Can Mass Electrification (Still) Cause Structural Change?

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Abstract

Despite its ubiquity in high income countries among households and in most industries, evidence is mixed for the socioeconomic impacts of electrification in low and middle income countries. Can mass electrification today still induce changes in productivity, labor allocation, and incomes which are associated with structural change, as it seems to have in the past? In this paper we discuss current evidence and directions for future research.

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1 Introduction

Electricity is used by households and by firms in virtually every major industry and is a core input into modern consumption, leisure, and production. Electricity is so fundamental an input that output growth can be tracked by nighttime lights produced by electric lightbulbs (Henderson, Storeygard, & Weil, 2012). It is intuitive, then, that structural transformation and the transition to modern economic growth are tightly linked to increasing access and usage of electricity both across and within countries (e.g. Lee, Miguel, & Wolfram, 2020; Lewis & Severnini, 2020, respectively). The link between electricity and economic development has also resonated strongly with policymakers, who are investing public resources into rapidly expanding electricity access. Examples include Kenya's Last Mile Connectivity Project which aims to provide universal electricity access for Kenyans by 2030, and Ethiopia's National Electrification Program which aims for universal electricity access by 2025.

Although associations between economic development, structural change, and electrification are not necessarily causal, they are supported by a large quasi-experimental literature aimed at estimating the causal impact of electrification on outcomes such as income and sector of employment. While results vary from country to country and between different quasi-experimental approaches, the findings of this literature are broadly consistent with electricity leading to higher incomes (Lipscomb, Mobarak, & Barham, 2013; Moretti, 2014), higher employment and human capital particularly for women (Dinkelman, 2011; Gaggl et al., 2019; Vidart, 2022), rural productivity (Kitchens & Fishback, 2015), and higher industrial output (Kassem, 2021; Rud, 2012), all of which are hallmarks of structural change.

More recent work conducting well-identified evaluations of electrification in policy-relevant settings, however, has found negligible effects on economic outcomes, with little indication that electricity changed key outcomes associated with structural change, including income, labor market behaviors, or education. These results are reinforced by the fact that household demand and willingness-to-pay for electricity is measured to be very low, consistent with the idea that the benefits are small.

Taken together, these results present a puzzle. If access to electricity does not substantially change household behavior, how can electrification be a driver of structural change? Resolving this tension is crucial to expanding our understanding of how structural change and electrification interact. This is also critical for policy, with USD 3.6 billion spent annually on electrification from 2000 through 2014 justified by its socioeconomic impacts (World Bank 2015). Our goal in this paper is to synthesize the existing literature and identify productive paths for future research aimed at improving our understanding.

In Section 2 below, we take stock of what is known about the relationship between electrification and structural change. We begin by summarizing some key cross-country facts about the relationship between electrification and GDP. As is well-known, there is a strong relationship between access to electricity and output. In addition to this, we document a strong cross-country relationship in electrical connection quality (as measured by frequency and duration of outages for firms) and output. The large variation in connection quality between rich and poor countries suggests that connection quality may be as important as access in driving structural change. We also compare the cross-country relationship between access to electricity and output to the historical relationship within the United States and United Kingdom and show that the cross-country relationship is substantially "flatter" than these historic relationships; countries today have much higher electrification rates for any given level of development. We will return to both of these facts later when we discuss productive research paths forward.

Next, we discuss the empirical microeconomic literature on the impacts of electrification. We conduct a brief literature review and show that there is substantial variation in the estimated effects of electrification on economic development across the literature. A closer examination of the literature reveals that the large variance of estimated effects seems explainable, at least in part, based on the characteristics of the episode of electrification being studied. Papers that examine older historic episodes of electrification, such as those in the United States, Brazil, and certain India states, tend to find larger effects while those studying more recent episodes find small effects. Similarly, studies of large-scale electrification initiatives with large units of analysis such as states or regions tend to find larger effects than those that examine small-scale initiatives targeted at households or villages. Of course, these patterns are only suggestive, driven by a small set of recent studies finding null results, and possibly conflating heterogeneous effects across settings with possible identification issues or publication bias. Further studies of electrification at various scales in various time periods would be highly valuable in confirming these trends. Notably, there are very few studies (that we are aware of) of electrification in the East and Southeast Asia regions. Such studies would be particularly valuable as these countries cover a wide range of income levels and many have achieved universal electrification in recent decades during times of rapid economic change.

Having documented some cross-country facts and established some stylized facts in the quasi-experimental literature, we spend the rest of the paper discussing promising avenues for future research into the impact of electrification on structural change. We focus in particular on potential mechanisms that can rationalize the large role of electricity as a historical driver of structural change with the small impacts measured in more recent studies of last-mile electrification.

We identify three types of mechanisms, each of which represents a productive path for future research, and we discuss briefly the work related to each mechanism. First, electricity reliability and quality may be as important as electricity access in driving structural change. If electricity drives structural change by enabling the use of electrified industrial machines, poor quality connections that provide little power and are frequently unusable may not be sufficient to induce industrialization. Future research can better examine the importance of improved electricity quality (e.g. for firms in different sectors and for households) and economic and political barriers to achieving improved quality. Second, investment in electrical infrastructure may be strongly complementary to other types of investments. For example, improved public infrastructure, such as roads and ports, may enhance the impacts of electrification, which may justify "big push" style programs. Relatedly, electricity as an input to production may be strongly complementary to investments in physical capital (e.g. electrical appliances and machinery) and human capital (e.g. additional schooling). It's possible that electricity may have low returns in the poorest regions that possess very little capital and have low levels of education. Future research can productively document key areas of complementarity and barriers that may cause underinvestment. Third, electrification at scale may have important features such as agglomeration, migration, and selection of locales into electrification that can help explain why smaller-scale improvements in electricity infrastructure in a partially electrified region could have limited impacts.

In the final section of the paper, we conclude with a brief summary of what we have discussed and highlight the importance of a multitude of research approaches–including experimental and quasi-experimental approaches and general equilibrium macroeconomic modeling–to address these key questions and further our understanding of the relationship between electrification and structural change.

2 What Do We Know About Electrification?

In this section, we consider what is known about the relationship between electrification and structural change. We first present some simple cross-country facts about electrification and income. Next, we discuss experimental and quasi-experimental studies on the effects of electrification. Rather than a comprehensive literature review (which is accomplished by Van de Walle et al., 2015), we aim to provide a representative summary capturing the broad findings of the literature.

2.1 Key Cross-Country Facts

We begin by summarizing some cross-country and historic facts on the relationship electrification and development. These are descriptive and not causal in nature, and we view these as the key facts that any macroeconomic theory of structural change and electrification must be able to replicate. They also provide a lens through which we can interpret the discussion of experimental and quasi-experimental studies in subsection 2.2 and motivation for our suggested paths forward for future research.

Unsurprisingly, cross-country data document a strong negative relationship between GDP per capita and access to electricity. Figure 1 plots the proportion of the population with access to electricity (taken from World Bank's World Development Indicators) against GDP per capita for the year 2018 (in black). Although there is little variation in the top half of the income distribution, where all countries have essentially universal access to electricity, the bottom half of the distribution exhibits a strong, albeit noisy, positive relationship.

