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Electrification and Economic Development: A Microeconomic Perspective*

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ABSTRACT

In this Energy for Economic Growth (EEG) state-of-knowledge paper, we review literature on the microeconomics of electrification in developing countries and organize existing and future work around three questions: First, how should governments and firms expand the supply of electricity? Second, for newly connected households, firms, and public facilities, what are the drivers of consumption growth? Third, what are the impacts of electrification and how can they be maximized, for example, through the design of the electrification program or the provision of complementary inputs? We highlight three general priorities and five key areas for future empirical research.

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I. INTRODUCTION

There is a large macroeconomic literature documenting the positive correlation between electricity consumption and key measures of economic development, such as GDP per capita and the Human Development Index.[1] What is still missing, however, is a more comprehensive microeconomic perspective on how electrification drives changes in key economic variables. In this Energy for Economic Growth (EEG) state-of-knowledge paper, we review the existing literature on this topic and propose several areas that would benefit from further research.

The paper is organized as follows. Section II describes research that may be valuable for policymakers making decisions to expand the supply of electricity along either the extensive or the intensive margin. Then, shifting the focus towards grid-connected households, firms, and public facilities, Section III discusses key drivers of consumption, including the acquisition of electrical appliances, electricity prices, and metering technologies. Section IV presents several observations from the growing literature estimating the impacts of electrification, noting in particular, the role of complementarities and spillovers in determining the types of observed impacts.

The final section proposes both general priorities and key areas for further research. General priorities include: (1) generating more disaggregated data on the access rates, reliability levels, and prices faced by not only households, but also firms and public facilities; (2) producing empirical estimates using rigorous, experimental methods, such as randomized evaluations, and from studies with larger sample sizes; and (3) comparing the impacts of electrification across urban and rural settings, agricultural and non-agricultural users, and other important lines of distinction.

Key areas for further research include: (1) estimating the demand for and costs of expanding the supply of electricity using different types of technologies; (2) exploring how electricity consumers acquire major energy-using assets; (3) understanding how electricity consumers respond to changes in prices and other policies; (4) understanding how electrification at the microeconomic level leads to broader economic development; and (5) estimating the economic and social impacts of electrification (for both residential

[1] See Stern (2017), a companion EEG state-of-knowledge paper, for a discussion on the macroeconomic relationship between electricity and economic growth.

and non-residential consumers), and the role of complementarities and spillovers in maximizing these impacts.

II. EXPANDING THE SUPPLY OF ELECTRICITY

Governments and firms can increase the supply of electricity by investing in infrastructure. We categorize investments as either expanding supply along the extensive margin or the intensive margin. Investments along the extensive margin target increases in access, and include programs to extend the grid to new areas or to promote the adoption of solar lanterns in off-grid areas. Investments along the intensive margin target improvements in the quality of electricity supply, and include upgrading the distribution network and building new generating capacity to increase reliability.[2] In this section, we first discuss the data and research that are relevant to expanding the supply of electricity along the extensive and intensive margins, and then briefly discuss the political economy and governance challenges that arise in many settings.

A. Extensive margin increases

There is general consensus that electricity is a key input to development. Yet there are active debates about the extent to which extensive margin increases should be driven by investments in the grid versus decentralized technologies, such as solar lanterns and solar home systems. These debates may benefit from improved data on variation in electricity access across space, as well as the costs and benefits of addressing energy poverty using alternative technologies.

In the data, access to electricity has historically been characterized as a binary outcome. Households were either "on grid" or "off grid," which often suggested that they were too far away to connect to the national electricity network.[3] Recently, there have been efforts to generate more disaggregated data on access. The Energy Sector Management Assistance Program at the World Bank, for instance, has developed a multi-

[2] See Mitchell, Ragwitz and Woodman (2017) and Gertler, Lee, and Mobarak (2017), two companion EEG state-of-knowledge papers, for detailed discussions on investments in power plants and electricity reliability, respectively.

[3] In the World Development Indicators (WDI) database, the only regularly tracked electrification variable is "access to electricity," which is presented as a percentage of the population and is not tracked for non-residential sectors of the economy.

tier framework (MTF) for defining and measuring access (ESMAP 2015). In this framework, there are five tiers of consumption (Tiers 1 through 5), and a separate tier (Tier 0) for individuals that are in total energy poverty. Consumers are gradually placed into higher tiers as the capacity, duration, reliability, quality, affordability, legality, and safety of their connections improve.[4]

These distinctions are important because governments can now choose from a wide range of supply solutions that are not always equal in terms of the amount and quality of energy provided. Solar lanterns, for example, offer just enough power to meet the Tier 1 standard. In contrast, grid connections have the potential to meet the Tier 5 standard, though this depends greatly on the reliability of power supplied.

Common supply solutions include solar lanterns and solar home systems (we refer to these collectively as "home solar"), microgrids, and grid connections.[5] In recent years, the increasing efficiency of end-use appliances, as well as reductions in the cost of photovoltaics, have driven rapid growth in the adoption of home solar (Alstone, Gershenson, and Kammen 2015). In addition, companies developing home solar have introduced innovations that have transformed the way in which these products are marketed, financed, and distributed. By integrating pay-as-you-go (PAYG) technologies directly into their products, home solar companies are able to offer their customers financing, directly addressing credit constraints. As a result, there has been a high level of interest in home solar as a solution to energy poverty. However, data on appliance ownership and aspirations indicate that, at current technologies, home solar may not satisfy the full range of energy needs (Lee, Miguel, and Wolfram 2016a).

Microgrids, which we define as a small network of users connected to a centralized and standalone source of generation and storage, fill the space between the grid and home solar. Most microgrids are powered by renewable energy, and provide longer hours and higher capacities in comparison to home solar, although they are better suited for communities with higher population densities. There are questions, however,

[4] An additional category of electricity access (that is not considered in the MTF) includes users that are connected to electricity but have been disconnected due to nonpayment.
[5] See Munuera, Dubbeling, and Mueller (2017) and Modi (2017), two companion EEG state-of-knowledge papers, for detailed discussions on power system technologies and low-voltage system designs in developing countries, respectively.

about whether such technologies can be integrated into rapidly expanding electricity networks over the long run.

For governments and firms, a key consideration is the cost of supplying different technologies. Studies in the engineering literature simulate the costs of electricity provision using geospatial data, as well as assumptions on the installation and operating costs of the various available technologies. Under this approach, a number of studies conclude that grid electrification is optimal for the majority of unelectrified households (see, e.g., Kemausuor et al. 2014; Mentis et al. 2015; Ohiare 2015).[6] Lee et al. (2016) reach a similar conclusion in Kenya, where they observe that a large proportion of unconnected households are located within a couple hundred meters of existing low-voltage network infrastructure, a situation they characterize as "under grid."[7]

Few studies, however, match cost estimates to demand. One exception is Lee, Miguel, and Wolfram (2016b), which builds on Lee et al. (2016) and generates experimental estimates on the demand and cost curves associated with a rural household electrification program. In the study setting, the total cost of construction is nearly five times higher than the consumer surplus derived from the experimental demand curve, even after accounting for economies of scale, suggesting that residential electrification may reduce social welfare.[8] In the future, additional rigorous evidence on the demand for and costs of increasing access may be valuable.

B. Intensive margin increases

Even if an electricity connection is available, the supply of electricity may still be limited due to poor reliability. Survey data from the Afrobarometer, for instance, shows

[6] Kemausuor et al. (2014) utilize Network Planner, a web-based software platform, to simulate the costs of providing electricity to unelectrified communities in Ghana. Grid electrification is determined to be optimal for more than 85 percent of all unelectrified communities. Mentis et al. (2015) develop their own Geographic Information System (GIS)-based methodology, taking into consideration population density, existing and planned transmission networks and power plants, economic activities, and other inputs. Grid electrification is similarly identified as the lowest cost option for roughly 86 percent of the unelectrified population in Nigeria. Ohiare (2015) utilizes Network Planner and finds that 98 percent of Nigerians will be able to access the grid by 2030.

[7] Subsequent calculations suggest that under grid households make up a substantial share of unelectrified households across Sub-Saharan Africa. For example, see: http://www.cgdev.org/blog/shedding-new-light-grid-debatepower-africa-countries.

[8] In other words, in order to justify such a program, discounted future social welfare gains of $511 would be required for each household in the community, above and beyond any economic or other benefits already considered by households in their own private take-up decisions.

that just 30 percent of grid-connected households in Sub-Saharan Africa consider their connections to work "all of the time" (Oyuke, Penar, and Howard 2016). While this suggests that reliability is a major issue, we currently have almost no data on even the most basic patterns of outages in developing countries. In addition, there are many ways to characterize the quality of an electricity connection. Outages, for example, may be planned or unplanned, and may vary in terms of their frequency, duration, and the extent to which they are communicated to consumers in advance.

