves a power cut that affected all of the users connected to a specific 11kVA feeder line.[22] The data covers the urban electricity network in Dhaka, consisting of 52 substations and 648 feeder lines. The number of feeders connected to each substation ranges from 4 to 35, with a median of 13. Over the course of the 25 months covered in our data, there were nearly 180,000 load shedding incidents in total, or 7,157 outages per month on average. The median duration of each outage was 60 minutes.

In the remainder of this section, we describe three basic patterns in the data. First, load shedding appears to follow a predictable pattern each week. In Figure 4A, we plot the share of load shedding incidents at the substation level by the day of week (Panel A)

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[20] In 2010, for example, the government subsidized the average unit of electricity consumption by 25 percent (Ahmed, Trimble, and Yoshida 2013).

[21] The dataset covers all load shedding incidents at 33 DPDC substations and 19 DESCO substations.

[22] We do not know the cause of each outage or whether each incident occurred at the reported time and lasted the reported duration. We only know that each load shedding incident was recorded in the administrative records.

and month (Panel B). There is a large drop in load shedding on Fridays and Saturdays, which constitute the weekend in Bangladesh. This is most likely due to reduced demand.

Second, load shedding is more common along feeders that serve a larger number of households and businesses, raising the possibility that reliability may vary in some kind of predictable way across space. In Figure 4B, each point represents one of the 648 feeders in our sample. For each feeder, we plot the fraction of all outages against the number of connected households (Panel A) and businesses (Panel B). One explanation for this finding is that high levels of residential and commercial demand cause higher incidents of load shedding. Another possibility is that load shedding is directed more frequently towards poorer neighborhoods, many of which have large numbers of households and small commercial establishments.

Third, load shedding is more common at higher local temperatures. In Figure 4C, there is a positive (and nonlinear) relationship between the average number of hourly load shedding incidents and temperature at the substation level. This relationship holds even after controlling for substation, day of week, month of year, and year fixed effects. This is perhaps due to increased energy demand at higher temperatures, as more people turn on their fans and air conditioners, a relationship that is documented in Davis and Gertler (2015). Equipment failures may also be more common at higher temperatures.

We do not have data on the full set of supply side, demand side, and political economy factors that cause load shedding to be necessary in Dhaka. The patterns above suggest that demand shocks play an important role. What is unknown is how the same shocks would impact urban electricity systems of lesser or greater qualities. There is also a certain degree of predictability in load shedding. Blackouts are more likely on certain days of the week and on extremely hot days, for example. What is unknown is the extent to which consumers adapt to these patterns, perhaps by rescheduling energy-intensive activities to weekends or renting back-up generators during the hottest months of the year. The relationship between temperature and load shedding suggests that in the future, temperature can be used to predict peak demand loads, a potential improvement over current forecasting methods.

VII. Future research

The relationship between electricity reliability and economic growth is poorly understood. In our conceptual approach, we use a path diagram to emphasize that we need more research in two areas. First, we need more descriptive data and evidence because we currently know very little about the causes and consequences of outages in the developing world. Second, we need causal evidence on the impacts of specific technologies, policies, and other types of interventions on electricity reliability and economic growth, in order to identify the most effective solutions.

Although randomized evaluations are often ideal, the effects of outages can also be identified using non-experimental methods. For example, the relationship between temperature and load shedding documented in Section VI.B is suggestive of a first-stage in an instrumental variables research design, where one can study the effect of outages on certain outcome variables using temperature as an instrument (although the outcome would need to be selected with caution).[23]

In the remainder of this section, we outline four areas where additional empirical work will be valuable. For each area, we list examples of questions that researchers may wish to address in future work.

1. To what extent do households, firms, and public facilities suffer from unreliable electricity supply in cities in developing countries?
   a. How do cities compare in terms of the frequency and duration of outages?
   b. Within cities, how do outages vary across space (i.e., neighborhoods and districts), across different groups of users (i.e., poor versus wealthy), and across time?
   c. Within cities, how do outages vary at the feeder, transformer, and sub-transformer levels?
   d. What can we learn from comparisons of different data sources, including self-reported surveys, administrative records, and measurements taken by sensors?

