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Benefits of Electrification and the Role of Reliability

Evidence from India

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Abstract

This paper estimates the welfare impact of rural electrification in India using nationally representative household panel survey data for 2005 and 2012. Analysis based on a propensity-score-weighted fixed-effects model finds that while electrification is associated with a broad range of social and economic benefits, the size of the effects depends importantly on the reliability of electricity service. Gaining access to electricity combined with a reliable power supply is associated with a 17 percent increase in income during the sample period, but gaining access to electricity alone is associated with only a 9.6 percent increase in income. The net gain from both increasing the access rate and reducing power outages in rural India is estimated to be US$11 billion a year. Moreover, India's rural electrification policy appears to be progressive because lower-income households benefit more from access to electricity than higher-income households during the sample period.

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Benefits of Electrification and the Role of Reliability: Evidence from India[1]

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Key Words: Rural Electrification, Reliability of Electricity, Distributional Impact, Quantile Regression

JEL: D6, Q4, R2

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I. Introduction

More than a billion people around the world still lack access to electricity. For untold others who are nominally connected to the grid, access to electricity is often uneven and unreliable, characterized by frequent, long-lasting power outages.[2] Outages often occur because of technical failures. In many developing countries, they also reflect the efforts of utilities to cope with persistent power shortages through load shedding (or rolling blackouts). According to business surveys, firms in about a third of developing countries experience at least 20 hours of power outages a month on average. The situation is even worse in South Asia, where firms report almost one outage a day, with an average duration of 5.7 hours.[3]

Providing access to reliable electricity is vital for ending extreme poverty and boosting shared prosperity. Many studies have examined the welfare effects of grid connections on households (for example, Dinkelman 2011; Khandker, Barnes, and Samad 2012; Lipscomb, Mobarak, and Barham 2013; Banerjee et al., 2015, and Chakravorty, Emerick, and Ravago 2016). While earlier analyses focused on credibly estimating the causal relationship between household welfare and a binary variable of electricity access, few have taken into account whether the "connected" household actually receives an adequate level of service.

Going beyond basic connectivity is essential to understanding the effects of modern energy in the developing world. Even where electrical wires are present, children cannot study in the evenings if there is no power to provide light—nor can people keep their businesses open. Poor-quality electricity service also means that households must continue to rely on costly backup services. And because consumers often pay a fixed monthly charge regardless of their actual consumption, long power outages increase their effective electricity tariff. All this suggests that models ignoring the quality of electricity service may underestimate the net benefits associated with reliable electricity supply. A recent World Bank study concluded that reliable supply is the defining issue in achieving the economic benefits of grid-connection (Pargal and Banerjee 2014).

The purpose of this paper is to examine the impact of rural electrification on household welfare while paying special attention to how the quality of electricity supply affects the results. Our study takes advantage of newly available panel data from the Indian Human Development Survey (IHDS), which includes a question asking households to estimate the daily average duration of outages. Using hours of

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[2] In the following, we use the terms "access" and "grid-connection" interchangeably.
[3] World Bank Enterprise Surveys (http://www.enterprisesurveys.org).

availability as a measure of the reliability of electricity supply, we find that outages have a negative effect on economic outcomes and that the effects of gaining access to electricity become stronger after controlling for outages. For example, per capita income decreases by 0.5 percent for each additional hour of outages. And while electrification combined with a 24-hour-a-day power supply is associated with a 17 percent increase in income, electrification alone (with outages not controlled for) is associated with only an 11 percent increase. The aggregate benefit of obtaining reliable electricity in rural India is estimated to be US$11 billion a year, with US$4.7 billion from increasing the access rate and US$6.5 billion from improving the reliability of existing supply.

Several studies have examined the benefits of rural electrification in India. For example, van de Walle et al. (2015) estimate the long-run effects of electrification on household consumption in rural India based on data for 1981–98; Burlig and Preonas (2016) investigate the effect of India's national rural electrification program on labor force participation, living standards, and other village-wide outcomes using census data for 2001 and 2011; and Khandker et al. (2014) estimate the benefits of electrification projects in rural India based on cross-sectional data for 2005. A study by Chakravorty, Pelli, and Marchand (2014) is one exception that examines the effects of reliability on the benefits of electrification. Also relying on IHDS data, the authors find that a grid connection and a higher quality of electricity increased nonfarm income by 28 percent during 1994–2005, while a grid connection alone increased nonfarm income by 9 percent.

Our study differs from the one by Chakravorty, Pelli, and Marchand (2014) in several ways. First, we analyze the effects of rural electrification based on a more recent two-round panel survey conducted in 2005 and 2012. In addition to providing updated evidence, the survey data for this period are particularly interesting for understanding rural electrification in India. An important reason is that 2005 was the year in which the Indian government launched its national rural electrification program committed to connecting all 100,000 unelectrified villages. By 2010 the program had connected 283 million people to the grid. But despite the improvement in the connection rate, fewer homes benefited from uninterrupted power supply in 2012 than in 2005, suggesting that outages became more common during this period. The relatively large variation in both connection rates and reliability over time provides a unique opportunity to identify how lack of reliability interferes with achieving the benefits of electrification. In addition to analyzing the effect of electrification on households' income, as done in Chakravorty, Pelli, and Marchand (2014), we also analyze its effect on a broad range of households' social and economic outcomes, including expenditure, education, employment, and poverty status.

Second, we estimate a two-stage propensity-score-weighted fixed-effects model to control for time-invariant and time-varying heterogeneity between treatment and control groups. Our approach is based on the literature that suggests that time-varying heterogeneity is correlated with initial conditions (Heckman 1981; Chamberlain 1984; Arulampalam, Booth, and Taylor 2000), and follows Hirano, Imbens, and Ridder (2003) which explores how initial conditions can be controlled for.

Third, we also investigate the distributional impact of electrification across income groups. Specifically, following Gamper-Rabindran, Khan, and Timmins (2010), we use a semiparametric approach to examine the quantile distributional effects of nonrandom treatment from electricity supply. We find that the marginal impact of electrification increases as one moves from higher-income to lower-income quantiles—that is, that poorer households benefit more than wealthier ones.

The rest of the paper proceeds as follows: Section II discusses the mechanisms through which electricity provides development benefits and provides a brief overview of rural electrification in India. Section III describes the data. Section IV discusses the estimation strategies. Section V presents the main estimation results. Section VI estimates the distributional impact of rural electrification based on quantile regression. Section VII concludes the paper.

II. Development benefits of electricity and rural electrification in India

Electricity brings a broad range of social and economic benefits to households. For many rural households in India, however, these benefits have been slow to come.