What are the causes and consequences of outages, and how should governments address them? As Gertler, Lee, and Mobarak (2016) summarize, outages are caused by supply side factors, such as insufficient generating capacity; demand side factors, such as local capacity overloads; and political economy factors, such as the "infrastructure quality and subsidy trap" described in McRae (2015). Each of these categories points to a different set of technological, economic, and political solutions. Carranza and Meeks (2016), for instance, demonstrate that encouraging the adoption of energy-efficient appliances can reduce peak loads and lower the chances of local capacity overloads.

Most of the existing evidence on outages focuses on firm-level impacts. These studies find that firms adapt to outages in various ways, for example, by investing in back-up generators (Steinbuks and Foster 2010); by switching to more electricity-efficient technologies (Alam 2013); or by substituting intermediate inputs to production (Fisher-Vanden, Mansur, and Wang 2015). In some studies, the negative impacts of outages on productivity are quite limited (see, e.g., Allcott, Collard-Wexler, and O'Connell 2016).[9]

Outages are one prominent source of power quality disruptions. Voltage sags, line noise, harmonics, and other power quality issues may also be detrimental to customers, particularly non-residential customers with sensitive equipment. We need more research on the economic consequences of different levels of power quality, as well as the potential gains from investing in improvements.

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[9] Allcott, Collard-Wexler, and O'Connell (2016) propose that for firms with generators, outages act like a time-varying input tax (i.e., firms must self-generate power at a higher cost), whereas for firms without generators, the primary productivity loss is the waste of non-flexible inputs. However, since most non-flexible inputs can be stored, the negative impact on average productivity is somewhat limited.

C. Political economy and governance factors

In the discussion thus far, we have focused on different approaches to expanding the supply of electricity assuming those approaches are seamlessly implemented. Yet, the management of electricity systems, like other types of public goods, can be negatively impacted by a number of political economy and governance issues. These issues may affect the pace at which government-run utilities respond to electricity problems in different communities, or the leakage that occurs during the procurement of materials required to build and maintain infrastructure.

In many countries, the process of procuring and managing materials is especially prone to leakage. In Western Kenya, Lee, Miguel, and Wolfram (2016b) find that 21.3 percent of electricity poles invoiced in the construction of low-voltage networks were never installed. Banerjee et al. (2015) suggest that contracting out government services can improve efficiency and reduce rents. Considering the massive investments that are required to expand the supply of electricity, further research on the impacts of improved governance and enhanced monitoring in the construction of electricity infrastructure may be especially valuable.

Political economy considerations can also play a role in determining the quality of supply. In some countries, consumer subsidies are politically necessary, even though they may discourage investments in local infrastructure and trap consumers into a nonpaying, low-quality equilibrium (see, e.g., McRae 2015). In other countries, there is evidence that politicians manipulate the supply of electricity (e.g., by allowing more theft to occur) in order to influence the outcomes of upcoming elections (see, e.g., Min and Golden 2014). Finally, petty corruption (e.g., low level utility staff members seeking bribes) can also result in power cuts and service delays.

III. Drivers of electricity consumption

Major power producing countries in Sub-Saharan Africa have recently announced plans to dramatically expand their generating capacities, while maintaining or increasing their reliance on non-fossil fuel sources (Lee, Miguel, and Wolfram 2016a). A key assumption underpinning these investments is that supply-side increases will be matched by demand-side increases, driven in part by ongoing rural electrification initiatives to expand the supply of electricity along the extensive margin. Rural electrification, however, naturally leads to poorer and poorer households being connected to the grid. Thus, understanding the drivers of electricity consumption for newly connected consumers will emerge as a major priority for policymakers in the future.[10]

To illustrate this point, in Figure 1, we present public data on the number of residential, commercial, and industrial electricity accounts for each year in Kenya since 2001 (Panel A), as well as the change in average consumption over the same period (Panel B).[11] Two patterns stand out. First, the sharp increase in the number of residential customers has been matched by an equally sharp decrease in average residential consumption, suggesting that the majority of recent residential additions have been associated with low levels of consumption. Second, a growing share of customer additions are being connected to the grid using prepaid meters, a technology that is expected to soon dominate the metering market in many countries.

The Kenyan example is interesting for two reasons. First, Kenya has recently made large strides in expanding its electricity sector, and its experience could therefore serve as a useful example for other countries in Sub-Saharan Africa. Second, with electricity access rates now exceeding 50 percent, as well as multiple generation investments on the horizon, policymakers will soon shift their focus towards increasing average consumption and improving rates of revenue collection. These will become critical issues, considering that electricity sectors must repay the capital costs of expansion, as well as the increased costs of maintaining more expansive networks. In developing countries, increasing average consumption levels may also be desirable from a social perspective if it translates into economic growth, higher income levels, and individual wellbeing

In this section, we discuss research on the drivers of electricity consumption, focusing on the population of households, firms, and public facilities that are connected to the grid (i.e., "electricity consumers").

[10] In addition, a priority will be mitigating the potential environmental impacts of increased appliance usage and electricity consumption.
[11] Since Kenya Power is the regulated monopoly distribution and retail utility, these figures reflect national patterns of electricity access and average consumption.

A. Electrical appliances

Increases in consumption driven by first-time purchases of energy-using assets are expected to play a major role in determining medium run growth in global energy demand (Wolfram, Shelef, and Gertler 2012). Factors influencing household adoption of appliances include income levels, access to financing, preferences, and intra-household bargaining. Note that there is relatively little work on how firms and public facilities acquire energy-using assets.

As incomes rise, households acquire more and more appliances.[12] In recent field experiments, poor households experiencing positive wealth shocks increase the value of their appliance holdings, as well as their use of electricity (see, e.g., Hanna and Oliva 2015; Haushofer and Shapiro 2016; Gonzalez-Navarro and Quintana-Domeque 2016).[13]

Ownership of major appliances, however, is unlikely to rise linearly with income. Using data from a conditional cash transfer program in Mexico, Gertler et al. (2016) show that refrigerator ownership increases in an S-shaped pattern, rising slowly at low incomes, then rapidly, before slowing down again at high incomes.

With access to financing, low-income households and smaller firms may be able to acquire relatively expensive appliances. As noted earlier, PAYG models are alleviating some of the credit constraints that are common in poor, rural settings. In the future, firms may apply these technologies to a wider set of appliances, including productive equipment such as milling machines that can be used to generate income.[14]

Preferences may also play a role in driving appliance adoption, just as they factor into decisions to adopt certain cookstoves. For example, even though cooking with wood, charcoal, and kerosene contributes to indoor air pollution and respiratory illnesses, several studies document low demand for and usage of nontraditional cookstoves, despite

[12] Based on DHS (Demographic and Health Surveys) data from 37 countries in Sub-Saharan Africa, a one percent increase in GDP per capita is associated with a 12.3 percent increase in the likelihood that a household owns a refrigerator.

[13] For example, Hanna and Oliva (2015) find that an asset transfer program in India increases the likelihood of reporting that electricity is the primary source of lighting by 13 percent; Haushofer and Shapiro (2016) find that an unconditional cash transfer in Kenya increases the value of radios and televisions owned by 28 percent; Gonzalez-Navarro and Quintana-Domeque (2016) find that a positive shock to wealth in Mexico, in the form of a street paving program, increases the number of home appliances owned by 12 percent.

[14] In many parts of Sub-Saharan Africa, it is common for electricity to be used for illumination, radio, or television, but not for agriculture, handicraft, or services. This pattern, which has been described as the low productive use of electricity, has remained a puzzle for policymakers since the 1980s (Bernard 2012).

their apparent health benefits (see, e.g., Mobarak et al. 2012; Hanna, Duflo, and Greenstone 2016). Distaste for smoke emissions has been found to drive improved cookstove adoption in India (Jeuland, Pattanayak, and Tan-Soo 2015). Similar factors may play a role in the adoption of electrical appliances.[15]

If men and women have different preferences over home appliances, adoption decisions may depend on intra-household bargaining. The consequences may be large, particularly if the benefits of electrification are concentrated amongst women, as Dinkelman (2011) and others find.

What can policymakers do to mitigate the environmental impacts of increases in appliance usage? Improving energy efficiency allows consumers to achieve the same level of services with less energy. Fowlie and Phadke (2017) point out, however, that the majority of research on energy efficiency takes place in high-income countries and the findings do not always apply to developing countries. In the future, we need more work characterizing optimal levels of energy efficiency investments in different settings, as well as the market failures and barriers that prevent these investments from being made.[16]

B. Electricity prices

How do electricity consumers respond to changes in the price of electricity? In the U.S., there is a large literature addressing increasingly sophisticated questions about how electricity consumers respond to changes in and information about electricity prices. Jessoe and Rapson (2014), for example, estimate the impact of high-frequency consumption information on the price elasticity of demand; Ito (2014) investigates whether households respond to marginal prices or average prices; Ito, Ida, and Tanaka (2015) compare the relative impacts of economic incentives and moral suasion in reducing consumption during peak demand hours. These studies are possible in countries like the U.S. where the quality of administrative data is high.