More interestingly, Figure 1 also plots (in red) the historic relationship between GDP per capita (as estimated by the Maddison project) and electricity access in the United States (taken from the Census's *Historical Statistics of the United States, Colonial Times to 1957*) starting in 1907 when only 8 percent of the population had access to electricity and continuing until 1957 when the US achieved near-universal electricity access of 99 percent. The pattern is striking as the slope of this line is substantially steeper than that of the cross-country relationship. The interpretation of the

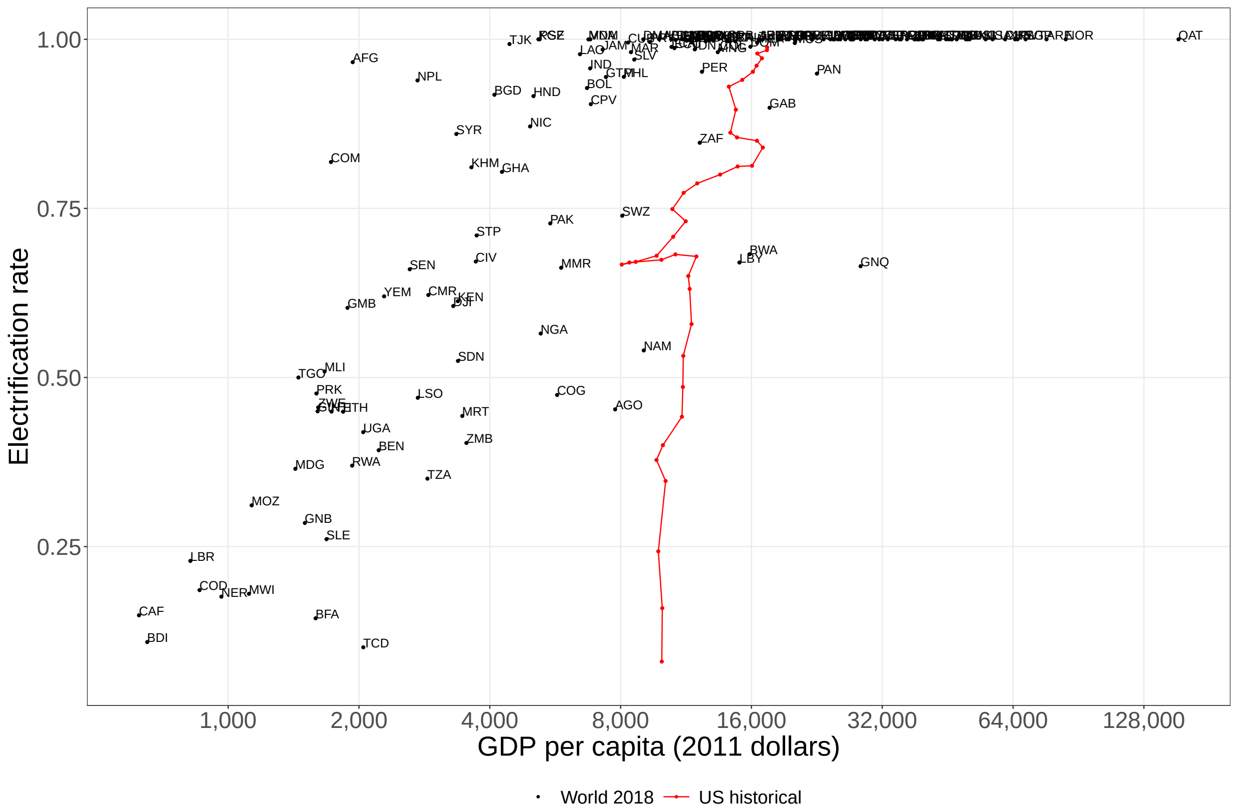

Figure 1: Relationship between GDP and Electricity Access

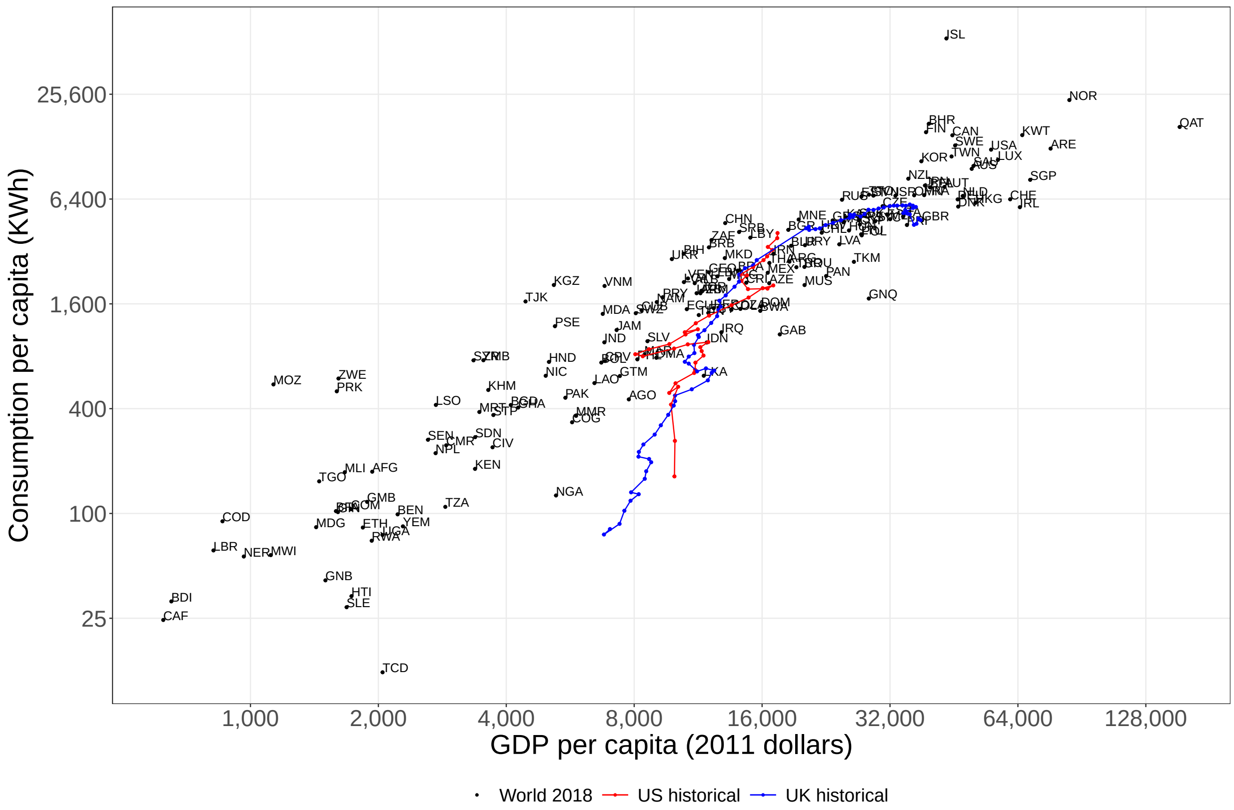

Figure 2: Relationship between GDP and Electricity Consumption

steep red line is straightforward; although only 8 percent of the US had access to electricity in 1907, the vast majority of countries today with GDP per capita comparable to the 1907 US exhibit universal or near-universal access.

We can perform a similar analysis by looking at electricity usage, rather than electricity access. Figure 2 does this by plotting electricity consumption per capita (from the US Energy Information Administration) against GDP per capita for various countries. As in Figure 1, the relationship is positive and strong. Historical energy consumption in the US from 1907-1957 is plotted by the red line (this choice of years makes the red lines in Figures 1 and 2 directly comparable). The blue line plots the same for the United Kingdom over a longer time horizon from 1920 to 2017 (data taken from the *Digest of United Kingdom Energy Statistics*). The overall story is similar to the previous figure; modern countries with GDP per capita comparable to the historic US or UK consume substantially more electricity (note that electricity consumption follows a log scale) than either country did at that level of GDP.