A. Benefits of electricity

Once households are connected to electricity, the first and most immediate benefit is more lighting. This enables children to spend more time studying in the evening, gives adults more time and flexibility for completing household chores, and allows home-based income-generating activities (such as shops) to continue later into the evening (Khandker et al. 2014; Khandker, Barnes, and Samad 2012; Barnes, Peskin, and Fitzgerald 2003; Nieuwenhout, van de Rijt, and Wiggelinkhuizen 1998; van der Plas and de Graaff 1988; Filmer and Pritchett 1998). More study time for children can lead to higher school enrollment and grade attainment (Khandker and others 2014; Khandker, Barnes, and Samad 2012, 2013). In addition, electric lighting reduces households' dependence on alternative lighting sources, most notably kerosene, thereby lowering smoke and indoor air pollution and the probability of various respiratory diseases. After electrification, households acquire such things as radios, television sets, fans, air conditioners, space heaters, and refrigerators—increasing exposure to knowledge and information and improving comfort, food storage, and hygiene. Given the substantial benefits of electricity, access to modern energy has been identified as key to fulfilling the United Nations Millennium Development Goals (UNDP 2005).

The gains from electrification often materialize through multiple and interrelated pathways, leading to substantial accumulated benefits (figure 1). Take the income-related benefits of electrification as an example: Improved lighting allows shops and other businesses to operate for more hours in the evening, leading to higher revenue and profits. Electricity-powered tools and machinery also help increase business profits, because they are more productive and cost-effective than mechanical ones in the long run. Moreover, greater exposure to knowledge and information (through radio, television, and the internet) can empower business owners with up-to-date business knowledge and technology, allowing them to run their businesses more profitably. And the health and education benefits of electrification can lead to greater long-run income potential.

B. Rural electrification in India

The pace of rural electrification in India was slow in the early years after independence in 1947. The government put more emphasis on developing industrial capacity and infrastructure. As a result, only around 10 percent of villages were electrified by 1965. In the mid-1960s, however, famine prompted the government to shift its focus from developing the industrial sector to connecting more farmers to the grid so as to exploit groundwater pumping and increase agricultural production. The Rural Electrification Corporation was established in 1969 with a mandate to accelerate the pace of rural electrification and facilitate the use of electric pump sets to provide irrigation water. While this pro-agriculture policy increased the number of electrified villages, it did not promote household adoption of electricity. In 1991 about two-thirds of rural households in India still had no access to electricity (India, Bureau of Census 1993; World Bank 2001).

Electricity used by the agricultural sector was heavily subsidized. As the sector's share of electricity consumption rose, the financial difficulties of the State Electricity Boards worsened. To deal with these financial problems, along with poor service quality and the low household connectivity rate, the government launched a major policy initiative to make electricity generation and supply commercially viable. In April 1998, it issued the Electricity Regulatory Commissions Ordinance to set up the Central Electricity Regulatory Commission and the State Electricity Regulatory Commissions for tariff rationalization and other activities. The central commission sets the bulk tariffs for all central generation and transmission utility companies and decides on issues relating to interstate exchange of electricity. The state commissions have the authority to set tariffs for all types of electricity customers in their respective states; however, state governments are entitled to set policies on the subsidies allowed for electricity supply to any consumer class and are authorized to cross-subsidize. With this administrative setup in place, the government outlined an ambitious plan for achieving 100 percent electrification of villages by the end of 2007 and universal coverage of households by 2012 (Cust, Singh, and Neuhoff 2007).

In 2005 the government launched the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) program, the national program aimed at electrifying all 100,000 unelectrified villages of more than 100 people. The program was also to provide free electricity connections to more than 23 million rural households living below the poverty line. The program has led to substantial progress: according to a recent World Bank report (Pargal and Banerjee 2014), India's official electrification rate rose by 15 percentage points in 10 years, from 59 percent in 2000 to 74 percent in 2010. Most of the new customers were located in rural areas. The new targeted timeline for 100 percent connectivity is during the 12th five-year plan (2013–17).

While the electrification rate has risen, the quality and reliability of electricity service vary considerably. For example, using night lights data, Min and Gaba (2016) show that many villages in India that were officially classified as electrified under the RGGVY program remained in the dark for years after the completion of electrification projects. In addition, India continues to face widespread power outages. In July 2012, the country experienced the largest blackout in world history, with more than 600 million people unexpectedly losing power for two days. The scale of this blackout highlights the challenges that India faces in keeping the lights on. The government has made achieving universal and fully reliable electricity supply an important policy priority. In 2014, the Government of India and State Governments launched a "24×7 Power for All" Joint Initiative with the objective to provide 24×7 power across the country by 2019. Several important policy decisions have since been implemented to strengthen generation, transmission and distribution, as well as to improve the financial viability of state distribution companies.

III. Data

The study is based on two-period panel data collected by the IHDS, which was jointly carried out by researchers from the University of Maryland and the National Council of Applied Economic Research (NCAER) in New Delhi. This nationally representative survey covers a wide-ranging set of topics, including energy use, income, expenditure, education, health, and employment. The survey covers all of India's key states and union territories except Andaman and Nicobar Islands and Lakshadweep. The first round of the survey was carried out in 2004–05 (mostly in 2005) and collected information on 41,554 households in 33 states and union territories, 383 districts, 1,503 villages, and 971 urban blocks. The second one, conducted in 2011–12 (mostly in 2012), re-interviewed 83 percent of the original households and split households (if located within the same village or town), and interviewed 2,134 new households, for a total of 42,152 households.[4]

Besides collecting detailed information on income, consumption, and other household-level welfare measures, the IHDS includes elaborate questions on household energy consumption behavior, such as fuel use, cash expenditures for fuels, time spent collecting biomass fuels, and types of stoves and electric appliances used in the household. It also asks questions related to the reliability of power supply and the source of household electricity. These detailed questions allow us to analyze the impact of electricity supply and its quality on a broad range of household economic outcomes.

The survey also covers key features of the villages where surveyed households are located. It is important to control for village-level characteristics in the analysis because they can directly affect both the outcomes of interest (such as employment, income, and poverty status) and the probability of electricity being present in the village. While the survey was carried out in both urban and rural areas, community characteristics are available only for the rural sample. In the analysis, we therefore use only the rural sample, consisting of more than 24,000 original households.

The 2005 sample had 24,191 households. Because many of these split into multiple households over time, the number of households increased to 28,446 in 2012. Table 1 shows the distribution of sample households among six geographic regions as well as union territories as a group. North India accounts for the largest share of households in the sample (more than 30 percent), followed by South India.

Data on the rural electrification rate among sample households in 2005 and 2012 show large variation by region and year (table 2). The union territories and the rural vicinity of the national capital, New

[4] For a detailed description of the IHDS, see the IHDS website at http://www.ihds.umd.edu.

Delhi, have the highest electrification rate (almost 100 percent in 2012). Among the regions, South India has the highest electrification rate—about 87 percent in 2005 and 96 percent in 2012. East India, which includes the states of Bihar, Jharkhand, Orissa, and West Bengal, has the lowest rate among the regions. But electrification increased quite a bit in these states during the seven years from 2005 to 2012, rising from a rate of 37 percent to almost 65 percent. Overall in rural India, the electrification rate increased from 62 percent in 2005 to 77 percent in 2012, implying annual growth of about 2 percentage points.