In contrast, developing countries tend to be characterized by poor organizational performance, institutional, and governance issues. Billed consumption amounts may be

[15] Note that few studies have estimated the impact of electrification on cooking with electricity. In El Salvador, Barron and Torero (2015) find no evidence that grid connections induce changes in cooking practices. This could be due to budget constraints, electrical load limits, or other factors like preferences.

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

inaccurate or fabricated; consumers may have limited knowledge about the tariff structure; and utility staff members may demand bribes in exchange for basic services, or collude directly with consumers to facilitate theft. Consumers may even have different perceptions about the extent to which electricity should be subsidized by the government.

Poorly designed tariffs can lead to discrepancies in the prices facing different types of consumers. Monthly fixed charges, for example, can be especially regressive in countries where poor households consume tiny amounts of power. These issues make it challenging to apply lessons from the U.S. literature to developing country settings.

Empirical evidence in this area is extremely limited.[17] An exception is Abeberese (2016), which finds that Indian firms respond to exogenous increases in the price of electricity by switching to less electricity-intensive production processes and reducing their machine intensities, lowering output and growth in productivity.

C. Metering technologies

Metering technologies can also affect consumption as well as revenue recovery. Revenue recovery is critical in many developing countries, where utilities are often unable to raise enough cash to cover their capital and operating costs of generation.[18]

The standard technology is the postpaid meter, which allows users to pay for consumption at the end of each billing cycle. There are several issues with these meters. For example, utilities must periodically dispatch meter readers to visit each customer and physically record consumption amounts, a process that is nearly impossible to monitor. If the billing systems are not working properly, customers may end up waiting long periods to receive their bills. These issues can erode trust in utilities, encourage customer complaints and disputes, and exacerbate problems of nonpayment.

Recently, utilities have begun a transition towards prepaid meters, which require users to pay for electricity consumption in advance. From the perspective of the utility, prepaid meters are preferable, especially for poorer, liquidity-constrained customers (i.e.,

[17] In one study, Pellerano et al. (2015) examine the impacts of information interventions (e.g., increasing the salience of notches in the tariff structure) on residential consumption in Ecuador.

[18] Nearly all of the power sectors across Sub-Saharan Africa suffer from financial shortfalls and problems in the quality of electricity supply. In a sample of 39 countries in Sub-Saharan Africa, Trimble et al. (2016) find that only two countries (the Seychelles and Uganda) have electricity sectors that collect enough cash to cover the capital and operating costs of providing electricity. Due to these financial shortfalls, utilities may be unable to invest in network maintenance and upgrades, increasing the risk of blackouts.

the ones who have difficulty paying lumpy bills) (Jack and Smith 2015). From the perspective of the electricity consumer, each technology has its advantages. On the one hand, postpaid meters offer the advantage of consuming in advance, which is akin to receiving a free consumption loan. On the other hand, prepaid meters offer consumers greater control of their electricity expenditures.

Recent studies find that switching customers from postpaid to prepaid meters reduces consumption in the range of 10 to 13 percent (Qiu, Xing, and Wang 2016; Jack and Smith 2016).[19] These estimates can be explained in several ways. Prepaid meters may increase the salience of consumption due to in-home displays that provide feedback on usage. Alternatively, they may transfer some of the transaction costs from the utility to the consumers. Further research is needed, however, to better understand the mechanisms driving these impacts, as well as the extent to which broader governance problems in the electricity sector, such as bribery and theft, can be addressed through metering technologies.

IV. MAXIMIZING THE IMPACTS OF ELECTRIFICATION

Much of the recent literature on the microeconomics of electrification focuses on estimating the impacts of increasing access to electricity for rural households and communities. Table 1 provides a summary of the main findings from a selection of recent articles. We also present key aspects of the underlying setting, including the country, time period, unit of analysis, and primary econometric identification strategy.

We draw several conclusions from Table 1. First, there is substantial variation in the types of outcomes examined, as well as the magnitudes of impacts estimated. While most studies conclude that electrification improves wellbeing, there is a wide range of impacts. Second, the context varies enormously across studies, making it difficult to assess the external validity of any given set of results. Each study estimates the impacts of introducing electricity to a population that is at a unique stage of development, and through an electrification program that may or may not generate spillovers, which may or may not be captured in the research design. Third, in a closely related point, given how

[19] Jack and Smith (2016) estimate that switching customers to prepaid meters decreases consumption by 10 to 13 percent in Cape Town, South Africa. Similarly, Qiu, Xing, and Wang (2016) estimate a 12 percent reduction in Phoenix, Arizona.

electricity is an enabling technology, it is possible that large impacts in certain studies are driven by the availability of unobserved complementary inputs. The possibility of differential impacts isn't systematically addressed in the literature. Fourth, many studies rely on instrumental variables (IV) techniques for econometric identification. In certain cases, the exclusion restriction is difficult to defend. Fifth, there is currently limited evidence on the impacts of alternative, decentralized solutions, such as solar microgrids and home solar. Most of the listed studies estimate the impacts of grid connections. Sixth, the primary focus has been on residential consumers, even though in most countries, non-residential consumers account for the bulk of energy consumption, and may thus drive economic development.

Note that answering these questions can aid governments, donors and firms in maximizing the potential impacts of electricity. Electrification through a mass connection program, rather than a one-off approach, for example, may result in greater spillovers. Alternatively, subsidies for complementary appliances targeting newly connected households may lead to greater impacts.

A. Outcomes of interest

In the recent literature, there is substantial variation in the types of outcomes examined, as well as the magnitudes of impacts estimated. Several studies find evidence that providing rural households with access to electricity increases summary measures of wellbeing such as income, expenditures, and consumption (see, e.g., Khandker, Barnes, and Samad 2012; Khandker et al. 2014; van de Walle et al. 2015).[20] In certain cases, the estimated gains are large. Chakravorty, Emerick, and Ravago (2016), for instance, find that the arrival of electricity in the last ten percent of unelectrified villages in the Philippines increased household income and expenditures by 42 and 38 percent, respectively—gains that are large enough to offset the physical costs of grid extension after just a single year. But not all studies reach this conclusion. In rural Kenya, Lee, Miguel, and Wolfram (2016b) estimate experimental demand and cost curves suggesting

[20] For example, Khandker, Barnes, and Samad (2012) estimate increases in household income and expenditures in Bangladesh of 15.1 and 13.6 percent, respectively; Khandker et al. (2014) estimate increases in household income and expenditures in India of 36.1 and 16.2 percent, respectively; and van de Walle et al. (2015) estimate that household consumption increased by 0.5 percentage points per annum over a 17-year period in India. Relatedly, Lipscomb, Mobarak, and Barham (2013) estimate that a 10 percent increase in electrification in Brazil increased housing values by 6.8 percent.

that rural electrification reduces welfare. Similarly, Burlig and Preonas (2016) estimate the effects of India's national electrification program, which increased access to electricity in 400,000 villages, and find close to no effects on labor markets, asset ownership, housing characteristics, and village-wide outcomes.

Although there is growing evidence on the impacts of electrification, there is much less work on the mechanisms through which electrification may improve wellbeing. One plausible channel, described in Dinkelman (2011), is through the acquisition of electrical appliances. The availability of electric lighting extends the number of potential working hours in each day, increasing the supply to labor to the market. At the same time, higher quality lighting raises the productivity of home-based work. Although this productivity effect encourages individuals to substitute more time towards domestic work, there is a limit to the amount of domestic work available. If the first (endowment) effect outweighs the second (substitution) effect, electrification increases the supply of labor outside the home. In settings where women are responsible for much of the domestic work, the effect on labor supply should be especially large for women. This is observed in South Africa, where rural electrification results in a 9.5 percentage point increase in the female employment rate (Dinkelman 2011).[21]

In Figure 2, we plot key labor supply estimates by gender and compare across studies. Although the South Africa female labor supply result is cited often, there is wide variation in estimated impacts, with some studies even estimating negative coefficients. One potential reason for this discrepancy is that the impacts of electrification on female labor supply are heavily dependent on the characteristics of the underlying setting. For instance, van de Walle et al. (2015) point out that in South Africa, a large proportion of households cook with electricity, which is in stark contrast to most other countries in Sub-Saharan Africa.[22] Understanding why there may be an effect in certain settings and not in others remains an area for further research.

There is a long list of potential mechanisms, beyond the acquisition of electrical appliances and their influence on household productivity. For example, electrification

[21] Similar results are found in Grogan and Sadanand (2013), where women in Nicaragua are 23.3 percent more likely to be employed; and in Barron and Torero (2014), where women in El Salvador are 45.8 percent more likely to be engaged in non-farm employment.