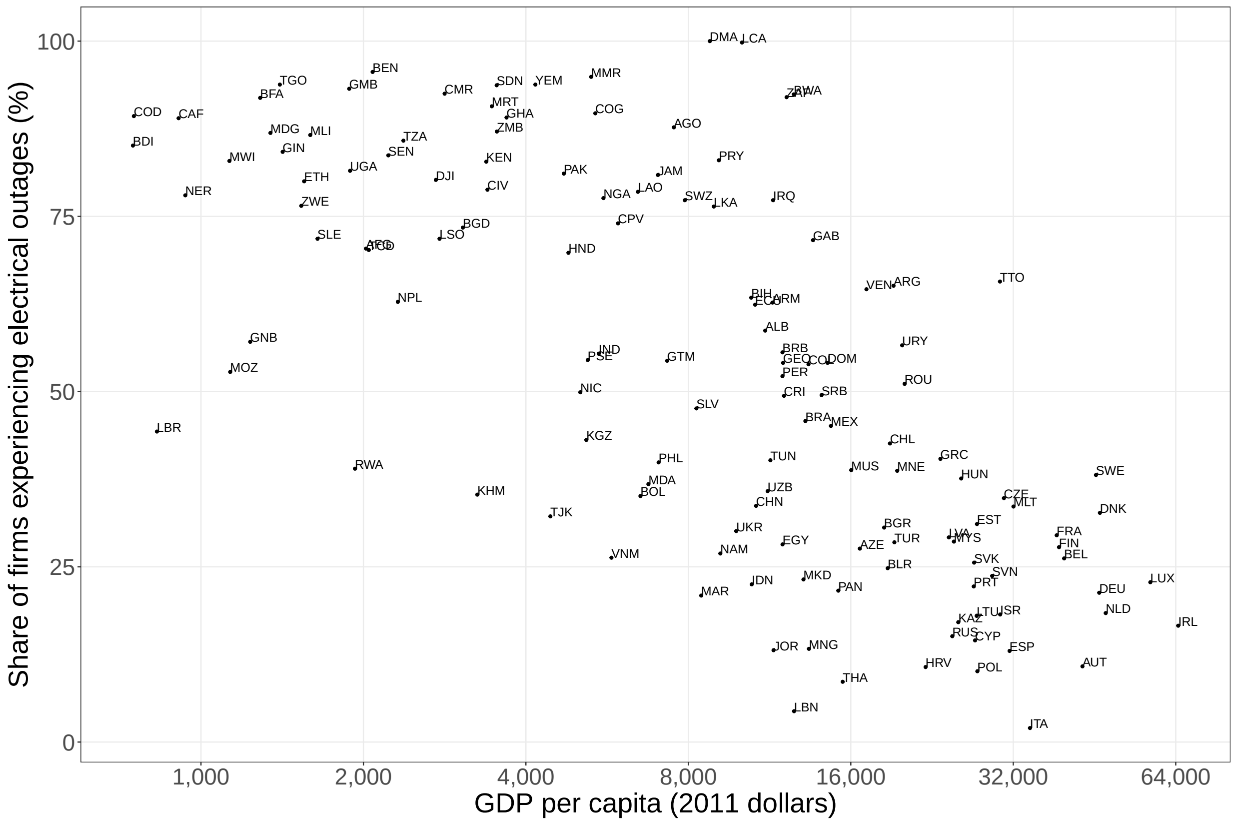

Figure 3: Relationship between GDP and Electricity Consumption

One notable difference between Figure 2 and the previous figure is that the difference between the US time series and the cross-country relationship vanishes much quicker when looking at consumption. In particular, although the 1907 US starts at substantially lower electricity consumption than a modern country with the same GDP per capita, by the 1930s the difference in consumption between the United States and modern countries with comparable levels of GDP is minimal. The story is somewhat different for the UK which lags behind the US on energy consumption per capita and does not reach the consumption level of a modern country with the same GDP per capita until the 1950s, although this difference is hard to interpret without reliable data on electricity access in the UK for the same time period.

In addition to access and usage, there is also substantial cross-country variation in the reliability and availability of electricity. Figure 3 displays how the percentage of firms who self-report ever experiencing electricity outages varies with GDP per capita. These data are taken from the World Bank Enterprise Surveys (WBES) which span a variety of years, differing from country to country.

For all countries possible, we use GDP per capita data from the year in which the enterprise survey took place, ranging from 2006 to 2018. Figure 3 displays a clear pattern; electricity is available much less reliably in poor countries. The variation is substantial. In many of the poorest countries, unreliable electricity is nearly universal with around 90 percent of firms reporting that they experience electrical outages. This number falls below 25 percent for the richest countries.

Although purely observational, these facts provide motivation for further research on the role of electricity in driving structural transformation. They also provide some basic stylized facts against which to test macroeconomic models of structural change incorporating electrification. One broad takeaway from Figures 1 and 2 is that the modern experience of electrification and structural change may be substantially different from the historical experience, at least for the US and UK. These historical episodes of rapid electrification seemed to have occurred when these countries were fairly rich relative to not-fully-electrified countries today. This difference may be key in explaining the contrast in results between evaluations of electrification using historical episodes and data and those examining modern interventions in developing countries.

2.2 Quasi-Experimental and Experimental Evidence

While the previous subsection focused on summarizing motivating cross-country facts without regard for causality, there is a moderate and growing literature using experimental and quasi-experimental techniques to evaluate the causal effect of electrification. Our discussion is not exhaustive and instead aims to provide a concise and accurate summary of the broad findings of the literature.

The earliest papers to investigate the causal effect of electrification on development outcomes largely exploited mass roll-outs of electrical infrastructure and electricity to households by government infrastructure projects. Broadly speaking, many of these papers address endogeneity concerns using a "least cost" instrumental variables strategy. Geographic features such as hills, mountains, and rivers all influence how much it costs to bring electricity to a particular area but are plausibly exogenous to demand-side concerns. As such, the predicted cost of electrification for an area constructed only from the surrounding geography serves as a plausible instrument for whether the area is connected to the electrical grid.

Two prominent early papers among these are Dinkelman (2011) and Lipscomb, Mobarak, and Barham (2013) which employ a least-cost IV identification strategy in South Africa and Brazil respectively. Both papers find results consistent with electrification inducing structural change. Dinkelman (2011) finds increases in earnings, hours worked, and female employment while Lipscomb, Mobarak, and Barham (2013) find increases in income, education, and formal employment. The most direct evidence for the link between electricity and structural change comes from Rud (2012) who uses data from India and finds that electricity increases manufacturing output.

Other papers employing a similar approach find similar results. Chakravorty, Emerick, and Ravago (2016) find that electrification lead to large increase in income in the Philippines (although unlike the previous studies they find no impact on employment, with gains driven by agricultural income). In a similar vein as Rud (2012), Kassem (2021) finds that electricity access increases the number of manufacturing firms, workers, and manufacturing output in Indonesia. Grogan (2016), Grogan and Sadanand (2013), and Salmon and Tanguy (2016) all find that electrification increases female employment.

While the unit of observation varies from study to study, ranging from individuals to entire counties, it's important to note that a least-cost instrumental variable design based on geography generally exploits high-level variation in electrification. If geography makes it costly to bring electricity to one individual, it is also costly to bring electricity to their neighbor. Thus we view all of these studies as measuring the effect of electrification "at scale", which may differ from the effect of providing electricity to only a few households or villages in an area. We will return to potential implications of this in Section 3.

A similar strand of literature uses geographic or temporal variation in the roll out of electricity to measure the impacts of electrification in a differences-in-difference or natural experiment framework. Like the least-cost IV studies, we view these papers as estimating the causal effect of electrification at a large scale. Unlike the IV literature, these papers establish causality either through a naturally occurring control group and plausibly exogenous variation in which areas are chosen to receive electricity (as in the natural experiment literature) or through a parallel trends assumption which facilitates comparisons between the treatment and control even if assignment to treatment is not random (as in the Differences-in-Differences literature).