Data on the duration of power outages (in hours per day) for the two survey years show that outages worsened during the sample period: While 9 percent of connected households reported no outages in 2005, that share dropped to 7 percent in 2012 (table 3). And while about 35 percent of the households reported power outages of at least 13 hours a day in 2005, almost 45 percent experienced outages of similar duration in 2012. The average duration of outages was 9.3 hours a day in 2005 and 10.7 hours a day in 2012. The hours of electricity availability per day vary substantially across states (figure 2). While connected households in union territories such as Daman and Diu have more than 20 hours of electricity per day on average, those in such states as Arunachal Pradesh and Assam have less than 6 hours per day on average.

Summary statistics for outcome variables show that grid-connected households consume less kerosene and spend less time collecting fuel than off-grid households do (table 4). They also have higher incomes and expenditures and a lower poverty rate. In households with an electricity connection both boys and girls spend more time studying and complete higher grades. Labor force participation is lower among adults in grid-connected households than among those in off-grid households—for both men and women. But when employment is measured by hours worked per month (in both wage and self-employment activities), grid-connected households have more hours of employment than their off-grid counterparts. These results are statistically significant and hold in both survey years. Also noticeable is that the trend in outcome variables differs between grid and off-grid households. For example, while kerosene consumption drops over time for all households, it drops more for grid-connected households.

Another way to look at the summary statistics for outcome variables is by duration of electricity availability. We compare two groups of households: those that have access to electricity for at least 20 hours a day and those that do not (table 5). Unsurprisingly, households with more hours of electricity available spend less on kerosene, have higher incomes and expenditures, and see their children achieve better education outcomes. Employment outcomes are somewhat mixed. Men in households with shorter electricity outages have higher labor force participation and fewer hours of employment in 2005 than those in households with longer outages; the opposite is true in 2012. Women in households with more reliable electricity supply have lower labor force participation and 6.1 fewer hours a month of employment in 2005 than their counterparts. The difference in women's labor force participation and hours of employment decreases slightly between 2005 and 2012 but the sign remains the same. In the next section we explore the relationship between hours of electricity and households' welfare outcomes in more detail.

Anecdotal evidence suggests that many households have illegal connections especially in rural areas. IHDS reports both official and non-standard connections. As a result, the access rate reported by IHDS is higher than that by official records. Since IHDS inquires about the mode of payment for electric connections and the amount of payment, we are able to estimate the percentage of non-standard connections, which include those who reported having access to electricity but did not receive bills and did not make a payment or paid to neighbors. We find that about 15 percent connections were non-standard in 2005. The number reduces to 9 percent in 2012. There is also a strong correlation between non-standard connection and service unavailability. Overall, households who are unofficially connected experience 12 hours of power outages per day, compared to 10 hours for those with official connections. This result suggests that illegal connections could make service availability worse, and thereby, adversely affects the effects of electrification. It should be noted that illegal connection could still be underreported by IHDS. If that is the case, then benefits of electrification based on IHDS data could also be underestimated.

IV. Estimation model

A base model for estimating the impact of electrification is described by equation 1:

$$Y_{it} = \beta X_{it} + \gamma E_{it} + \delta(E_{it} * D_{it}) + T_t + u_i + \varepsilon_{it} \qquad (1)$$

where Y_{it} denotes the outcome variables of interest for household i in year t, such as kerosene consumption, income and expenditure, time spent on studies by children, and labor force participation by men and women. X_{it} is a vector of household- and community-level characteristics. Household-level control variables include the age, gender, and education of the head of household; the number of adult males and females in the household; the amount of household agricultural land; and measures of the household's sanitation status, such as access to running water, a flush toilet, and a separate kitchen. Community-level control variables include dummy variables measuring the presence of paved roads, schools, markets, banks, nongovernmental organizations (NGOs), and development programs; and village prices of alternative fuels (firewood, kerosene, and liquefied petroleum gas [LPG]) and of essential food items (staples, meat, fish, vegetables, and so on).

E_{it} is a dummy variable measuring the household's electricity connection status, with 1 indicating having electricity and 0 otherwise. D_{it} is a continuous variable measuring the daily average hours of power outages reported by the household. T_t is year fixed effects controlling for shocks common to all households in the sample.

u_i represents unobserved, time-invariant household- and community-level determinants of the outcome. ε_{it} is the idiosyncratic error term. β, γ, and δ are unknown parameters to be estimated. Specifically, γ measures the impact of electrification while δ measures the effect of power outages.

An OLS estimation of equation 1 is likely to be biased because of the endogeneity of E_{it} and D_{it}. The endogeneity arises from both nonrandom grid expansion at the village level and nonrandom adoption of electricity at the household level such that the unobserved household- and community-level characteristics (u_i) are correlated with both outcome and treatment. For example, the government may target electrification projects to areas that are more easily accessible and have greater growth potential. Conversely, once connected, less developed villages are more likely to experience load shedding. In addition, when electricity becomes available in a village, better-off households are more likely to obtain grid connections first.

If the unobserved factors are time-invariant, we can address the endogeneity concern using a household-level fixed-effects regression that eliminates u_i by taking the difference of equation (1) between the two periods (0 represents the year 2005, and 1 the year 2012):

$$Y_{i1} - Y_{i0} = \beta(X_{i1} - X_{i0}) + \gamma(E_{i1} - E_{i0}) + \delta(E_{i1} * D_{i1} - E_{i0} * D_0) + (T_1 - T_0) + (u_i - u_i) + (\varepsilon_{i1} - \varepsilon_{i0})$$

or $$\Delta Y_i = \beta \Delta X_i + \gamma \Delta E_i + \delta \Delta (E_i * D_i) + \Delta T + \Delta \varepsilon_i \qquad (2)$$

Since there is no unobserved component, equation (2) gives an unbiased estimate of the impact of electrification.

It is possible, however, that the unobserved factors are not fixed over time. For example, the perceived benefits of electrification may change over time. This could affect both households' decision on whether to be connected to the grid and the outcome variables.

Taking into account the existence of time-varying heterogeneity, we rewrite equation (1) as follows:

$$Y_{it} = \beta X_{it} + \gamma E_{it} + \delta(E_{it} * D_{it}) + T_t + u_i + \eta_{it} + \varepsilon_{it} \qquad (3)$$

where η_{it} is the time-varying unobserved household- or village-level characteristics (or both). Taking the difference of equation (3) between the two periods yields the following:

$$\Delta Y_i = \beta \Delta X_i + \gamma \Delta E_i + \delta \Delta(E_i * D_i) + \Delta T + \Delta \eta_i + \Delta \varepsilon_i \qquad (4)$$

Equation (4) shows that the unobserved factors are not eliminated and the simple fixed-effects estimation based on equation (2) will be biased. One way to resolve the time-varying effects of the unobserved factors is to find instrumental variables as exogenous sources of variation in the adoption of electricity (E_i) and the reliability of electricity service (D_i). In the absence of suitable instrumental variables, we exploit the potential correlation between initial characteristics and unobserved heterogeneity as suggested in the literature (Heckman 1981; Chamberlain 1984; Arulampalam, Booth, and Taylor 2000). More specifically, following Hirano, Imbens, and Ridder (2003), we control for the effects of initial characteristics by estimating a two-stage propensity-score-weighted fixed-effects regression model. In the first stage the conditional probability of being connected to the grid (the propensity score) is estimated using a probit function controlling for a set of household- and village-level characteristics observed in 2005. In the second stage each household is assigned a weight derived from the propensity score; that is, the weight is equal to 1 for households with electricity and $1/(1 - p)$ for those without electricity, where p is the propensity score. The impact of electrification is then estimated using the household-level fixed-effects model with the weight. Using the propensity score as a weight in this way can be thought of as providing an estimate of the counterfactual outcome: households that look more similar to connected households in 2005 receive more weight.