[22] In a survey of grid connected rural households in Western Kenya, less than 1 percent of respondents owned an electric cookstove (Lee, Miguel, and Wolfram 2016a).

may improve wellbeing through education. If children have better quality lighting, they may study later into the night (see, e.g., Khandker, Barnes, and Samad 2012; Khandker et al. 2014; Barron and Torero 2014).[23] Alternatively, electrification may improve wellbeing through health. Electric lighting reduces the need for kerosene lanterns, reducing indoor air pollution and the incidence of respiratory infections (Barron and Torero 2016). Finally, electrification may improve wellbeing through increased media consumption (through televisions, radios, and computers) and greater knowledge of language and current affairs, and updated attitudes towards health.[24]

B. Context

In Table 1, each of the studies estimates the impacts of introducing electricity to a population that is at a unique stage of development, and through an electrification program that may or may not generate spillovers, which may or may not be captured in the research design.[25] Due to these differences, it is difficult to assess the external validity of any given set of results.

In Table 2, we summarize key aspects of the electrification program evaluated in each study. The comparison highlights large differences in program length and intensity. For example, Dinkelman (2011) estimates community-level impacts of a major post-apartheid electrification initiative in South Africa that increased the national electrification rate by 25 percentage points over a relatively short timeframe. In contrast, Khandker et al. (2014) estimate household-level impacts in India using a single cross-section of a nationally representative household survey.

[23] In terms of studying time, Khandker, Barnes, and Samad (2012) estimate an increase of 12 to 14 minutes per day in Bangladesh; Khandker et al. (2014) estimate an increase of 1.4 to 1.6 hours per day in India; and Barron and Torero (2014) estimate a 78 percent increase in time spent studying and at school in El Salvador. In terms of test scores, Hassan and Lucchino (2016) find that distributing solar lanterns to 7th grade pupils in Kenya increases math grades by 0.88 standard deviations, although spillover effects for control students complicate the interpretation of the results; Furukawa (2014) finds that distributing solar lanterns in Uganda reduces test scores (possibly due to the flickering, low quality of light), but increases studying time by roughly 30 minutes per day. Estimates of impacts on test scores, however, have been mixed (see, e.g., Furukawa 2014; Hassan and Lucchino 2016).

[24] Other potential mechanisms include the establishment of electricity-based enterprises, higher levels of psychological wellbeing, changes in household fertility decisions, and improvements to the community (for example, through street lighting). See Bacon and Kojima (2016) for an in-depth review.

[25] Note that if there are nonlinearities in the production of spillovers, the impacts will depend even more on the features of the underlying program.

In order to interpret differences and similarities in results, we need a better understanding of how the impacts of electrification are influenced by characteristics of the underlying setting, which can determine, for example, the types of mechanisms and impacts that are possible. A positive effect on female employment may be more likely if the electrification program is paired with an initiative promoting the establishment of complementary local industries, or improvements to local transportation infrastructure that make it easier for women to travel to their places of work. Similarly, aspects of the underlying electrification program and setting can also determine the extent of spillovers. A positive effect on security and safety may be more likely if community streetlights are included as part of the mass electrification program.

To what extent does electrification generate spillovers? As van de Walle et al. (2015) describe, electrification can result in symmetric spillovers (e.g., changes in labor markets due to the electrification of local businesses), asymmetric spillovers (e.g., shared power connections), and social interaction effects. Few studies rigorously identify or estimate the effects of these various spillovers. One exception is Bernard and Torero (2015), who find that in Ethiopia, household decisions to connect to the grid are influenced by the decisions of their neighbors (i.e., social interaction effects). For the most part, studies that account for spillovers do so because the unit of analysis is the village, community, county, or state level. Future work shedding light on the most relevant spillovers from electrification, as well as the policies that increase the likelihood of realizing these spillovers, will be especially valuable moving forward.

C. Complementarities

Electricity is an enabling technology—its value depends almost entirely on the availability and accessibility of complementary inputs, ranging from electrical appliances to the quality of local roads. In order for grid connections to raise income levels, households may need electrical appliances (to increase the productivity of household activities), access to credit (to finance purchases of these electrical appliances), robust local businesses (which provide opportunities to earn cash income), access to good roads (which reduce the cost of transportation to places of work), and many other inputs. In order for school electrification to impact student performance on standardized tests, schools may need photocopiers, water pumps, and fans. In many of the hypothesized channels through which electricity impacts economic development, complementary inputs are a necessary condition to development.

The fact that there are so many potential time-varying complementarities, many of which are unobserved in data, presents an additional challenge for non-experimental studies. This may particularly be the case in studies evaluating the impacts of historical electrification initiatives through difference-in-difference (DID) approaches, many of which were accompanied by major investments in complementary projects.[26]

D. Instruments

Many of the studies listed in Table 1 use IV techniques for econometric identification. Table 3 presents a summary of some of the instruments that have been used. Many instruments are constructed using characteristics of the local geography, such as land gradient and distance to pre-existing grid infrastructure. The exclusion restriction is violated if these factors influence economic outcomes through channels other than their effect on increasing the likelihood of electrification. In certain cases, this assumption may be difficult to defend. In future analyses on impacts, there is an opportunity for randomized field experiments to add significant value.

E. Alternative energy technologies

Nearly all of the studies listed in Table 1 focus on measuring the impacts of grid connections. This pattern highlights a gap in the literature on the demand for and impacts of alternative solutions, such as solar microgrids and home solar.[27] Research on these topics may be valuable for policymakers choosing between centralized and decentralized electrification solutions. Research exploring the dynamic effects of choosing one technology over others may also be beneficial. Policymakers, for example, may wish to understand the tradeoffs of first providing under grid and off grid populations with home solar, before transitioning to grid connections, as incomes rise.

[26] For example, efforts to increase access to electricity during the early-2000s in Vietnam were complemented with investments in roads, water, education, and health (Khandker, Barnes, and Samad 2013).

[27] Recent studies evaluating the demand for and impacts of home solar include Rom, Gunther, and Harrison (2016) and Grimm et al. (2016). In addition, there are a number of ongoing field experiments to estimate these impacts. Appendix Table A1 presents a summary of all electrification-related studies registered on the AEA RCT Registry as of December 31, 2016.

F. Non-residential consumers

The existing literature largely ignores the economics of expanding the supply of electricity for non-residential consumers, such as SMEs, industrial firms, and public facilities. These consumers, however, are typically responsible for the majority of energy consumption. To illustrate this point, in Figure 3, we plot the share of electricity consumed by non-residential customers against the log of each country's GDP per capita in 1994 and 2014.[28] Generally, non-residential consumers account for more than half of total demand, and this pattern has held over time, as countries passed through various stages of development.

What is the impact of expanding the supply of electricity for firms? Basic theory would suggest that a cheaper and more reliable source of energy will reduce the cost of production, increase efficiency, and lower the prices of goods and services, leading to higher levels of employment and production.[29] There are only a few studies that focus on non-residential consumers. An exception is Rud (2012), which documents a 14.7 percentage point increase in state-level manufacturing output as the result of rural electrification in India.

Most of the existing literature on the relationship between electricity and firms in developing countries estimates the costs of outages. As we note earlier, several studies find that firms partially mitigate the short run costs of outages by adopting various coping mechanisms (see, e.g., Allcott, Collard-Wexler, and O'Connell 2016). However, there is suggestive evidence that persistent outages can negatively impact industry structure in the long run by influencing the rate at which firms enter and exit markets.[30]

There is even less rigorous evidence on the impacts of electrifying public facilities, such as schools, health clinics, and markets. Generating precise estimates of these impacts may be important, particularly if the costs of rural household electrification

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[28] Note that the colored lines in the bottom figure show how the non-residential share of electricity consumption and log GDP per capita have changed from 1994 to 2004 to 2014.

[29] In the U.S., for example, Deschenes (2010) finds that high electricity prices (between 1976 and 2007) reduced employment rates; Kline and Moretti (2014) find that the expansion of the Tennessee Valley Authority during the 1930s, which involved large investments in hydroelectricity, increased manufacturing employment.

[30] Alby, Dethier, and Straub (2012) find that in countries with frequent shortages, sectors that are relatively electricity-intensive are characterized by a lower number of small firms, suggesting that outages act as a barrier to entry.

are high (see, e.g., Lee, Miguel, and Wolfram 2016b), and it is the non-residential consumers that drive the economic gains from electrification.

V. FUTURE RESEARCH

We now outline general priorities, as well as key areas for future research. We begin with three general priorities. First, we need more disaggregated data describing how the supply of electricity—in terms of access rates, reliability levels, and prices—varies for different types of energy consumers. Data on firms and public facilities are extremely limited, yet essential if non-residential consumers are the primary drivers of economic growth.[31] Second, we need to prioritize empirical estimates obtained from rigorous methods, such as randomized evaluations, and from studies with sufficiently large sample sizes. Third, we need comparisons of demand estimates and impacts across important lines of distinction (e.g., urban versus rural consumers; agricultural versus non-agricultural users, etc.).

In the remainder of this section, we propose five key areas for future research, offering examples of specific questions that researchers can address in future work.