Prominent among these studies is Moretti (2014) which examines the Tennessee Valley Authority as a natural experiment (using proposed but failed authorities as controls) that built electricity infrastructure (along with other infrastructure investments) and provided of electricity to a specific region of the United States. They find that the program effectively induced structural change in the long-run, raising aggregate income and manufacturing employment permanently. Similarly, Lewis and Severnini (2020) study the roll out of the power grid in the United States and find that electricity boosted incomes in remote rural areas and led to (sub)urbanization in rural areas near cities. Also in the United States, Vidart (2022) finds that electrification led to substantial increases in female labor supply and human capital.

Other papers employ difference-in-difference designs outside the US. Van de Walle et al. (2015) find that gaining electricity access increased consumption and employment in rural India. Khandker, Barnes, and Samad (2013) study Vietnam and find that being connected to the grid increases household income and education. Finally, Dasso and Fernandez (2015) find that electrification in Peru increased employment, female earnings, and the probability of engaging in non-agricultural work for females.

Excepting Moretti (2014) which takes the form of a natural experiment, our discussion of the causal effects of electrification has been limited only to studies employing instrumental variable or difference-in-difference techniques. In recent years, researchers have turned to experimental approaches to more precisely investigate the effects of electrification. We focus on Lee, Miguel, and Wolfram (2020), who experimentally evaluate the effects of providing a grid connection to unconnected households in rural Kenya, as well as experimentally varying the cost of electricity to households in order estimate demand curves. Unlike the papers above, they find very limited economics impacts of electrification and nothing consistent with the idea of electricity as a driver of structural change. Although being connected to the grid does seem to change household behavior (they spend less on kerosene and are more likely to own appliances), there is no change in economic behavior. Households neither earn nor consume more, are no more likely to be employed or operate a business, and do not experience any gains in physical health or human capital (but do report higher life satisfaction). Altogether, these results seem to suggest that, at least for modern developing countries, electricity does not seem to have large effects, casting doubt on the idea that it can play a driving role in structural transformation.

One notable paper missing from our discussion so far is Burlig and Preonas (2021). Although not a randomized controlled trial, they estimate the effect of village-level electrification in rural India using a regression discontinuity. Like Lee, Miguel, and Wolfram (2020), they find almost no effect of electricity on economic outcomes (on average); electrified villages experience no change in average consumption or earnings, agricultural or non-agricultural employment, number of firms, or human capital. We defer further discussion of this paper to the next section.

Overall, despite a strong intuitive link between electricity and structural change, the evidence for such a relationship seems unclear. Cross-country relationships and historical episodes of development make it clear that the two happen in tandem in the aggregate. Quasi-experimental evaluations of these historical episodes support a causal interpretation of the link, namely that access to and expansion of electricity leads to structural change. However, recent rigorous evaluations call this link into question by failing to find any impact of electrification on economic outcomes for households or villages. These conflicting results serve as a starting point for our next section where we discuss promising paths for future research.

3 Promising Paths for Future Research

In this section, we lay out open questions about the relationship between electrification, economic growth, and structural change. We view these questions through the lens of the conflicting results found in the previous section, operating under the assumption that these studies, generally speaking, accurately identify the impacts of electrification (i.e. they are not the result of publication bias or misidentification) and discuss questions whose answers may be able to reconcile the conflicting results. We identify three broad paths forward, each of which has some preliminary research suggesting that they are important. We also discuss recent research into each path and suggest how each research agenda could be pushed forward.

3.1 Electricity reliability

Electricity reliability may be as important as electricity access in causing structural transformation. As documented in Figure 3, gaps between lower income and higher income countries are stark not only for electricity access but also for electricity reliability. If the link between structural change and electrification is driven primarily by the use of electricity-intensive production machinery, then unreliable connections that experience regular outages, unstable voltage, or insufficient power to operate such machines may rationalize the small experimentally estimated effects of being provided a grid connection. Consistent with this, data from the World Bank Enterprise Survey indicates that firms frequently perceive unreliable electricity as a key constraint (McCulloch & Zileviciute, 2017), and household surveys have found that households are willing to pay more for more reliable electricity (Alberini, Steinbuks, & Timilsina, 2022; Deutschmann, Postepska, & Sarr, 2021). In this section, we discuss two sets of questions related to electricity reliability. First, how important is reliable electricity for outcomes associated with structural change? Second, what causes poor reliability and what policies can help? Better understanding both the consequences of improving reliability and the root causes is important for policy. The answers may influence how policymakers may wish to optimize investments to improve the grid (e.g. extending the grid and creating new customer connections versus improving the quality of the existing grid) and how to prioritize power supply when capacity is insufficient to supply all sources of demand.

3.1.1 How important is improved electricity reliability?

Fried and Lagakos (2021) explore this channel in quantitative macroeconomic model of electricity production and usage. Central to their analysis is the point that even if microeconomic estimates of the effects of electricity shortages are small (as in e.g. Allcott, Collard-Wexler, and O'Connell, 2016; Cole et al., 2018; Fisher-Vanden, Mansur, and Wang, 2015) the general equilibrium macroeconomic effects can be large. The core mechanism is that unreliable electricity substantially reduces firms' incentives to invest in electricity-complementing capital; even relatively short outages require idling electrified machinery, leading to under-investment.

This research suggests that the link between electricity reliability and investment and long-run firm output is potentially large. Work aimed at confirming and quantifying this link causally is a promising path forward in and of itself and would be extremely useful in providing quantitative discipline to future models. Exploiting a permanent change in electricity reliability is key to accurate measurement of these effects as investment is forward looking and beliefs about future reliability are the key driver of investment decisions in the current period. Similarly, measuring outcomes at a sufficiently long follow-up time is important as the capital stock is a slow-moving object, particularly in developing countries where financial frictions are severe. More broadly, future research could further investigate which aspects of grid reliability are most important in increasing electricity usage. Are shorter more frequent outages preferable to longer but less frequent ones? Do voltage surges play a key role? Do outages matter for firms more than households? The answers to these question are unclear but would suggest immediate actions for policy makers to mitigate the consequences of unreliable grid power. In this vein, the only study we are aware of is Meeks et al. (2021) which finds that elimination of household voltage surges (through the installation of smart meters) increases household appliance purchases and usage.

A related channel is that the productivity of many uses of electricity many be non-linear in electricity reliability. By this, we mean that some machines would more than double their usefulness if electricity reliability increased from 50 percent to 100 percent. As a simple example, a fridge is substantially more useful if electricity is fully reliable as any outage risks spoiling the contents of the fridge – perhaps a minor issue in the case of food but a large issue in other cases, such as storage of vaccines and medical supplies. Other examples include incubators of premature newborns, food preservers (e.g. electric dryers), or electric irrigation pumps (unwatered crops may die) Unlike a piece of production machinery, such as a thickness planer used for producing wood products such as doors (as in Bassi et al., 2022), which would be half as productive on average if electricity was only available half of the time, these machines and many others may be entirely unfeasible for certain uses if electricity is sufficiently unreliable. Research, either empirical or structural, on this phenomenon is scant and could prove a promising path.