V. Results

Tables 6–9 report the estimation results. Panel 1 in each table shows findings from estimating a model that ignores the variation in electricity availability; that is, the model does not include the interaction term between access and hours of electricity outages. The results reported in panel 2 of each table reflect the effects of both access and reliability. Panel 3 in each table reports the estimated aggregate impact of electrification conditional on hours of availability of electricity reported in the sample. In each panel the first column presents estimations of a simple fixed-effects model, while the second column reports propensity-score-weighted fixed-effects estimators.

There are noticeable discrepancies in all three panels between the fixed-effects estimators and the propensity-score-weighted estimators, with the latter generally resulting in larger effects. This is consistent with findings in the literature. For example, Chakravorty, Pelli, and Marchand (2014) find that instrumental variable models that correct for unobserved heterogeneity reveal larger effects of electrification than OLS models do. The following discussions are based on propensity-score-weighted estimators.

Without electricity, households rely mostly on inefficient and polluting kerosene-fueled lamps or burning biomass fuels (such as dung, wood) to meet basic lighting needs. An immediate benefit of household electrification is a reduction in the consumption of kerosene and time spent on collecting biomass fuels. As table 6 shows, electrification leads to a 12 percent reduction in household kerosene consumption, and 1.6 hours less time spent on collecting biomass fuel every month when the reliability of electricity service is not controlled for. But when reliability is controlled for, electrification is associated with a 14 percent reduction in kerosene consumption, and 3.5 hours less time spent on fuel collection per month on average. It is not surprising that the impact increases when the quality of electricity service is taken into account. Given persistent power shortages, many households in rural India continue to use kerosene and biomass fuel as backup sources of lighting even after gaining access to the grid. The longer the power outage, the more the traditional fuel is consumed. On average, gaining access to the grid conditional on the prevailing reliability of electricity service is associated with a 12.6 percent reduction in kerosene consumption and 1.8 hours per month less time spent on fuel collection (panel 3). Notably, the estimated aggregate effects of electrification conditional on the quality of electricity supply (panel 3) are larger than the estimated effect from a model ignoring quality (panel 1). This suggests that omitting the quality of electricity supply in the model could lead to biased estimates of both the net effect of gaining access to the grid and the aggregate effects of rural electrification given existing reliability levels.

Household income and expenditure both show significant growth after electrification (table 7). The impact becomes stronger after the duration of electricity outages is controlled for. While electrification does not have a statistically significant effect on per capita farm income, it is associated with a 15 percent increase in per capita nonfarm income and an 11 percent increase in per capita total (farm and nonfarm) income when outages are not taken into account. When outages are controlled for, gaining access to the grid is associated with a 37 percent increase in per capita nonfarm income and a 17 percent increase in per capita total income. That is, controlling for the effect of power outages increases the impact of grid access on total income by 6 percentage points. And each one-hour increase in outages per day is associated with a 2 percent reduction in nonfarm income and a 0.5 percent reduction in total income on average. This large impact of power outages shows that unreliable electricity supply has led to the loss of a great deal of the potential benefits from electrification. Conditional on the average duration of power outages, the aggregate impact of electrification on per capita total income is only 9.6 percent.

Similarly, after controlling for the duration of outages, gaining access to the grid is associated with an 8.4 percent increase in households' per capita food expenditure, a 14.9 percent increase in their per capita nonfood expenditure, and a 12 percent increase in their per capita total expenditure. Every one-hour increase in power outages is associated with a 0.2 percent reduction in food expenditure on average. The aggregate effects of electrification conditional on both access and quality are thus generally smaller: a 5.6 percent increase in food expenditure, a 16.4 percent increase in nonfood expenditure, and a 10.5 percent increase in total expenditure. A comparison of the results reported in panel 1 with those shown in panels 2 and 3 again reveals considerable omitted variable bias resulting from not controlling for the quality of power supply.

Corresponding to the increases in income and expenditure, the household poverty rate decreases after connection to the grid. After controlling for outages, gaining access to the grid is associated with a 9.5 percentage point reduction in the household poverty rate; an extra hour of power outages per day is associated with a 0.2 percentage point increase in the poverty rate. The aggregate effect of electrification conditional on outages reported in the sample is a 6.8 percentage point reduction in the poverty rate. By comparison, a model omitting the effect of outages suggests a 7.4 percent point reduction in the poverty rate.

Among the long-term benefits of electricity is its potential to improve households' education outcomes. As shown in table 8, when outages are not controlled for, access to electricity increases boys' and girls' study time in the evening by 0.35 hours (or about 21 minutes) a week on average. But this increase in study hours does not translate into higher school attainment. When outages are not controlled for, electrification has no statistically significant impact on grade completion by either boys or girls.

When the interaction term between access and electricity outages is incorporated, the results show that boys' study time increases by 1 hour a week and girls' study time by 0.64 hour given access and no power outages. In addition, boys' grade completion increases by 0.14 years on average. The effect on girls' grade completion is positive by not statistically significant. In all cases outages are found to have a statistically significant negative effect on schooling. Every additional hour of outages per day is associated with a reduction of 0.05 hour a week in boys' study time, 0.02 hour a week in girls' study time, 0.01 year in boys' grade completion, and 0.009 year in girls' grade completion. As a result, the aggregate effects of electrification after taking into account the negative impact of power outages are much smaller: boys' study time increases by 0.27 hour (or about 16 minutes) a week, and girls' study time by 0.30 hour (or about 18 minutes) a week; neither of these increases results in a significant improvement in grade completion.

The effect of electrification on employment is also gender sensitive. As table 9 shows, electrification has a significant positive effect on women's hours of employment, increasing them by 31 percent (15.6 percent when outages are not controlled for), but no effect on men's hours of employment. On the other hand, every additional hour of outages per day reduces women's hours of employment by 1.4 percent on average. This may be because electrification helps free up time that women have traditionally spent on collecting fuel, allowing them to spend more time on other productive activities. The results also show that electrification slightly increases labor force participation among adult males in the household by about 1.1 percent. However, it does not have a significant effect on women's labor force participation.