1. What is the demand for and costs of expanding the supply of electricity (along either the extensive or the intensive margin), using different types of technologies (e.g., home solar versus grid electrification) and across different types of settings (e.g., urban versus rural)?
    a. To what extent are these technologies complements or substitutes? How do electricity consumers make decisions about choosing different technologies?
    b. How can donors and utilities improve the overall governance of programs to expand the supply of electricity? For example, how can governments reduce corruption and leakage in infrastructure construction?

[31] One strategy is to identify low-cost, scalable methods to capture spatial and temporal variations in the supply of electricity. For example, this may be accomplished by facilitating the collection of user-generated data. Grid Watch, a software program designed to compile high-resolution data on blackouts and brownouts by harvesting data on the charge states of smart phones, might one day harness enough user-generated data to accurately characterize the spatial and temporal variations in the quality of electricity for a city like Nairobi (Klugman et al. 2014).

    c. Are there any supply side path dependencies that should be taken into consideration when making these decisions? For example, how might the rapid scale-up of community-level microgrids affect the willingness of the government to provide access to the national grid in the long run?
    d. Are decisions about the supply of electricity influenced by the goals of politicians and elites, and if so, what are the economic consequences?

2. How do electricity consumers acquire major energy-using assets, and what can policymakers do to reduce the environmental impacts of rising consumption?
    a. What are the barriers to the adoption of electrical appliances and how can they be addressed? For example, how would the provision of access to financing, through integrated PAYG technologies, for example, impact appliance adoption rates and subsequent electricity consumption?
    b. What are the costs and benefits of energy efficiency investments in developing countries, and what policies can encourage these investments for different groups of electricity consumers?

3. How do electricity consumers respond to changes in prices and other policies?
    a. What can be done about falling average consumption rates (and idle electricity meters) in countries like Kenya? What is the price elasticity of demand in developing countries and how is electricity consumption impacted by different policies, such as (i) improved information about tariffs; (ii) regular feedback on consumption; and (iii) the introduction of peak-period pricing policies?
    b. How is the relationship between the price of electricity and consumption demand affected by poor organizational performance, faulty billing systems, and petty corruption, which often lead to disputes about billed amounts?
    c. What is the impact of the metering technology on consumption, repayment, and organizational performance?
    d. What can be done to reduce non-technical losses? For example, how should utilities respond to electricity theft, particularly in high-density urban neighborhoods?

e. What are the impacts of different interventions to improve revenue recovery from large commercial customers, which typically account for the bulk of revenue in many developing countries?

4. How does electrification lead to broader economic development?

   a. What are the mechanisms through which electrification impacts households, firms, and public facilities?
   b. How does the supply of electricity impact employment levels, as well as the types of jobs and wages that are offered in the economy?
   c. How do improvements in reliability impact households, firms, and public facilities? For firms, what are the long run impacts of unreliable supply on industry structure and economic diversification?
   d. How do the cost and benefits compare between investments to expand supply along the extensive margin versus the intensive margin? Should governments prioritize access or quality?

5. What are the impacts of electrification, and how can benefits be maximized, for both residential and non-residential consumers?

   a. What are the spillover impacts of electrification? How does the design of an electrification program influence the spillovers that are generated? For example, is there something different about a "mass electrification" program, compared to a more gradual and natural electrification process?
   b. How does the presence and availability of complementary inputs influence the impacts of electrification?

REFERENCES

Abeberese, Ama Baafra. 2016. “Electricity Cost and Firm Performance: Evidence from India,” unpublished manuscript.

Alam, Muneeza M. 2013. “Coping with Blackouts: Power Outages and Firm Choices,” unpublished manuscript.

Alby, Philippe, Jean-Jacques Dethier, and Stephane Straub. 2012. “Firms Operating under Electricity Constraints in Developing Countries.” *World Bank Economic Review* 27(1): 109-32.

Allcott, Hunt, Allan Collard-Wexler, and Stephen D. O’Connell. “How Do Electricity Shortages Affect Industry? Evidence from India.” *American Economic Review* 106(3): 587-624.

Alstone, Peter, Dimitry Gershenson, and Daniel M. Kammen. 2015. “Decentralized Energy Systems for Clean Electricity Access.” *Nature Climate Change* 5: 305-314.

Bacon, Robert, and Masami Kojima. 2016. “Energy, Economic Growth, and Poverty Reduction: A Literature Review.” World Bank. Washington, DC: World Bank.

Banerjee, Abhijit, Rema Hanna, Jordan C. Kyle, Benjamin A. Olken, and Sudarno Sumarto. 2015. “Contracting out the Last-Mile of Service Delivery: Subsidized Food Distribution in Indonesia,” unpublished manuscript.

Barron, Manuel, and Maximo Torero. 2014. “Electrification and Time Allocation: Experimental Evidence from Northern El Salvador,” unpublished manuscript.

Barron, Manuel, and Maximo Torero. 2016. “Household Electrification and Indoor Air Pollution”, unpublished manuscript.

Bernard, Tanguy. 2012. “Impact Analysis of Rural Electrification Projects in Sub-Saharan Africa.” *World Bank Research Observer* 27(1): 33-51.

Bernard, Tanguy, Maximo Torero. 2015. “Social Interaction Effects and Connection to Electricity: Experimental Evidence from Rural Ethiopia.” *Economic Development and Cultural Exchange* 63(3): 459-484.

Burlig, Fiona and Louis Preonas. 2016. “Out of the Darkness and Into the Light? Development Effects of Electrification in India,” unpublished manuscript.

Carranza, Eliana, and Robyn Meeks. 2016. "Shedding Light: Understanding Energy Efficiency and Electricity Reliability in Developing Countries," unpublished manuscript.

Chakravorty, Ujjayant, Kyle Emerick, and Majah-Leah Ravago. 2016. "Lighting Up the Last Mile: The Benefits and Costs of Extending Electricity to the Rural Poor," unpublished manuscript.

Deschenes, Olivier. 2012. "Climate Policy and Labor Markets." In The Design and Implementation of U.S. Climate Policy, edited by Don Fullerton and Catherine Wolfram, University of Chicago Press.

Dinkelman, Taryn. 2011. "The Effects of Rural Electrification on Employment: New Evidence from South Africa." *American Economic Review* 101(7): 3078-3108.

ESMAP (Energy Sector Management Assistance Program). 2015. "Beyond Connections: Energy Access Redefined." http://www.worldbank.org/content/dam/Worldbank/Topics/-Energy%20and%20Extract/Beyond_Connections_Energy_Access_Redefined_Exec_ESMAP_2015.pdf

Fisher-Vanden, Karen, Erin T. Mansur, and Qiong (Juliana) Wang. 2015. "Electricity Shortages and Firm Productivity: Evidence from China's Industrial Firms." *Journal of Development Economics* 114: 172-188.

Fowlie, Meredith, and Amol Phadke. 2017. "Energy Efficiency in the Developing World," unpublished manuscript.

Furukawa, Chishio. 2014. "Do Solar Lamps Help Children Study? Contrary Evidence from a Pilot Study in Uganda." *Journal of Development Studies* 50(2): 319-341.

Gertler, Paul J., Kenneth Lee, and A. Mushfiq Mobarak. 2017. "Electricity Supply and Urbanization: A Microeconomic Research Agenda," unpublished manuscript.

Gertler, Paul J., Orie Shelef, Catherine D. Wolfram, and Alan Fuchs. 2016. "The Demand for Energy-Using Assets among the World's Rising Middle Classes." *American Economic Review* 106(6): 1366–1401.

Gonzalez-Navarro, Marco, and Climent Quintana-Domeque. 2016. "Paving Streets for the Poor: Experimental Analysis of Infrastructure Effects." *Review of Economics and Statistics* 98(2): 254–267.

Grimm, Michael, Luciane Lenz, Jorg Peters, and Maximiliane Sievert. 2016. “Demand for Off-Grid Solar Electricity: Experimental Evidence from Rwanda,” unpublished manuscript.

Grogan, Louise, and Asha Sadanand. 2013. “Rural Electrification and Employment in Poor Countries: Evidence from Nicaragua.” *World Development* 43: 252-265.

Hanna, Rema, Esther Duflo, and Michael Greenstone. 2016. “Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves.” *American Economic Journal: Economic Policy* 8(1): 80–114.

Hanna, Rema, and Paulina Oliva. 2015. “Moving up the Energy Ladder: The Effect of an Increase in Economic Well-Being on the Fuel Consumption Choices of the Poor in India.” *American Economic Review: Papers & Proceedings* 105(5): 242-246.

Hassan, Fadi, and Paulo Lucchino. 2016. “Powering Education,” unpublished manuscript.

Haushofer, Johannes, and Jeremy Shapiro. 2016. “The Short-Term Impact of Unconditional Cash Transfers to the Poor: Evidence from Kenya.” *Quarterly Journal of Economics*.

Ito, Koichiro. 2014. “Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing.” *American Economic Review* 104(2): 537–563.

Ito, Koichiro, Takanori Ida, and Makoto Tanaka. 2015. “The Persistence of Moral Suasion and Economic Incentives: Field Experimental Evidence from Energy Demand,” unpublished manuscript.