[23] This is because many economic outcomes may be influenced by temperature through channels other than electricity outages.

    e. How can new data sources be used to forecast future electricity demand, peak loads, and outages?

2. What are the supply side, demand side, and political economy causes of outages?
    a. How do the causes of outages vary across cities and in different settings?
    b. What market and governance solutions can be used to address the various causes of outages?
    c. What are the socio-economic correlates of the various causes of outages?

3. What are the economic impacts of outages?
    a. How do households, firms, and public facilities adapt to outages?
    b. What are the impacts of outages on households, firms, and public facilities?
    c. What are the impacts of outages on specifically urban outcomes, including migration, agglomeration, safety, transportation, and pollution?
    d. How do outages interact with other complementary factors, such as water and sanitation and transportation, to drive economic growth in cities?
    e. What is the impact of outages on long run industry structure?

4. How should energy suppliers respond to outages?
    a. How have major cities in newly industrialized countries historically addressed constraints to electricity supply, including poor reliability?
    b. What mix of technological and economic solutions have been utilized and to what extent are these solutions relevant today?
    c. What are the impacts of specific policy, technology, and economic interventions on reliability and economic growth in cities?

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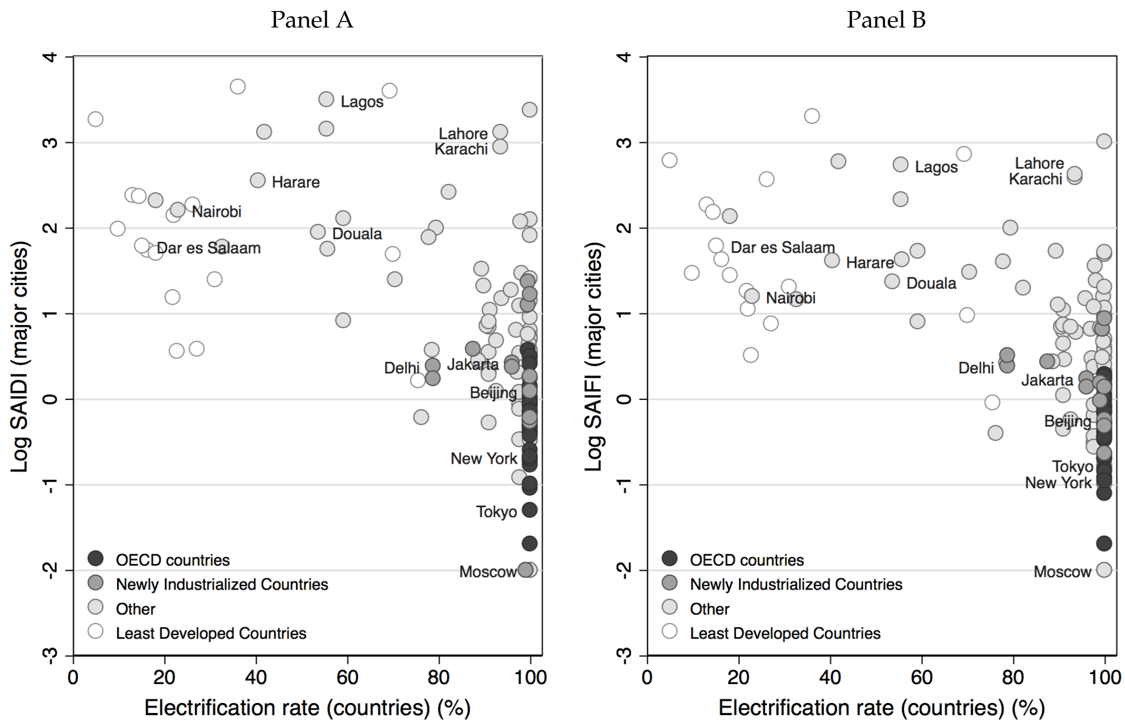
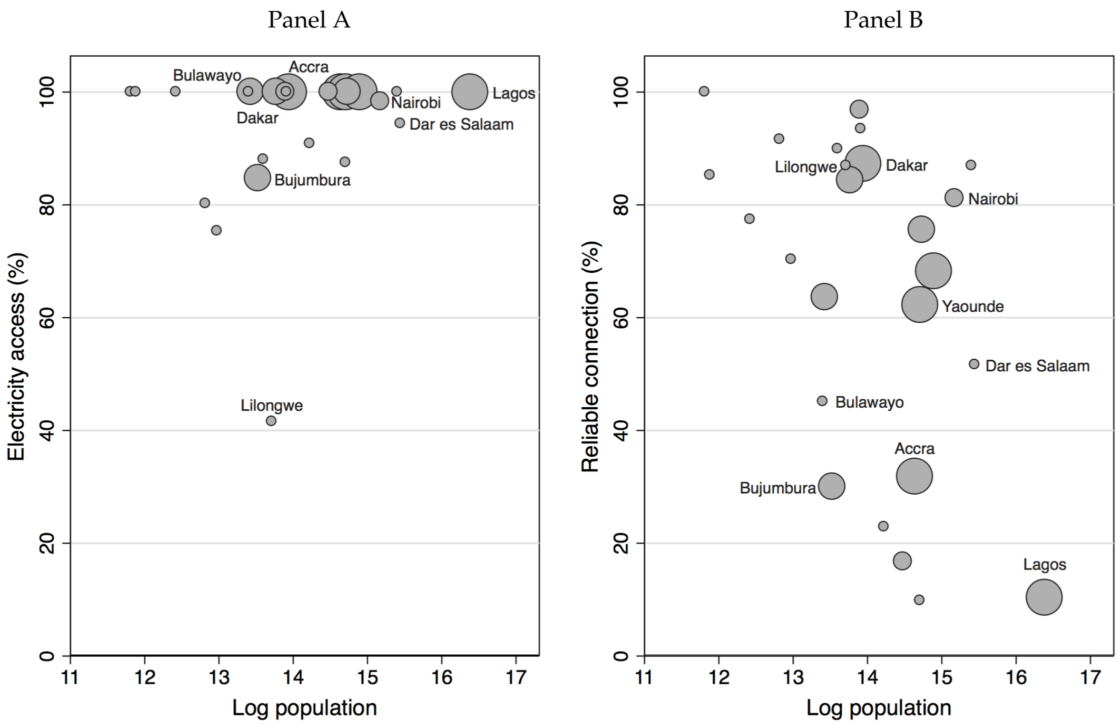
Figure 1—Comparisons of access to electricity (country-level) and electricity reliability (city-level)