In addition to this work, more macro work exploring and quantifying the potential link between electricity reliability and macroeconomic outcomes is necessary. Unreliable electricity may reduce incentives to invest (or ability) to invest in human capital, similar to the effect for physical capital described in Fried and Lagakos (2021). If incumbent firms receive preferential access to rationed electricity – either through straightforward political preference or through Special Economic Zones – this creates a wedge in the cost of using electricity that can lead to misallocation of the Hsieh and Klenow (2009) variety. In a similar vein, recent work finds that the impact of electrical outages depends on firm size with microenterprises (i.e. those without employees) experiencing large reductions in output and large firms experiencing small, if any, decline (Hardy & McCasland, 2021). Such heterogeneity would also have implications for how unreliable grid power interacts with misallocation and aggregate output.

3.1.2 What explains poor reliability, and what policies may help?

While research into the effects of unreliable grid electricity is important, equally important is improving our understanding of the fundamental reasons for poor reliability and what can be done to improve reliability. From a technical standpoint, poor reliability can arise for two reasons. First, demand may exceed supply. Second, even if generation capacity is sufficient to meet demand, failure in transmission between generation and the end-user can cause low quality power supply. While both types of problems have technical explanations which may relate to underinvestment and insufficient or substandard grid infrastructure, recent research suggests that poor grid reliability may be thought of as a political economy problem arising from limited state capacity and policy choices to pursue lower-price-lower-reliability service.

One body of related literature focuses on how limited accountability can lead to low-quality public service provision. This is relevant to electrification, as the national electricity utility is heavily subject to government regulation, if not state controlled, in many countries. Given well-understood technical specifications for electricity transmission, the immediate causes for chronically poor electricity reliability is expected to be closely related to enforcement of existing regulations and specifications for infrastructure construction and management. If poor accountability allows corruption to divert funds away from their intended activites, this can cause poor quality services. Some work has shown that lack of observability in the provision of public goods and services can causes poor quality public goods (Ferraz & Finan, 2008, 2011; Olken, 2007). This is suggestive that in the context of electrification, improving transparency may similarly help improve power quality. These types of policy solutions may also help address concerns that electoral incentives may skew the allocation of public goods (Briggs, 2021; Burgess et al., 2015; Harris & Posner, 2019). Future research could usefully examine the relative importance of these causes of poor reliability, and examine what policies can improve accountability and service delivery. For example, improved transparency could improve service quality through electoral accountability. On the other hand, improved transparency could also be seen as improving state capacity, say by allowing managers to better monitor workers or allowing law enforcement agents to better monitor utility actions.

Another direction of research focuses on how political constraints that cause low prices for electricity may explain poor reliability. Burgess et al. (2020a) present evidence that subsidies to household electricity prices – either explicitly or implicitly through tolerance of non-payment (an issue which we will further discuss) – lead to losses for public electricity distributors and that distributors respond by rationing power. The result is unreliable grid electricity from frequent outages due to rationing. Other research supports this explanation; for example, Kabir Malik and Singh (2015) finds that the unbundling of State Electricity Boards in India lead to an increase in capacity utilization, suggesting that plants were previously idling capacity rather than failing to supply electricity due to capacity constraints.

The key political difficulty is that free or heavily subsidized electricity is a common and popular stance. Huenteler et al. (2020) document that in many lower-income settings, electricity is priced below cost. This may be due to the acceptance of the idea that electricity is a human right (as suggested by Burgess et al., 2020a) or could simply be due to the fact that households in developing countries enjoy the amenities of home electricity (e.g. phone chargers, light bulbs, and television) but cannot pay unsubsidized rates. In other words, unreliable but affordable electricity may simply be preferable (in partial equilibrium) to reliable, expensive electricity for voters. Beyond low officially sanctioned prices, de facto prices may be even lower due to acceptance of non-payment. For example, Mahadevan (2019) and Min and Golden (2014) find patterns that suggest politicians in India successfully take actions such as manipulating billing data to provide free electricity for political gain.

The political economy problem is made worse by the fact that the reliability of the electricity grid unsurprisingly appears to be a big determinant of demand for electricity and political support for higher electricity prices. In essence, people are unwilling to pay higher prices for unreliable electricity – or support local leaders who advocate for this – which leads to revenue shortfalls for public utility providers who then must ration power to control losses (as discussed above) which leads to unreliable grid power, a so-called "renvune trap". Dzansi et al. (2018) document this cycle in Ghana; households exposed to more power outages are more likely to have unpaid electricity bills. Similarly, Khanna and Rowe (2020) find that non-payment rates increase substantially in response to higher electricity prices in India.

If these forces are sufficiently strong (i.e. enough to induce multiple equilibria), temporarily accepting higher losses may be enough to break public utilities out of this revenue trap or at least reduce losses even in the long term. This notion is strengthen by the fact that improved electricity reliability can lead to large increases in investment and output, suggested in Fried and Lagakos (2021), as higher long-run output can be taxed and these funds can be used to further escape the revenue trap and/or pay off debt accrued while running the utility at a loss. Together, these factors suggest that carefully crafted policy may make it possible to escape a revenue trap at relatively little cost (in present discounted values terms) and accelerate the process of structural change. Further research into these issues, both macroeconomic analysis of such a policy and microeconomic research investigating the presence and strength of a revenue trap, seems a productive path.

These political economy problems may also be partially addressed by technological solutions, through advancements that make revenue recovery more effective and reliable. Prepaid electricity meters, which must be loaded with credits, dramatically increases repayment rates and decreases the cost of revenue recovery (Jack & Smith, 2020). Home solar systems, financed over time, may also be a solution as these systems operate entirely off grid (see e.g. Lang, 2020); however, it's important to note that even in the presence of off-grid solar, there are still many household who benefit from gaining access to grid power (Burgess et al., 2020b). Carranza and Meeks (2021) examines how load-reduction from adoption of energy-efficient appliances may improve electricity quality. Other work (Gonzales, Ito, & Reguant, 2022; Jha, Preonas, & Burlig, 2022; Ryan, 2021) examines how investments in transmission lines could promote within-country trade in electricity, influencing the price and quality of electricity that utilities make available. On another note, it is possible that other policies such as threat of consequences for non-payment or targeted messaging can be effective in changing payment norms (Coville et al., 2020; Pomeranz, 2015). Meanwhile, to the extent that much of the reason de facto prices are too low is that electricity is stolen or bills are manipulated fraudulently for political gain, that is suggestive that improved monitoring and strengthened sources of accountability may help counter dynamics that lead to lower-prices and lower-quality electricity.

3.2 Complementary inputs

Electricity may be necessary for structural transformation, but its effects are likely to depend on additional investments or inputs. In this section we discuss possible complementarities between electrification and public investments, such as roads and ports. Such investments may influence the returns to using electricity by improving market access. We also discuss complementarities with private investments, such as electrical equipment, as returns to electrification may depend heavily on the presence of these complementary inputs. In the case of private investments, it is also useful to examine what constraints may lead private actors to underinvest, and what kinds of policies can help counteract those constraints. Developing better answers to these questions can be important for policymakers –electrification efforts may be targeted differently based on the presence of key complementary inputs or bundled with complementary programs.

3.2.1 To what extent are complementary public investments important?

"Big push" infrastructure projects that invest heavily in electrification tend to also invest heavily in other infrastructure. If there are complementarities between electricity and other infrastructure, the effects of such a project could be larger than the effects of electrification alone. This could explain why evaluations of large-scale projects have measured links between electrification and structural change while individual-level experiments have not.

Early work along these lines suggests that electricity may have large complementarities with other infrastructure. Moneke (2020) studies the expansion of the electricity network and road network in Ethiopia and finds dramatic increases in manufacturing employment as well as various measures of income (e.g. household expenditures, durable ownership, and nightlights) for areas that receive an expansion of both. Although the focus on the paper is on the effects of roads with and without electricity rather than the other way around, this is suggestive evidence that the effects of "big push" investments may be large. Improved roads may facilitate market access for outputs produced by firms using electricity. They may also lower the cost of constructing and maintaining electricity infrastructure.