Jack, B. Kelsey, and Grant Smith. 2015. “Pay as You Go: Pre-paid Metering and Electricity Expenditures in South Africa.” *American Economic Review: Papers & Proceedings* 105(5): 237–241.

Jack, B. Kelsey, and Grant Smith. 2016. “Charging ahead: Prepaid electricity metering in South Africa,” unpublished manuscript.

Jessoe, Katrina, and David Rapson. 2014. “Knowledge Is (Less) Power: Experimental Evidence from Residential Energy Use." *American Economic Review* 104(4): 1417-1438.

Jeuland, Marc, Subhrendu K. Pattanayak, and Jie-Sheng Tan Soo. 2015. "Preference Heterogeneity and Adoption of Environmental Health Improvements: Evidence from a Cookstove Promotion Experiment," unpublished manuscript.

Kemausuor, Francis, Edwin Adkins, Isaac Adu-Poku, Abeeku Brew-Hammond, and Vijay Modi. 2014. "Electrification planning using Network Planner tool: The case of Ghana." *Energy for Sustainable Development* 19: 92-101.

Kitchens, Carl, and Price Fishback. 2015. "Flip the Switch: The Impact of the Rural Electrification Administration 1935-1940." *Journal of Economic History* 75(4): 1161-1195.

Khandker, Shahidur R., Douglas F. Barnes, and Hussain A. Samad. 2012. "The Welfare Impacts of Rural Electrification in Bangladesh." *Energy Journal* 33(1): 187-206.

Khandker, Shahidur R., Douglas F. Barnes, and Hussain A. Samad. 2013. "Welfare Impacts of Rural Electrification: A Panel Data Analysis from Vietnam." *Economic Development and Cultural Change* 61(3): 659-692.

Khandker, Shahidur R., Hussain A. Samad, Rubaba Ali, and Douglas F. Barnes. 2014. "Who Benefits Most from Rural Electrification? Evidence in India." *Energy Journal* 35(2): 75-96.

Kline, Patrick and Enrico Moretti. 2014. "Local Economic Development, Agglomeration Economies, and the Big Push: 100 Years of Evidence from the Tennessee Valley Authority." *Quarterly Journal of Economics*, 129: 275-331.

Klugman, Noah, Javier Rosa, Pat Pannuto, Matthew Podolsky, William Huang, and Prabal Dutta. 2014. "Grid Watch: Mapping Blackouts with Smart Phones."

Lee, Kenneth, Eric Brewer, Carson Christiano, Francis Meyo, Edward Miguel, Matthew Podolsky, Javier Rosa, and Catherine Wolfram. 2016. "Electrification for "Under Grid" Households in Rural Kenya." *Development Engineering* 1: 26-35.

Lee, Kenneth, Edward Miguel, and Catherine Wolfram. 2016a. "Appliance Ownership & Aspirations among Electric Grid and Home Solar Households in Rural Kenya." *American Economic Review: Papers & Proceedings* 106(5): 89-94.

Lee, Kenneth, Edward Miguel, and Catherine Wolfram. 2016b. "Experimental Evidence on the Demand for and Costs of Rural Electrification," unpublished manuscript.

Lipscomb, Molly, Mobarak, Ahmed Mushfiq, and Tania Barham. 2013. “Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil.” *American Economic Journal: Applied Economics* 5(2): 200-231.

McRae, Shaun. 2015. “Infrastructure Quality and the Subsidy Trap.” *American Economic Review* 105(1): 35-66.

Mentis, Dimitrios, Manuel Welsch, Francesco Fuso Nerini, Oliver Broad, Mark Howells, Morgan Bazilian, and Holger Rogner. 2015. “A GIS-based approach for electrification planning – A case study on Nigeria.” *Energy for Sustainable Development* 29: 142-150.

Min, Brian, and Miriam Golden. 2014. “Electoral cycles in electricity losses in India.” *Energy Policy* 65: 619-625.

Mitchell, Catherine, Mario Ragwitz, and Bridget Woodman. 2017. “Economic and Non-Economic Barriers and Drivers for the Uptake of Renewables,” unpublished manuscript.

Mobarak, A. Mushfiq, Puneet Dwivedi, Robert Bailis, Lynn Hildemann, and Grant Miller. 2011. “Low Demand for Nontraditional Cookstove Technologies.” *Proceedings of the National Academy of Sciences* 109(27): 10815-10820.

Modi, Vijay. 2017. “Low-voltage System Designs for Energy Access,” unpublished manuscript.

Munuera, Luis, Timon Dubbeling, Simon Mueller. 2017. “Modular and discrete: Opportunities for alternative power system planning, expansion and operation in developing countries,” unpublished manuscript.

Ohiare, Sanusi. 2015. “Expanding electricity access to all in Nigeria: a spatial planning and cost analysis.” *Energy, Sustainability and Society* 5:8.

Oyuke, Abel, Peter Halley Penar, and Brian Howard. 2016. “Off-grid or ‘off-on’: Lack of access, unreliable electricity supply still plague majority of Africans.” *Afrobarometer Dispatch* 75.

Pellerano, Jose A., Michael K. Price, Steven L. Puller, and Gonzalo E. Sanchez. “Price Salience and Social Comparisons as Policy Instruments: Evidence from a Field Experiment in Energy Usage,” unpublished slides.

Rom, Adina, Isabel Gunther, and Kat Harrison. 2016. “Economic Impact of Solar Lighting: A Randomised Field Experiment in Rural Kenya,” unpublished manuscript.

Rud, Juan Pablo. 2012. "Electricity provision and industrial development: Evidence from India." *Journal of Development Economics* 97: 352-367.

Steinbuks, J., and V. Foster. 2010. "When Do Firms Generate? Evidence on In-House Electricity Supply in Africa." *Energy Economics* 32(3): 505-14.

Stern, David. 2017. "The Impact of Electricity on Economic Development: A Macroeconomic Perspective," unpublished manuscript.

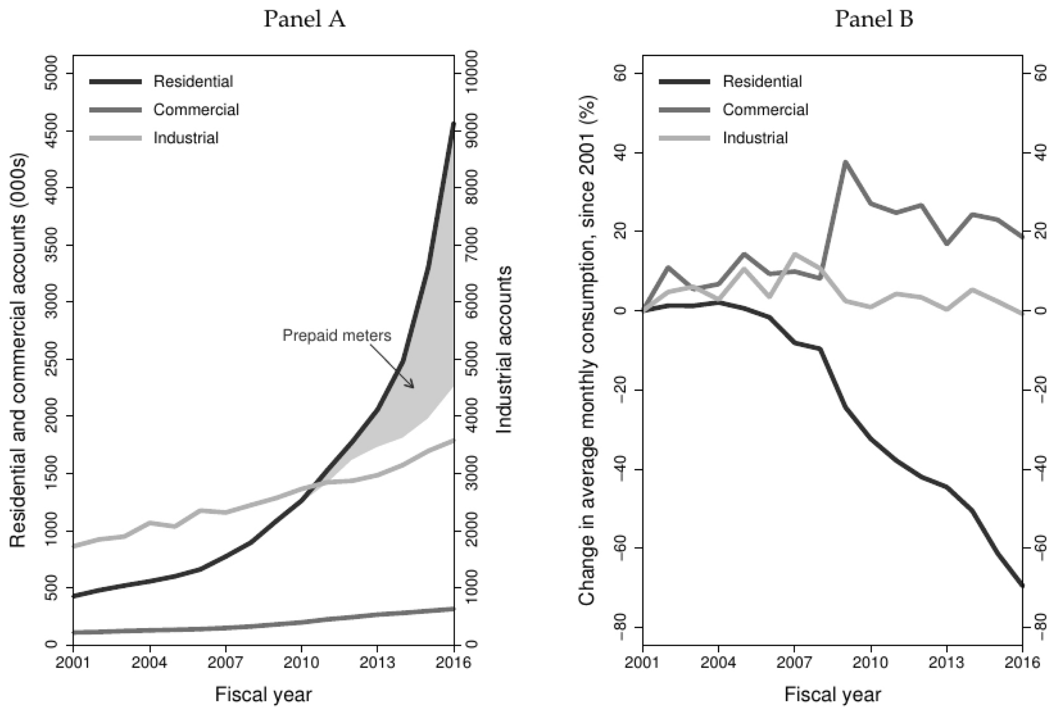
Trimble, Christopher, Masami Kojima, Ines Perez Arroyo, and Farah Mohammadzadeh. 2016. "Financial Viability of Electricity Sectors in Sub-Saharan Africa." *World Bank Policy Research Working Paper* #7788.

Qiu, Yueming, Bo Xing, and Yi David Wang. 2016. "Prepaid Electricity Plan and Electricity Consumption Behavior." *Contemporary Economic Policy*.

van de Walle, Dominique, Martin Ravallion, Vibhuti Mendiratta, and Gayatri Koolwal. 2015. "Long-Term Gains from Electrification in Rural India." *World Bank Economic Review*: 1-36.