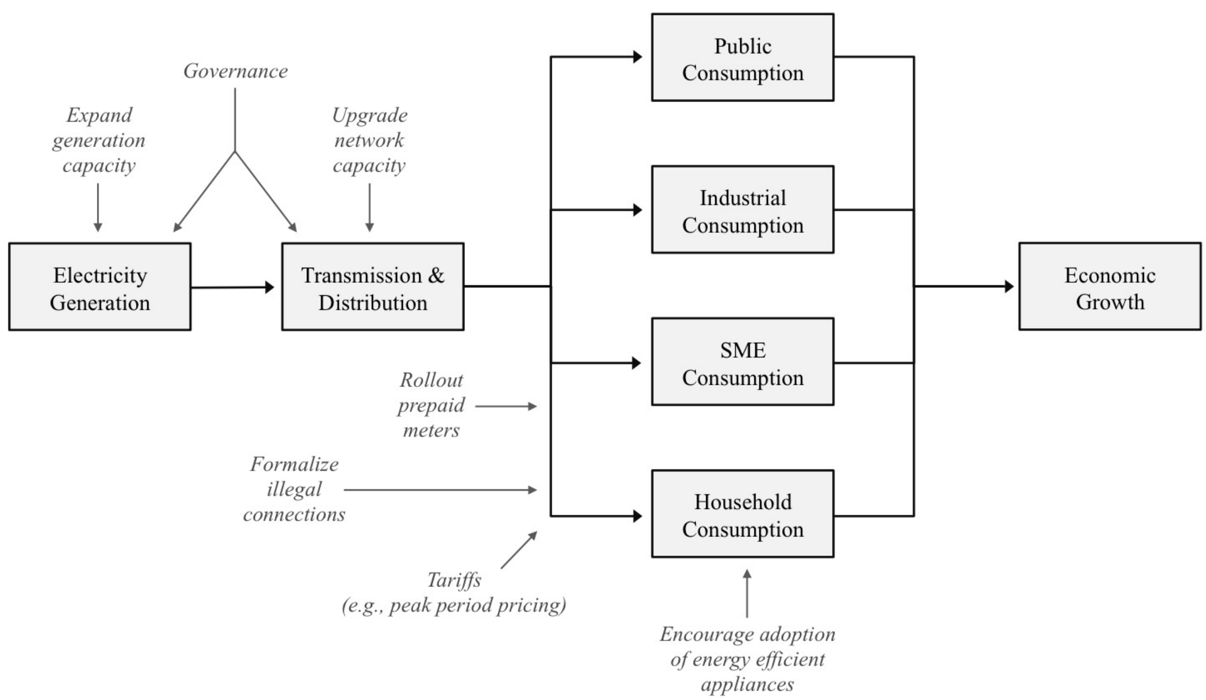
Notes: Data on the System Average Interruption Duration Index ("SAIDI") and System Average Interruption Frequency Index ("SAIFI") for the major city (or cities) in each country for a large sample of countries are obtained from the 2016 World Bank Doing Business ("WBDB") project. Data on national electrification rates are obtained from the World Bank Databank. The total sample includes 150 major cities (from 140 countries) for which data on access and reliability are both available.

Figure 2—Access to electricity and electricity reliability in major cities in Sub-Saharan Africa



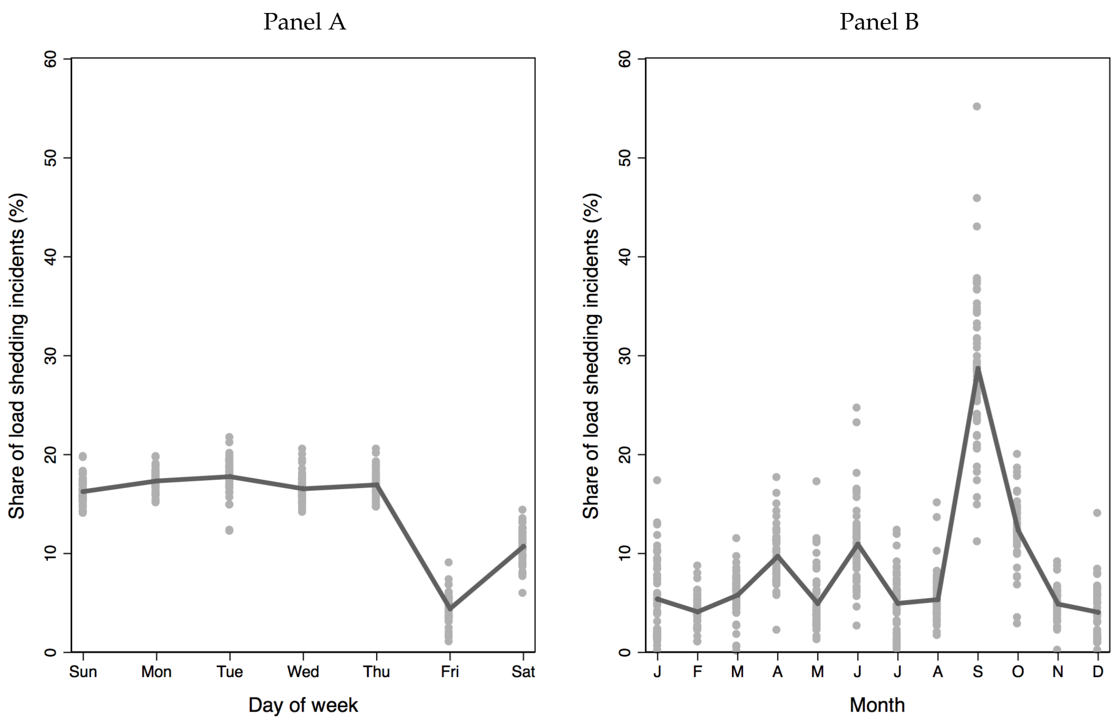
Notes: Based on Round 6 Afrobarometer data, which were collected in 2015, covering roughly 32,000 households from 21 countries in Sub-Saharan Africa. In order to isolate the city-level data, we limit the data to the subset of cities that can be identified by their county or district name. In Kenya, for instance, surveys corresponding to Nairobi can be identified because Nairobi County is coterminous with the city of Nairobi. Markers are scaled to reflect the estimated population density for each city, based on publicly available information. Electricity access (%) is defined as the proportion of households that are located in areas with electricity lines nearby. Reliable connection (%) is defined as the proportion of connected households with an electricity connection that works "most of the time" or "all of the time."