Further work examining the complementarities between electricity investment and other infrastructure would help shed more light on this question. In addition to roads, governments often make large investments into ports, railways, and water supply and knowing how electricity interacts with these other investments can help policymakers prioritize and target investments to have the largest effect on growth.

In additional to physical public infrastructure, the effects of electrification may depend heavily on the level of financial infrastructure. Although micro-credit initiatives have been expanding rapidly, it is well known that households and firms in developing countries face substantial financial frictions. The effects of electrification may depend on these frictions. For example, if electricity is provided to firms but firms are unable to finance electricity-using machinery, the effects may be limited. Similarly, if newly electrified smallholder farmers are unable to finance new equipment (e.g. electric dryers, pumps, or grain mills), the effects may be limited.

As far as we know, there is no research into the interaction of electrification and financial frictions at either a household or a firm level on macroeconomic outcomes such as structural change. This is likely due to the computational difficultly of solving multiple-asset models – as would arise when talking about electrically powered capital and non-electrically powered capital or household savings and electricity-using durable goods – in the presence of credit constraints. However, increases in computing power as well as recent computational techniques (e.g. Auclert et al., 2021, particularly Appendix E) mean that such models can now be solved fairly easily on a typical laptop. Additionally, the emergence of canonical models of financial frictions, microenterprise, and development (e.g. Buera, Kaboski, & Shin, 2011; Itskhoki & Moll, 2019) provide a strong framework upon which to build models that study how the interaction of financial frictions and electrification impact development outcomes. Empirical work on these interactions would also be extremely useful, both for its own sake and also to provide motivation and discipline to such models.

3.2.2 To what extent are complementary private investments important?

While complementarities with public infrastructure may be important, electricity is also complementary to private investments – for example physical capital (e.g. electrical appliances and machinery) and human capital (e.g. the skills necessary to operate and maintain complex electric machines). If electricity is provided but physical and human capital are in short supply, the full gains and structural change may not be realized. Recall Figure 1 which showed that as the United States expanded access to electricity, its GDP per capita was sufficiently high that most countries of similar GDP per capita today have nearly universal electricity access. In other words, modern evaluations of electrification are necessarily studying poorer countries than historic evaluations. Rich countries possess more physical and human capital than poor counties (Hsieh & Klenow, 2010) and if electricity is strongly complementary to both of these, it's possible that the returns to electricity in these countries are simply smaller than the returns evaluated in historic analyses.

Direct evidence on the complementary of electricity with other inputs is scarce and more research here would be useful. Ryan (2018) uses experimental assignment of energy consulting, which boosted energy efficiency, to Indian manufacturing firms to estimate a production function and finds that capital and high-skill labor are strongly complementary with electricity (while low-skilled labor and intermediates are substitutes). Vidart (2022) builds an OLG model and finds, among other things, evidence consistent with a skill-bias in electricity.

Relatedly, future research can usefully identify barriers to optimal levels of private investment. As a technology that is useful only in combination with electrical equipment and appropriate building wiring, any inefficiencies affecting these complementary goods can affect expected benefits of using electricity. For example, low levels of investment in electrical equipment by households and firms may be affected by poor access to credit or low income, or poor information about the costs and benefits of different equipment – including their existence, quality, and cost of usage. While a body of research on such barriers to adoption exists for other technologies and suggests types of information and methods of propagation that may matter (see Jack, 2013, for a review of related work on agricultural technologies), to our knowledge little comparable work has been done in electrification.

It is unclear to what extent physical and human capital complementarities can fully explain the differential effects of electricity measured in the empirical literature. While the empirical results above suggest that electricity is complementary to physical and human capital and thus lower levels of capital will lead to lower (marginal) returns to electricity in partial equilibrium, it is hard to see whether or not this explanation continues hold in general equilibrium or can generate a large enough quantitative effect to fully explain the measured differences. If electricity is truly less productive on the margin due to fewer complementary inputs in today's low and middle income countries, simple neoclassical theory predicts that electricity prices should be substantially lower (as marginal benefits and marginal costs must be equal) and, as a result, electricity access may lead to larger increases in output despite small marginal gains per unit due to lower per unit prices. In a such a model, how would the effect of electricity access differ between developing and advanced countries and what assumptions are necessary to ensure that the general equilibrium effect of lower prices does not undo the lower marginal return to electricity? The answers are not straightforward.

It is unclear whether or not the prediction of such a model that electricity prices should be lower in poorer countries is true (rigorous documentation of how electricity prices vary with development would be a useful contribution itself, complicated by the fact that *de facto* and *de juer* prices may differ). An alternative – and opposite – theory could posit that electricity production in developing countries is extremely inefficient, leading to high electricity prices that limit the transformative effect of being provided an electrical connection. Such a notion sounds equally plausible but operates on opposite principles. Further theoretical and empirical work is needed to help illuminate which of these aspects is more consistent with data. Additionally, conventional wisdom holds that electricity markets are highly regulated and that many of the issues with electricity in developing countries stems from a breakdown of markets entirely (Burgess et al., 2020a, see again). In light of this, it's possible that a neoclassical approach may not have much explanatory power and research expanding such a framework to account for the realities of energy markets would also be productive.

3.3 Effects at Scale

Another possible explanation that requires more research is whether the effects of electrification vary based on the scale of the intervention and, if they do, the channels through which scale matters. As we mentioned in Section 2, one key difference between the early literature that found a positive causal relationship between electrification and structural transformation and the modern literature finding small effects is that the former tended to examine large-scale "big push" instances of electrification that impacted entire regions while the latter studied the effects of providing an electrical connection to a single household in a village.

Existing evidence suggests that the scale of electrification may matter. Burlig and Preonas (2021) exploit a regression discontinuity and diff-in-diff introduced by India's national electrification program to estimate the effects of electrification at the village level. Importantly, their quasi-experimental design allows estimation of electrification's effects for small (median size about 1000) and large (median size about 2000) villages separately and find that while electrification seems to have no effect on small villages, large villages experienced an increase in per-capita expenditure. Although the effect is noisy (and not quite statistically significant), the point estimate is large and suggests that electrification almost doubled expenditure per capita. While not conclusive, this is suggestive evidence that scale is an important determinant of the effects of electrification. Overall little is known about what channels may drive such a scale effect. Research aimed at confirming the effect and investigating the driving forces behind it would be productive.

Selection and composition effects may explain why larger electrified areas may benefit more than smaller areas or individual households, and more generally may be important for understanding heterogeneous effects of electrification across settings. As discussed previously in Subsection 3.2, the presence of complementary inputs can drive such a pattern. Larger villages and towns may have more existing complementary public infrastructure and better ability to make private investments in physical or human capital that complement electricity. They may also feature different pre-existing industries, including higher or lower prevalence of small-holder farming.