Wolfram, Catherine, Orie Shelef, and Paul Gertler. 2012. "How Will Energy Demand Develop in the Developing World?" *Journal of Economic Perspectives* 26(1): 119-138.

Figure 1—Kenya Power electricity accounts and change in average consumption since 2001



Notes: Based on Kenya Power Annual Reports. As of June 2016, Kenya Power had 3,704,032 residential customers, 203,947 commercial customers, and 3,556 industrial customers. During the 2015/16 fiscal year, monthly residential, commercial, and industrial consumption averaged 45.2 kWh, 471.1 kWh, and 96.2 MWh, respectively. All prepaid meter installations are assumed to be associated with residential accounts. According to Kenya Power officials, prepaid meters represented less than 1 percent of all commercial accounts as of July 2015. In the 2016 Annual Report, Kenya Power mentions for the first time that prepaid meters were installed for both domestic (i.e., residential) and small commercial customers. No further information is provided.

Figure 2—Key labor supply estimates in recent literature (since 2011)

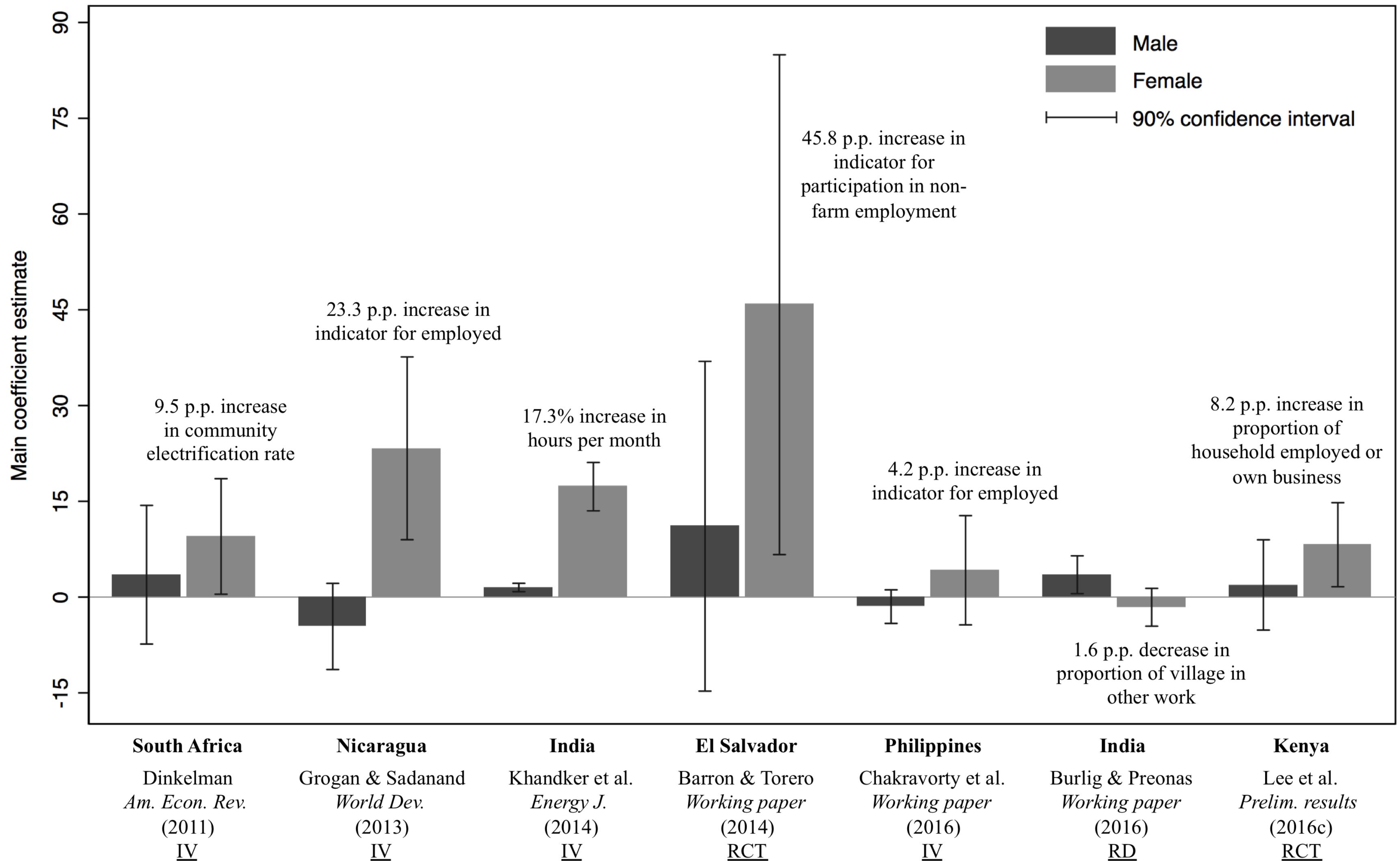
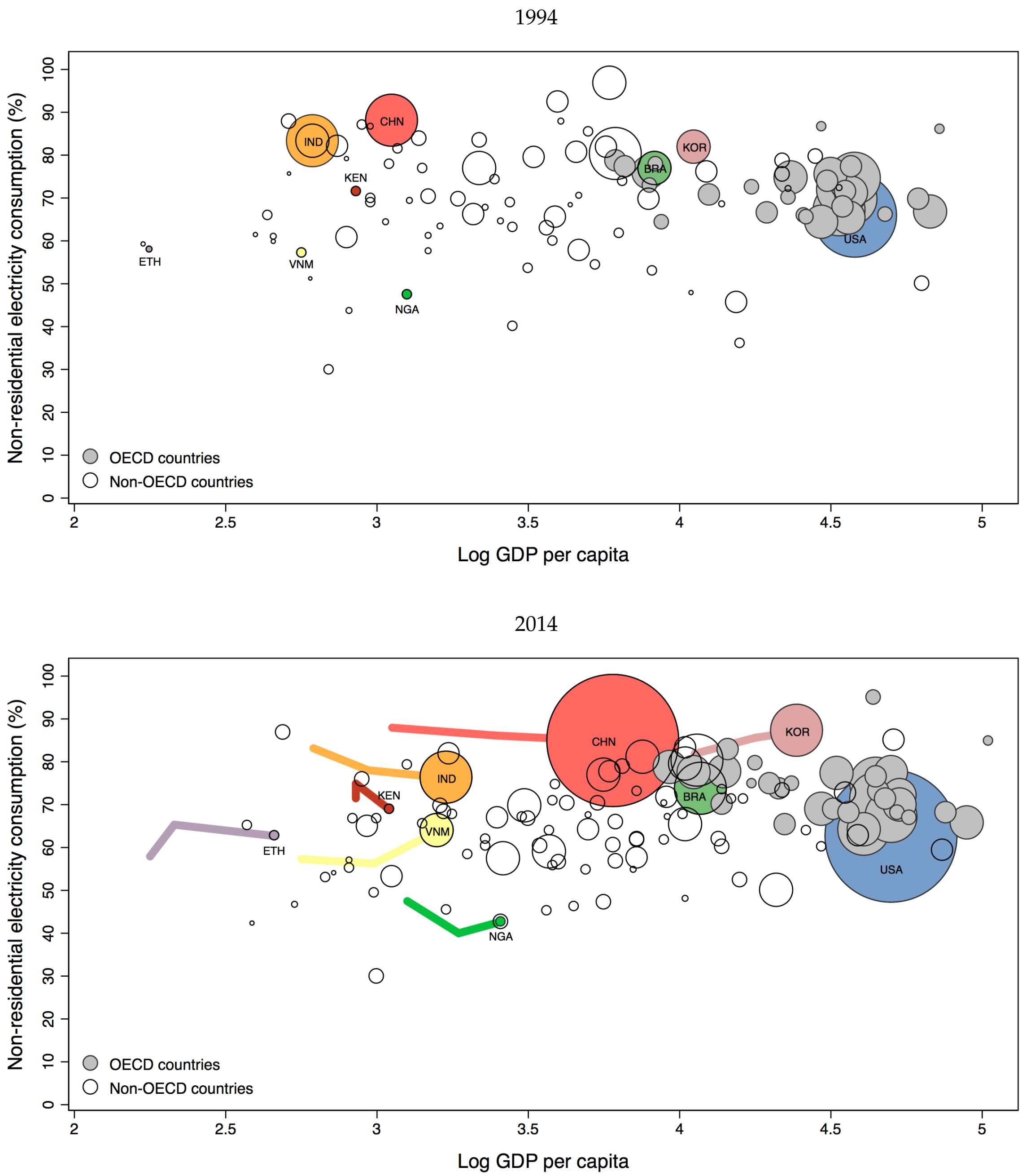


Figure 3—Non-residential share of electricity consumption versus log GDP per capita



Notes: Based on estimates from International Energy Agency and the World Bank Databank. For a selection of countries, including Brazil (BRA), China (CHN), Ethiopia (ETH), India (IND), Kenya (KEN), Nigeria (NGA), South Korea (KOR), the United States (USA), and Vietnam (VNM), the colored lines illustrate how the non-residential share of electricity consumption and log GDP per capita have changed between 1994 and 2014.