VI. Who benefits most from rural electrification in India?

In the previous section, we report the average treatment effect of electrification. But the benefits of gaining access to electricity may quite possibly vary by household welfare depending on existing welfare such as income, education, and consumption. For example, richer households may be equipped with more electric tools and appliances and more likely to use electricity more productively—and therefore may benefit more from electrification projects. Because government subsidies have been a key element of rural electrification programs around the world, understanding who benefits from rural electrification is important. If richer households benefit substantially more than poorer ones, this would argue for a different approach in designing and implementing subsidies for rural electrification.

In this section, we use a quantile regression approach to empirically estimate how households in different parts of the expenditure distribution benefit from electricity. We first discuss the theory of quantile regression, then present the findings.

While the objective of ordinary regression is to estimate the mean of the dependent variable, the objective of quantile regression is to estimate a quantile value (a median or other quantile value such as 0.25, 0.60, and so on) of the dependent variable. Technically, a quantile regression minimizes the sum of absolute residuals corresponding to each quantile, in contrast to minimizing the sum of the squares of the residuals as is done by ordinary regression. When the entire shape of the distribution changes significantly, simply estimating changes in the mean may not be sufficient and investigating changes in the outcomes observed at different points in the distribution becomes important (Buchinsky 1998).

Following Koenker and Bassett (1978) and using the same notation as in the previous estimation model, we can express the quantile regression model as follows:

$$Y_i = \beta_\theta X_i' + \varepsilon_{\theta i}, Quant_\theta(Y_i|X_i) = \beta_\theta X_i', \theta \in (0,1) \quad (5)$$

where $Quant_\theta(Y_i|X_i)$ denotes the quantile θ of the outcome conditional on the vector of covariates. In general, the θ-th sample quantile of *Y* solves as:

$$\min_\beta \frac{1}{n} \sum_{i:Y_i \geq \beta X_i'} \theta \left| Y_i - \beta X_i' \right| + \sum_{i:Y_i < \beta X_i'} (1-\theta) \left. Y_i - \beta X_i' \right| = \min_\beta \frac{1}{n} \sum_{i=1}^{n} \rho_\theta(\varepsilon_{\theta i}) \quad (6)$$

where $\rho_\theta(\varepsilon_{\theta i})$ is denoted as the "check function" and is defined as:

$$\rho_\theta(\varepsilon_{\theta i}) = \begin{cases} \theta\varepsilon_{\theta i}, & \theta\varepsilon_{\theta i} \geq 0 \\ (\theta-1)\varepsilon_{\theta i}, & \theta\varepsilon_{\theta i} < 0 \end{cases} \quad (7)$$

We estimate parameters in equation 5 semiparametrically by minimizing the sum of weighted absolute deviations, which fits medians to a linear function of covariates and can be performed using linear programming methods (Buchinsky 1998). To account for possible heteroskedasticity in the error term, we estimate the variance-covariance matrix of coefficients using bootstrap resampling. The quantile's coefficients can be interpreted as the partial derivative of the conditional quantile of Y_i with respect to one of the regressors X_i, namely, $\partial Quant_\theta(Y_i|X_i)/\partial X_i$.

We use a semiparametric approach to examine nonrandom treatment effects on conditional quantiles with panel data. Specifically, we use the quantile regression equations for the two survey years to estimate the distributional effects of electricity connection on household outcomes *Y*, as follows:

$$Q_\theta(Y_{it}|Z_{it}, E_{it}, \eta_{it}) = \psi_\theta Z_{it} + \delta_\theta E_{it} + \eta_{it}, \theta \in (0,1) \qquad (8)$$

where $Q_\theta(Y_{it}|Z_{it}, E_{it}, \eta_{it})$ denotes the quantile θ of *Y* in period *t*, conditional on the fixed effects and household- and village-level covariates. Vector *Z* measures both household and village exogenous attributes, while *η* subsumes unobserved household and village heterogeneity. One problem in applying the quantile regression model to panel data is that differencing variables are not generally equal to the difference in the conditional quantiles because quantiles are not linear operators. That is,

$$Q_\theta(Y_{i1} - Y_{i0}|Z_i, E_i, \eta_i) \neq Q_\theta(Y_{i1}|Z_{i1}, E_{i1}, \eta_{i1}) - Q_\theta(Y_{i0}|Z_{i0}, E_{i0}, \eta_{i0})$$

To overcome this problem, we follow Gamper-Rabindran, Khan, and Timmins (2010), who specify the unobserved effect *η* nonparametrically as an unknown function φ(.) of the covariates *X*, as follows:[5]

$$\eta = \varphi(Z_{i0}, Z_{i1}) \qquad (9)$$

Substituting equation (9) in each conditional quantile in equation (8), we get the following:

$$Q_\theta(Y_{i0}|Z_{i0}, E_{i0}, \eta_{i0}) = \psi_\theta Z_{i0} + \delta_\theta E_{i0} + \varphi(Z_{i0}, Z_{i0}), \theta \in (0,1) \qquad (10)$$

$$Q_\theta(Y_{i1}|Z_{i1}, E_{i1}, \eta_{i1}) = \psi_\theta Z_{i1} + \delta_\theta E_{i1} + \varphi(Z_{i0}, Z_{i1}), \theta \in (0,1) \qquad (11)$$

The difference of quantiles between the two periods is given by

$$Q_\theta(Y_{i1}|Z_{i1}, E_{i1}, \eta_{i1}) - Q_\theta(Y_{i0}|Z_{i0}, E_{i0}, \eta_{i0}) = \psi_\theta(Z_{i1} - Z_{i0}) + \delta_\theta(E_{i1} - E_{i0})$$

or, $\quad Q_\theta \Delta Y_i = \psi_\theta \Delta Z_i + \delta_\theta \Delta E_i$

Gamper-Rabindran, Khan, and Timmins (2010) show that the quantile regression can be estimated using a two-step procedure. First, following equations 10 and 11, $Q_\theta(Y_{it}|Z_{it}, E_{it}, \eta_{it})$ is nonparametrically estimated for each period *t* = 0,1, with *Z* and *E* entering linearly in the equation. Second, the differenced fitted values from the estimations $[\widehat{Q_\theta}(Y_{i1}|Z_{i1}, E_{i1}, \eta_{i1}) - \widehat{Q_\theta}(Y_{i0}|Z_{i0}, E_{i0}, \eta_{i0})]$ are regressed on the differenced regressors $(Z_{i1} - Z_{i0})$ and $(E_{i1} - E_{i0})$, since the proxies for the fixed effects are now eliminated from the estimation.