This compositional effect could also be a result of selection. Grid expansion is expected to be non-random. If utilities first connect larger towns and villages, or areas with certain industries or public sector agencies, with the understanding that higher-return areas should be prioritized, then the additional connections may simply be targeting areas with lower and lower marginal returns. In this view, it is possible that most of the gains from electrification have already been realized and additional electrification has very little to offer in terms of structural transformation. Additionally, individuals can select into regions, and most low and middle income countries are characterized by high levels of rural-urban migration. This certainly is true for India (studied by Burlig & Preonas, 2021) and Kenya (studied by Lee, Miguel, & Wolfram, 2020) both of which have been experiencing growing urban populations for decades. Recent studies on the effects of electricity access necessarily focused on electrification of rural areas, as urban areas have already largely been electrified. Given the flow of population from rural to urban areas, it seems likely that rural individuals with highly productive ideas or skills that complement electricity (or those with a high amenity value of electricity) would migrate away from rural areas and towards urban centers. Relatedly, even within rural areas with low levels of electrification, early adopters are likely to be self-selecting and have higher returns to having access to electricity, making later adopters who are the targets of today's rural electrification efforts see low returns. As a result, there could be little output and income gains from rural electrification (at least in the short term) simply because those with high returns to electricity already had access through spatial migration or early adoption. Under this story, an unintuitive relationship is possible – namely that rural electrification could reduce the rate of structural change. If access to electricity is a driver of rural-urban migration, bringing electricity to rural areas would reduce these flows, which are essential in the process of structural transformation. This is true regardless of whether selection takes place over productivity or amenity values.

Another potential channel not unique to electricity may be agglomeration effects of the Glaeser (2010) variety. Electrification of an entire area, as opposed to individual households, allows new business to form simultaneously and co-locate, may increase the education and the skilled labor pool from which businesses recruit locally, and could lead to increases in local demand as successful business owners spend their profits. If these agglomeration effects are strong, small observed effects from providing electricity to a single household does not rule out large aggregate effects of electrification at a regional or national level.

Thinking about electricity as an amenity may provide another related explanation for why the effects of electrification could differ with scale. Although our discussion so far has mostly treated electricity as an input into production for firms and farmers, households derive substantial utility from the use of electrified appliances, particularly radios, televisions, and lighting. A region that receives electricity and is now able to provide these amenities has a substantial advantage in attracting skilled labor, such as entrepreneurs, teachers, and technicians (needed to maintain electrical machines). While this infusion of skilled labor alone would accelerate the pace of structural change, it could also interact with the agglomeration effect discussed in the previous paragraph and further strengthen such an effect. To our knowledge, there is very little work looking into either of these questions, although both intuitively seem to be of first-order importance in understanding the impacts of electrification.

4 Conclusion

In this paper, we document some basic cross-country facts on the relationship between electrification and income and discussed the existing literature on the economic effects of electrification and how this literature informs our understand of the role that electrification plays in driving structural transformation. We have also laid out paths for productive future research. Many of these paths are motivated by the desire to fill holes and unanswered questions raised by existing research, but just as many arise from thinking about what questions need to be answered to develop a well-grounded macroeconomic theory of structural transformation and electricity.

We expect progress on this agenda in future research to benefit from both micro and macro approaches. For example, microeconomic studies that examine the consequences of relaxing constraints on improved reliablity or access to complementary inputs can help establish crucial empirical facts. Studying heterogeneous effects of current and historical large-scale programs, or studying researcher-led interventions along these lines may be fruitful. At the same time, macroeconomic modeling is likely to be needed to better understand the general-equilibrium effects of relieving such constraints and more generally for understanding effects of electrification at scale.

Our hope is that this summary and these paths will provide a solid framework through which young researchers (i.e. graduate students) and researchers interested in electrification but new to the literature can view the existing results and paths in which they can make contributions themselves. We also hope to convince researchers currently working on electrification that viewing their own work through the lens of structural transformation is important.

As a so-called general purpose technology, the applications of electricity are essentially endless. Many credit the development of electricity (and general purpose technologies more broadly) as fundamental to the long-run growth of the modern world (see e.g. Bresnahan & Trajtenberg, 1995; David, 1990; Ramey, 2020), making the relationship between structural change and electrification a clear area of interest for researchers interested in understanding economic development. This importance combined with its policy relevance today, overlap with other big questions in economics, and fact that there is a lot about electrification that is unknown makes this an exciting area of research.

References

Alberini, A., Steinbuks, J., & Timilsina, G. (2022). How valuable is the reliability of residential electricity supply in low-income countries? evidence from nepal. *The Energy Journal*, *43*(4). https://doi.org/10.5547/01956574.43.4.aalb

Allcott, H., Collard-Wexler, A., & O'Connell, S. D. (2016). How do electricity shortages affect industry? evidence from india. *American Economic Review*, *106*(3), 587–624. https://doi.org/10.1257/aer.20140389

Auclert, A., Bardóczy, B., Rognlie, M., & Straub, L. (2021). Using the sequence-space jacobian to solve and estimate heterogeneous-agent models. *Econometrica*, *89*(5), 2375–2408.

Bassi, V., Muoio, R., Porzio, T., Sen, R., & Tugume, E. (2022). Achieving scale collectively. *Econometrica*, *90*(6), 2937–2978.

Bresnahan, T. F., & Trajtenberg, M. (1995). General purpose technologies 'engines of growth'? *Journal of econometrics*, *65*(1), 83–108.

Briggs, R. (2021). Power to which people? explaining how electrification targets voters across party rotations in ghana. *World Development*, *141*.

Buera, F. J., Kaboski, J. P., & Shin, Y. (2011). Finance and development: A tale of two sectors. *American economic review*, *101*(5), 1964–2002.

Burgess, R., Greenstone, M., Ryan, N., & Sudarshan, A. (2020a). The consequences of treating electricity as a right. *Journal of Economic Perspectives*, *34*(1), 145–69.

Burgess, R., Greenstone, M., Ryan, N., Sudarshan, A., Et al. (2020b). *Demand for electricity on the global electrification frontier* (tech. rep.). Cowles Foundation for Research in Economics, Yale University.

Burgess, R., Jedwab, R., Miguel, E., Morjaria, A., & Padró i Miquel, G. (2015). The value of democracy: Evidence from road building in Kenya. *American Economic Review*, *105*(6), 1817–51.

Burlig, F., & Preonas, L. (2021). Out of the darkness and into the light? development effects of rural electrification. *Energy Institute at Haas WP*, *268*, 26.

Carranza, E., & Meeks, R. (2021). Energy efficiency and electricity reliability. *Review of Economics and Statistics*, *103*(3), 461–475.

Chakravorty, U., Emerick, K., & Ravago, M.-L. (2016). Lighting up the last mile: The benefits and costs of extending electricity to the rural poor. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2851907

Cole, M. A., Elliott, R. J., Occhiali, G., & Strobl, E. (2018). Power outages and firm performance in sub-saharan africa. *Journal of Development Economics*, *134*, 150–159. https://doi.org/10.1016/j.jdeveco.2018.05.003

Coville, A., Galiani, S., Gertler, P. J., & Yoshida, S. (2020). Financing municipal water and sanitation services in nairobi's informal settlements. *NBER Working Paper*, (w27569).

Dasso, R., & Fernandez, F. (2015). The effects of electrification on employment in rural peru. *IZA Journal of Labor &amp Development*, *4*(1). https://doi.org/10.1186/s40175-015-0028-4

David, P. A. (1990). The dynamo and the computer: An historical perspective on the modern productivity paradox. *The American Economic Review*, *80*(2), 355–361.

Deutschmann, J. W., Postepska, A., & Sarr, L. (2021). Measuring willingness to pay for reliable electricity: Evidence from senegal. *World Development*, *138*, 105209. https://doi.org/10.1016/j.worlddev.2020.105209

Dinkelman, T. (2011). The effects of rural electrification on employment: New evidence from South Africa. *American Economic Review*, *101*(7), 3078–3108.

Dzansi, J., Puller, S. L., Street, B., & Yebuah-Dwamena, B. (2018). *The vicious circle of blackouts and revenue collection in developing economies: Evidence from ghana* (tech. rep.). Mimeo.

Ferraz, C., & Finan, F. (2008). Exposing corrupt politicians: The effects of Brazil's publicly released audits on electoral outcomes. *The Quarterly journal of economics*, *123*(2), 703–745.