Table 1—Studies on the impacts of expanding access to electricity in developing countries

Country	Period	Type	Unit	Method(s)	Spillovers	Main impact(s)	Author(s) (year)
South Africa	1996-2001	Grid	Community	IV, FE	Yes	Female employment increases by 9 to 9.5 p.p. (IV); insignificant impacts on males	Dinkelman (2011)
Bangladesh	2005	Grid	Household	IV, PSM	No	Income increases by 12 to 24 percent; significant impacts on expenditures, school years, study hours	Khandker, Barnes, and Samad (2012)
India	1965-1984	Grid	State	IV	Yes	Manufacturing output increases by 14.7 p.p. (with 1 s.d. increase in number of rural connections) (IV)	Rud (2012)
Nicaragua	1998-2005	Grid	Household	IV	No	Female employment increases by 23 percent (IV); insignificant impacts on males	Grogan and Sadanand (2013)
Brazil	1960-2000	Grid	County	IV	Yes	Housing values increase by 6.8 percent (with 10 percent increase in electrification) (IV); significant impacts on HDI, income, literacy and school enrollment, poverty	Lipscomb, Mobarak, and Barham (2013)
El Salvador	2009-2013	Grid	Household	RCT	No	Time spent on education: 78 percent increase for school-age children (IV); Female employment: 46 p.p. increase (IV)	Barron and Torero (2014)*
India	2005	Grid	Household	IV	No	Income increases by 26 to 46 percent; significant impacts on labor supply, expenditures, school years, study hours	Khandker et al. (2014)
USA	1930-1940	Grid	County	FE	Yes	Total value of farm products sold, traded, or used increased by 4 percent; reduced long run declines in number of farms, farm output and land values	Kitchens and Fishback (2015)

(Table continued on next page)

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Country	Period	Type	Unit	Method(s)	Spillovers	Main impact(s)	Author(s) (year)
India	1982-1999	Grid	Household	IV, DD	Yes	Consumption increases by 8.4 p.p. (0.5 p.p. per annum) (IV)	van de Walle et al. (2015)
El Salvador	2010-2013	Grid	Household	RCT	No	Respiratory infections decrease by 34 p.p. for children under 6; exposure to $PM_{2.5}$ decreases by 33 to 60 percent (TOT)	Barron and Torero (2016)*
India	2001-2011	Grid	Village	RD	Yes	Reject even modest effects on labor markets, asset ownership, housing characteristics, village-wide outcomes	Burlig and Preonas (2016)*
Philippines	2003-2014	Grid	Household	IV	Yes	Income and expenditures increase by 42 and 38 percent, respectively (with arrival of electricity in village) (TOT); main channel is agricultural income	Chakravorty, Emerick, and Ravago (2016)*
Kenya	2013-2014	Solar lantern	Student	RCT	Yes	Math grades increase by 0.88 s.d. for treated students, and 0.22 s.d. for control students (with 10 percent increase in classroom treatment intensity) (ITT)	Hassan and Lucchino (2016)*

Notes: Summary of empirical findings on the impact of rural electrification on various outcomes. Sample includes both published articles and working papers, which are indicated with asterisks. Method(s) column summarizes the key identification strategy employed in the article, which ranges from instrumental variables (IV), fixed effects (FE), propensity score matching (PSM), difference-in-differences (DD), randomized control trial (RCT), and regression discontinuity (RD). TOT and ITT refer to treatment-on-the-treated and intention-to-treat estimates, respectively. Findings are as reported in the paper cited in the rightmost column.

Table 2—Timing and intensity of electrification initiatives evaluated in studies accounting for spillovers

Country	Program	Details	Period	Intensity	Author(s) (year)
South Africa	National Electrification Programme (NEP)	NEP targeted electrification of 300,000 low-income households annually from 1995 onwards	5 years	Electrification: Increased by 25 percent	Dinkelman (2011)
India	None	Adoption of new agricultural technologies during Green Revolution created demand for electricity to power irrigation	19 years	Ag. connections (per 1000): Increased by 8 connections	Rud (2012)
Brazil	None	During 1960s and 1970s, increasing number of isolated power generators expanded access to electricity	40 years	Transmission network: 8.9 percent annual growth, from 1950 to 2000	Lipscomb, Mobarak, and Barham (2013)
USA	Rural Electrification Administration (REA)	Between 1935 and 1939, REA issued loans (worth 0.3 percent of GDP) to newly formed cooperatives and existing utilities to extend power grid to rural farms	4 years	Rural farm electrification: Increased by 230 percent, from 1930-1940	Kitchens and Fishback (2015)
India	None	None	17 years	Electrification: 2.8 percent annual growth in rural areas	van de Walle et al. (2015)
India	Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY)	RGGVY (i.e., "Prime Minister's Rural Electrification Program") was launched in 2005 to expand electricity access to over 400,000 rural Indian villages in 27 states	6 years	Electrification: Increased by 50 percent for RGGVY eligible households	Burlig and Preonas (2016)*
Philippines	Barangay Electrification Program	In 2003, government officially shifted focus to electrifying last ten percent of unelectrified villages	11 years	Electrification: Increased from roughly 73 to 84 percent	Chakravorty, Emerick, and Ravago (2016)*

Notes: Descriptions of electrification initiatives evaluated in spillover studies summarized in Table 1. Sample includes both published articles and working papers, which are indicated with asterisks. Paper is cited in the rightmost column.

Table 3—Descriptions of instruments utilized in studies employing IV techniques

Country	Period	Endogenous variable	Instrument(s)	Author(s) (year)
South Africa	1996-2001	Community electrification	Average community land gradient	Dinkelman (2011)
Bangladesh	2005	Household electrification	Indicator for whether household is located in electrified village and is less than 100 feet from an electricity line	Khandker, Barnes, and Samad (2012)
India	1965-1984	State electrification	Availability of groundwater	Rud (2012)
Nicaragua	1998-2005	Household electrification	Municipal population density in 1971 and the mean slope land gradient in the municipality	Grogan and Sadanand (2013)
Brazil	1960-2000	County electrification	Counterfactual electricity network (based on network simulation that minimizes costs and uses as inputs geographic characteristics and the national budget)	Lipscomb, Mobarak, and Barham (2013)
India	2005	Household electrification	Proportion of village households with electricity and its interactions with various household characteristics (including age and gender of household head, highest education among males and females, and household agricultural land)	Khandker et al. (2014)
India	1982-1999	Household electrification	Distances to nearest power plant in 1965 and 1975, and household connection status in 1982	van de Walle et al. (2015)
Philippines	2003-2014	Arrival of electricitiy in village	Projected expansion of grid to last 10 percent of villages (assuming villages nearest to electricity network are connected first)	Chakravorty, Emerick, and Ravago (2016)*

Notes: Descriptions of instruments utilized in IV studies listed in Table 1. Sample includes both published articles and working papers, which are indicated with asterisks. Instruments are as reported in the paper cited in the rightmost column.

Appendix Table A1—Ongoing RCTs on the impacts of expanding access to electricity (AEA RCT Registry, as of December 31, 2016)

Country	Start date	Intervention(s)	Unit	Treatment	Main outcomes	Author(s) (trial no.)
India	2013	Solar microgrids	Household	Village	Price elasticity of demand, energy expenditures, health and education, mobile phone use, time use	Burgess et al. (#0000132)
Kenya	2014	Grid connections	Household	Community	Energy consumption, household structure, productivity and wealth, consumption, health and wellbeing, education, social and political attitudes, community outcomes	Lee, Miguel, and Wolfram (#0000350)
Tanzania	2015	Solar lanterns	Student / household	School	Reading ability, household income, income generating activities, time use	Aevarsdottir, Barton, and Bold (#0000989)
Kenya	2015	Solar lanterns	Student / household	Student	Education, health, happiness and depression, kerosene and lighting	Rom (#0000912)
Senegal	2016	Solar lanterns, through mass media campaign	Household	Household and village	Investment, Demand, Awareness, Understanding, Productive time use, ALRI, Fuel replacement	Coville, Orozco, and Reichert (#0000977)
Tanzania	2016	Solar systems, textbooks, videos, scholarships	Student	School	9th and 11th grade national examination scores, other self-reported measures of effort	Greenstone and Seo (#0001072)
Argentina	2016	Solar home systems, capacity trainings, tariff subsidy levels	Household	Community or group of communities	Household production, income, health, education, social capital, security, migration, energy use, expenditures, credit	Flory, List, and Reichert (#0000971)

Notes: Includes all relevant and ongoing trials registered on the AEA RCT Registry as of December 31, 2016. Completed trials with publications or working papers in circulation are excluded from this list. We also exclude trial #0000842, which appears to be a duplicate of trial #0001072.