Table 10 reports the marginal effects of electrification for expenditure quantiles {.20, .40, .60, .80}. While electrification is uniformly associated with higher per capita expenditure across all quantiles, the magnitude of the effects increases as one moves from higher quantiles to lower ones. For example, the

[5] Abrevaya and Dahl (2008) apply a similar approach based on the correlated fixed-effects model of Chamberlain (1984), where the fixed effect is specified as a parametric (linear) function of the covariates X.

aggregate effect of electrification conditional on outages reported in the sample is associated with a 16 percent increase in expenditure for households in the bottom quantile but a 6.1 percent increase for those in the top quantile. The results are robust in models with and without controls for power outages (columns 2 and 1, respectively). This result suggests that the return to electrification is higher for poorer households in India. The distribution of the marginal effects of electrification on households' expenditure by per capita expenditure quantile (when outages are controlled for) is further shown in figure 3. The marginal benefit of electrification gradually decreases as one moves from the 10th to the 50th quantile. From the 50th quantile onwards, the marginal benefit drops rather quickly and even becomes statistically insignificant.

This finding is somewhat different from those reported by Khandker et al. (2014). Using cross-sectional data from the IHDS for 2005, Khandker et al. (2014) find that a larger share of the benefits from rural electrification accrues to wealthier households rather than to poorer ones. Because we use panel data from the IHDS that span seven years, we report longer-term effects of electrification on the same households. The difference in findings suggests a possibility that over time the rate of return from electrification has declined among richer households while poorer households have caught up by diversifying their use of electricity.

VII. Conclusion

Universal access to modern energy services is one of the three objectives of the Sustainable Energy for All (SE4ALL) program launched by the United Nations in 2011. Access to electricity not only brings better-quality lighting; it also is a key driver of social and economic development. Using household-level panel data from a nationally representative survey conducted in 2005 and 2012, this study estimates the impact of rural electrification on a broad range of household welfare measures in India.

We find that electrification is associated with substantial improvements in households' income, expenditure, employment, and educational achievement. But the size of the effects depends importantly on the reliability of electricity service. For example, an additional hour of outages per day is associated with a 0.5 percent reduction in income on average. Gaining access to the grid combined with reliable electricity service is associated with a 17 percent increase in households' income, but when access comes with frequent power outages, income rises by only 11 percent.

About 240 million people in India still lack access to electricity (IEA, 2015). Findings from our analysis suggest that connecting all these people to electricity would lead to a cumulative income gain of about

US$4.7 billion a year. Improving the reliability of electricity supply would add to these gains. According to IHDS 2012 data, the average duration of power outages of households who have less than 24 hours of power supply is about 12.5 hours a day. Increasing the supply of electricity to 24 hours a day would lead to an estimated income gain for the rural population of US$6.5 billion annually.

The Indian government plans to achieve 100 percent electrification in rural areas by 2017, at a total estimated cost of US$4.4 billion between 2015 and 2017. Its plans call for both connecting the villages that remain without electricity and improving the reliability of power supply in villages that are already connected. Assuming a 20-year project lifespan, the annual average investment cost is about US$200 million. Even without accounting for other benefits associated with better health and education outcomes, our estimates suggest that the net income gain from providing reliable electricity to rural households would reach almost US$11 billion a year.

Based on quantile regression analysis, we also find that while every income group benefits from electricity, the benefits are larger for households in lower-income quantiles. This suggests that the current rural electrification policy in India is progressive.

Overall, the findings from our analysis suggest that merely ensuring connectivity is not enough; increasing the reliability of service is essential to realizing greater benefits from electrification. While the availability of electricity is important, it is only one of several factors that matter to the impact of electrification. Others include the frequency of power disruptions, fluctuations in voltage, and the ability to simultaneously use multiple appliances, including high-capacity ones. Ongoing initiatives are adding to our knowledge on these issues. One set centers on a multidimensional energy access matrix recently developed by the Sustainable Energy for All (SE4ALL) program, i.e. the Multi-tier Framework (MTF) of energy access. The Energy Sector Management Assistance Program (ESMAP) at the World Bank is using this framework to measure all the essential attributes of quality in electricity access around the world. And the World Bank is conducting a number of household surveys based on this framework to evaluate energy access in developing countries. Once such data become available, further analysis can be carried out to estimate how different aspects of the quality of service affect the impact of rural electrification.

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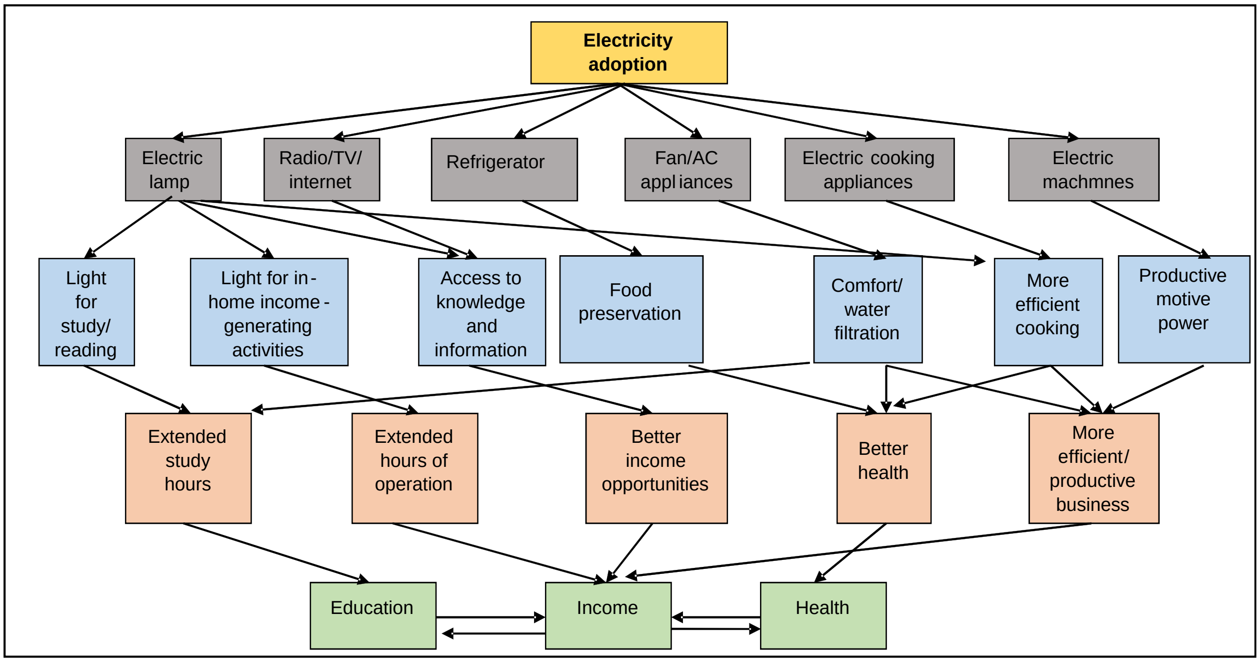
Figure 1. Benefits of electrification through interrelated pathways to education, income, and health outcomes



Source: Adapted from Khandker, Barnes, and Samad (2013).