Ferraz, C., & Finan, F. (2011). Electoral accountability and corruption: Evidence from the audits of local governments. *American Economic Review*, *101*(4), 1274–1311.

Fisher-Vanden, K., Mansur, E. T., & Wang, Q. ((2015). Electricity shortages and firm productivity: Evidence from china's industrial firms. *Journal of Development Economics*, *114*, 172–188. https://doi.org/10.1016/j.jdeveco.2015.01.002

Fried, S., & Lagakos, D. (2021). Electricity and firm productivity: A general-equilibrium approach. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3998028

Gaggl, P., Gray, R., Marinescu, I., & Morin, M. (2019). *Does Electricity Drive Structural Transformation? Evidence from the United States* (NBER Working Papers No. 26477). National Bureau of Economic Research, Inc.

Glaeser, E. L. (2010). *Agglomeration economics*. University of Chicago Press.

Gonzales, L. E., Ito, K., & Reguant, M. (2022). *The dynamic impact of market integration: Evidence from renewable energy expansion in chile* (tech. rep.). National Bureau of Economic Research.

Grogan, L. (2016). Household Electrification, Fertility, and Employment: Evidence from Hydroelectric Dam Construction in Colombia. *Journal of Human Capital*, *10*(1), 109–158. https://doi.org/10.1086/684580

Grogan, L., & Sadanand, A. (2013). Rural electrification and employment in poor countries: Evidence from nicaragua. *World Development*, *43*(100), 252–265.

Hardy, M., & McCasland, J. (2021). Lights off, lights on: The effects of electricity shortages on small firms. *The World Bank Economic Review*, *35*(1), 19–33.

Harris, J. A., & Posner, D. N. (2019). (under what conditions) do politicians reward their supporters? evidence from kenya's constituencies development fund. *American Political Science Review*, *113*(1), 123–139.

Henderson, J. V., Storeygard, A., & Weil, D. N. (2012). Measuring economic growth from outer space. *American Economic Review*, *102*(2), 994–1028. https://doi.org/10.1257/aer.102.2.994

Hsieh, C.-T., & Klenow, P. J. (2009). Misallocation and manufacturing tfp in china and india. *The Quarterly journal of economics*, *124*(4), 1403–1448.

Hsieh, C.-T., & Klenow, P. J. (2010). Development accounting. *American Economic Journal: Macroeconomics*, *2*(1), 207–23.

Huenteler, J. T., Hankinson, D. J., Rosenthal, N., Balabanyan, A., Kochnakyan, A., Rana, A., & Foster, V. (2020). Cost recovery and financial viability of the power sector in developing countries: Insights from 15 case studies. *World Bank Policy Research Working Paper*, (9136).

Itskhoki, O., & Moll, B. (2019). Optimal development policies with financial frictions. *Econometrica*, *87*(1), 139–173.

Jack, K. (2013). Market inefficiencies and the adoption of agricultural technologies in developing countries.

Jack, K., & Smith, G. (2020). Charging ahead: Prepaid metering, electricity use, and utility revenue. *American Economic Journal: Applied Economics*, *12*(2), 134–68.

Jha, A., Preonas, L., & Burlig, F. (2022). *Blackouts in the developing world: The role of wholesale electricity markets* (tech. rep.). National Bureau of Economic Research.

Kabir Malik, A. L., Maureen Cropper, & Singh, A. (2015). The impact of electricity sector restructuring on coal-fired power plants in india. *The Energy Journal*, *Volume 36*(Number 4). https://EconPapers.repec.org/RePEc:aen:journl:ej36-4-malik

Kassem, D. (2021). *Does Electrification Cause Industrial Development? Grid Expansion and Firm Turnover in Indonesia* (CRC TR 224 Discussion Paper Series crctr224$_2$018$_0$52). University of Bonn and University of Mannheim, Germany.

Khandker, S. R., Barnes, D. F., & Samad, H. A. (2013). Welfare impacts of rural electrification: A panel data analysis from vietnam. *Economic Development and Cultural Change*, *61*(3), 659–692. https://doi.org/10.1086/669262

Khanna, S., & Rowe, K. (2020). *Short-and long-run consumption and non-payment responses to retail electricity prices in india* (tech. rep.). Mimeo.

Kitchens, C., & Fishback, P. (2015). Flip the Switch: The Impact of the Rural Electrification Administration 1935-1940. *The Journal of Economic History*, *75*(4), 1161–1195.

Lang, M. E. (2020). Contracting for electricity in low income countries: The role of liquidity constraints and transaction costs.

Lee, K., Miguel, E., & Wolfram, C. (2020). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, *128*(4).

Lewis, J., & Severnini, E. (2020). Short- and long-run impacts of rural electrification: Evidence from the historical rollout of the U.S. power grid. *Journal of Development Economics*, *143*(100). https://doi.org/10.1016/j.jdeveco.2019.10

Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in brazil. *American Economic Journal: Applied Economics*, *5*(2), 200–231. https://doi.org/10.1257/app.5.2.200

Mahadevan, M. (2019). The price of power: Costs of political corruption in indian electricity. *Department of Economics, University of Michigan*.

McCulloch, N., & Zileviciute, D. (2017). *Is Electricity Supply a Binding Constraint to Economic Growth in Developing Countries?* (Tech. rep.). UC Berkeley: Center for Effective Global Action. https://escholarship.org/uc/item/5405n5g4

Meeks, R. C., Omuraliev, A., Isaev, R., & Wang, Z. (2021). *Smart Meters and the Benefits from Electricity Quality Improvements* (tech. rep.).

Min, B., & Golden, M. (2014). Electoral cycles in electricity losses in india. *Energy Policy*, *65*, 619–625.

Moneke, N. (2020). Can big push infrastructure unlock development? evidence from ethiopia. *STEG Theme*, *3*, 14–15.

Moretti, E. (2014). Local Economic Development, Agglomeration Economies, and the Big Push: 100 Years of Evidence from the Tennessee Valley Authority. *The Quarterly Journal of Economics*, *129*(1), 275–331.

Olken, B. A. (2007). Monitoring corruption: Evidence from a field experiment in Indonesia. *Journal of Political Economy*, *115*(2), 200–249.

Pomeranz, D. (2015). No taxation without information: Deterrence and self-enforcement in the value added tax. *American Economic Review*, *105*(8), 2539–69.

Ramey, V. A. (2020). Secular stagnation or technological lull? *Journal of Policy Modeling*, *42*(4).

Rud, J. P. (2012). Electricity provision and industrial development: Evidence from India. *Journal of Development Economics*, *97*(2), 352–367. https://doi.org/10.1016/j.jdeveco.2011.06

Ryan, N. (2018). *Energy productivity and energy demand: Experimental evidence from indian manufacturing plants* (tech. rep.). National Bureau of Economic Research.

Ryan, N. (2021). The competitive effects of transmission infrastructure in the indian electricity market. *American Economic Journal: Microeconomics*, *13*(2), 202–42.

Salmon, C., & Tanguy, J. (2016). Rural Electrification and Household Labor Supply: Evidence from Nigeria. *World Development*, *82*(100), 48–68. https://doi.org/10.1016/j.worlddev.2016.0

Van de Walle, D., Ravallion, M., Mendiratta, V., & Koolwal, G. (2015). Long-term gains from electrification in rural india. *The World Bank Economic Review*, lhv057. https://doi.org/10.1093/wber/lhv057

Vidart, D. (2022). *Human Capital, Female Employment, and Electricity: Evidence from the Early 20th Century United States* (Working papers No. 2021-08). University of Connecticut, Department of Economics.