Figure 3—Energy to economic growth path diagram and potential interventions to improve reliability



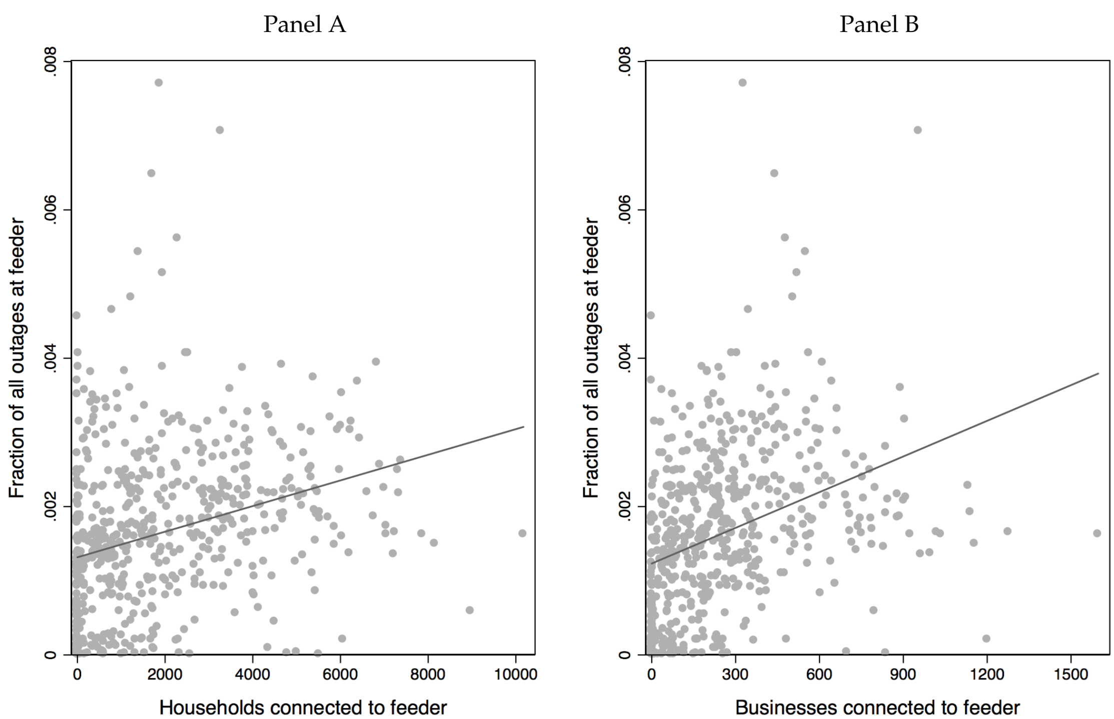
Notes: The sequence of boxes in the center of the diagram represents the main pathway from energy to economic growth. Energy is generated, distributed, and consumed by public, industrial, commercial, and residential users before it is finally reflected in measures of economic growth. We are interested in the quality of the electricity supply that is generated and distributed through this main pathway. Surrounding this pathway are examples of various policy, technology, and economic interventions that can potentially improve reliability.