Figure 2. Average hours of electricity available to grid-connected households per day by state or union territory, 2012

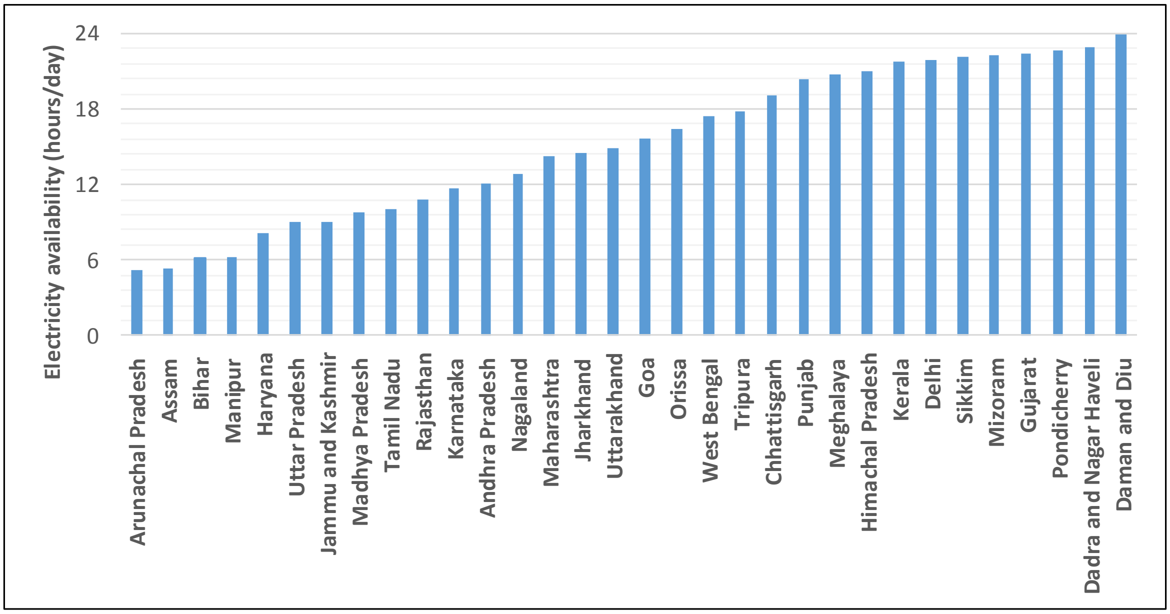
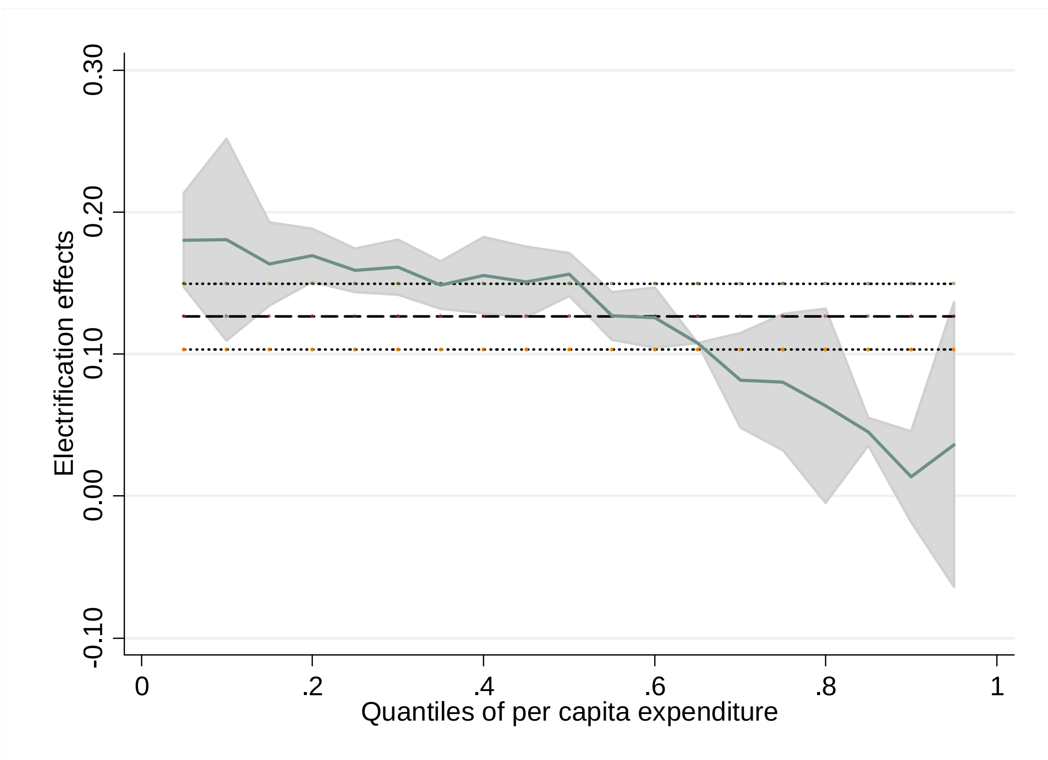


Figure 3. Effects of electrification on per capita expenditure by expenditure quantile



Note: Shaded area represents 95% confidence intervals

Table 1. Distribution of IHDS sample of rural households by region

Region	States and union territories	2005	2012
North	Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Rajasthan, Uttarakhand, Uttar Pradesh	7,589	9,334
West	Goa, Gujarat, Maharashtra	3,046	3,448
South	Andhra Pradesh, Karnataka, Kerala, Tamil Nadu	5,366	5,985
East	Bihar, Jharkhand, Orissa, West Bengal	3,865	4,530
Central	Chhattisgarh, Madhya Pradesh	2,852	3,572
Northeast	Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura	1,255	1,335
Union territories and the capital[a]	Dadra and Nagar Haveli, Daman and Diu, Delhi, Pondicherry	218	242
No. of Observations		24,191	28,446

Note: While this is a panel sample, the number of surveyed households in 2012 exceeds that in 2005 because many of the original 2005 households split during the seven years between the two surveys.
a. Union territories are administrative divisions that differ from the states. While each state is ruled by its own elected government, union territories are ruled by the central government.

Table 2. Electrification rate among sample households by region (percent)

Region	2005	2012
North	52.8	66.8
West	78.7	92.6
South	86.9	95.5
East	37.4	64.5
Central	66.3	91.9
Northeast	69.5	67.8
Union territories and the capital	94.2	99.8
Total	61.8	76.7
No. of Observations	24,191	28,446

Table 3. Distribution of sample households with electricity by duration of power outages

Outage duration (hours/day)	2005	2012
No outages	9.0	7.0
1–5	23.8	21.4
6–10	24.5	19.2
11–16	18.1	18.4
17–20	20.8	29.0
>20	3.8	5.1
Average duration of outages	9.3	10.7
No. of Observations	16,574	23,395