Figure 4A—Weekly and seasonal variation in load shedding in Dhaka



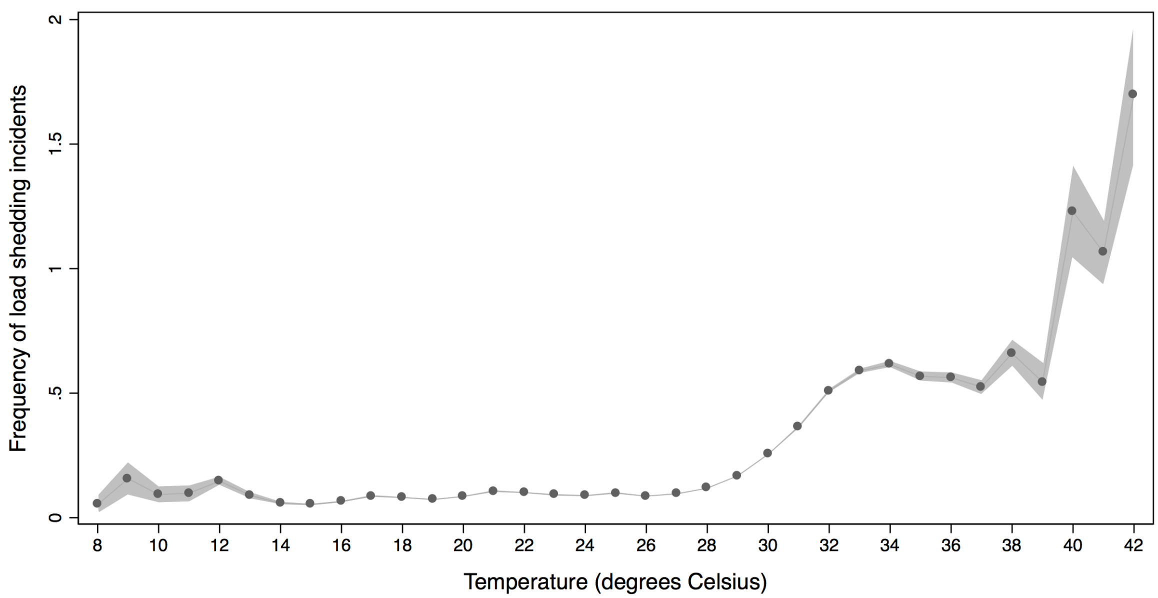
Notes: Each point represents the fraction of all substation-level load shedding incidents that occurred on each day of the week, or during each month. The dataset covers all load shedding incidents in Dhaka between September 2012 and September 2014, across 52 substations and 648 feeder lines in total. The number of feeder lines connected to each substation ranges from 4 to 35, with a median of 13. Over the course of the 25 months covered by the dataset, there were nearly 180,000 load shedding incidents in total, or 7,157 incidents per month on average. The median duration of each outage was 60 minutes.

Figure 4B—Household and business density variation in load shedding in Dhaka



Notes: Each point represents a specific feeder. The vertical axis captures the fraction of all feeder-level outages between September 2012 and September 2014 that occurred on each line.

Figure 4C—Temperature variation in load shedding in Dhaka



Notes: The vertical axis captures the frequency of load shedding incidents at the substation-level. The horizontal axis captures the temperature at the substation-level.