Table 4. Summary statistics for outcome variables by electrification status

	2005		2012	
Outcome variable	**Households with electricity**	**Households without electricity**	**Households with electricity**	**Households without electricity**
Consumption of kerosene and fuel collection time				
Kerosene consumption (liters/month)	3.59**	3.66	2.82**	3.04
	(2.77)	(2.04)	(2.18)	(1.04)
Time spent on biomass fuel collection (hours/month)	15.4**	19.5	11.3**	19.4
	(23.7)	(24.8)	(33.6)	(40.6)
Income, expenditure, and poverty				
Per capita farm income (Rs./year)	4,118.2**	2,526.7	5,126.6**	2,711.0
	(11,144.1)	(3,817.5)	(19,498.8)	(5,263.8)
Per capita nonfarm income (Rs./year)	5,131.2**	2,324.6	7,886.4**	3,830.0
	(9,053.5)	(4,611.9)	(15,579.4)	(5,494.6)
Per capita total income (Rs./year)	9,249.4**	4,851.4	13,012.9**	6,541.1
	(14,077.6)	(5,584.9)	(24,794.3)	(7,153.7)
Per capita food expenditure (Rs./year)	4,609.3**	3,735.7	5,498.6**	4,153.7
	(2,492.5)	(1,924.4)	(3,086.3)	(2,379.0)
Per capita nonfood expenditure (Rs./year)	6,779.9**	2,685.3	6,992.4**	3,341.1
	(11,988.4)	(4,220.4)	(12,916.1)	(6,361.3)
Per capita total expenditure (Rs./year)	11,389.2**	6,421.0	12,488.3**	7,493.7
	(13,189.4)	(5,186.4)	(14,317.1)	(7,293.9)
Moderate poverty rate (percent)	15.5**	33.7	16.6**	33.7
	(36.2)	(47.3)	(37.3)	(47.3)
No. of Observations	16,574	7,617	23,496	5,050
Education outcomes (ages 5–18)				
Time spent in studies by boys (hours/week)	5.97**	4.16	7.08**	5.10
	(6.56)	(5.83)	(6.79)	(5.67)
No. of Observations	14,875	7,898	16,101	4,118
Time spent in studies by girls (hours/week)	5.39**	3.55	6.71**	4.64
	(6.53)	(5.59)	(6.79)	(5.21)
No. of Observations	13,826	7,144	14,991	3,934
Grade completion by boys (years)	4.54**	3.20	4.94**	3.65
	(3.44)	(3.09)	(3.57)	(3.23)
No. of Observations	14,875	7,898	16,101	4,118
Grade completion by girls (years)	4.32**	2.65	5.05**	3.62
	(3.44)	(2.90)	(3.60)	(3.21)
No. of Observations	13,826	7,144	14,991	3,934
Employment (ages 15–65)				
Labor force participation by men	0.793**	0.848	0.830**	0.873
	(0.405)	(0.359)	(0.376)	(0.333)
No. of Observations	29,561	12,048	37,078	6,688
Labor force participation by women	0.473**	0.514	0.526**	0.565
	(0.499)	(0.500)	(0.499)	(0.496)

No. of Observations	29,446	11,836	38,822	7,131
Employment for men (hours/month)	207.7**	172.9	182.9**	149.0
	(158.4)	(129.8)	(152.9)	(125.3)
No. of Observations	16,574	7,617	23,496	5,050
Employment for women (hours/month)	76.9**	58.9	69.5**	51.1
	(99.1)	(78.8)	(89.9)	(72.0)
No. of Observations	16,574	7,617	23,496	5,050

Note: Figures in parentheses are standard deviations. ** represents a statistical significance of 5 percent or better for the difference in the outcome variable between households with electricity and those without. Monetary figures are adjusted by the consumer price index. Rs. = rupees.

Table 5. Summary statistics for outcome variables by duration of electricity availability

	2005		2012	
Outcome variable	**Electricity available for at least 20 hours/day**	**Electricity available for less than 20 hours/day**	**Electricity available for at least 20 hours/day**	**Electricity available for less than 20 hours/day**
Consumption of kerosene and fuel collection time				
Kerosene consumption (liters/month)	3.37**	3.68	2.71**	2.86
	(3.04)	(2.63)	(2.56)	(2.02)
Time spent in biomass fuel collection (hours/month)	13.3	16.4	9.3	12.4
	(25.1)	(23.0)	(28.4)	(35.9)
Income, expenditure, and poverty				
Per capita farm income (Rs./year)	3,933.4	4,203.4	5,513.4*	4,980.7
	(13,417.2)	(9,920.4)	(19,539.9)	(19,481.0)
Per capita nonfarm income (Rs./year)	6,570.1**	4,467.1	9,770.2**	7,174.6
	(10,027.2)	(8,485.5)	(17,594.0)	(14,685.1)
Per capita total income (Rs./year)	10,503.6**	8,670.5	15,283.7**	12,155.3
	(16,303.9)	(12,881.0)	(26,030.9)	(24,356.6)
Per capita food expenditure (Rs./year)	4,690.4**	4,571.8	5,687.3**	5,427.3
	(2,483.5)	(2,495.8)	(3,203.5)	(3,037.9)
Per capita nonfood expenditure (Rs./year)	8,329.5**	6,064.7	7,334.4**	6,862.9
	(13,402.9)	(11,204.5)	(13,048.8)	(12,863.6)
Per capita total expenditure (Rs./year)	13,020.0**	10,636.5	13,020.1**	12,287.2
	(14,669.7)	(12,375.0)	(14,534.4)	(14,229.0)
Moderate poverty rate (percent)	13.8**	16.2	16.9	16.6
	(34.5)	(36.9)	(37.5)	(37.2)
No. of Observations	5,338	11,236	7,246	16,149
Education outcomes (ages 5–18)				
Time spent in studies by boys (hours/week)	6.63**	5.74	7.92**	6.85
	(7.25)	(6.29)	(7.05)	(6.70)
No. of Observations	4,313	10,562	4,005	12,096
Time spent in studies by girls (hours/week)	6.51**	5.01	7.72**	6.42
	(7.69)	(6.04)	(7.33)	(6.61)
No. of Observations	4,043	9,783	3,662	11,329
Grade completion by boys (years)	4.90**	4.42	5.39**	4.82
	(3.42)	(3.44)	(3.54)	(3.56)
No. of Observations	4,313	10,562	4,005	12,096
Grade completion by girls (years)	4.84**	4.15	5.40**	4.95
	(3.41)	(3.44)	(3.63)	(3.58)
No. of Observations	4,043	9,783	3,662	11,329
Employment (ages 15–65)				
Labor force participation by men	0.797**	0.784	0.808**	0.838
	(0.402)	(0.412)	(0.394)	(0.369)
No. of Observations	9,200	20,361	10,182	26,896
Labor force participation by women	0.422**	0.493	0.486**	0.540

	(0.494)	(0.500)	(0.500)	(0.498)
No. of Observations	9,323	20,123	10,814	28,008
Employment for men (hours/month)	200.3**	211.0	194.3**	178.6
	(149.2)	(162.4)	(157.0)	(151.2)
No. of Observations	5,338	11,236	7,246	16,149
Employment for women	64.6**	70.7	66.3**	70.7
(hours/month)	(90.5)	(102.4)	(90.1)	(90.7)
No. of Observations	5,338	11,236	7,246	16,149

Note: Figures in parentheses are standard deviations. * and ** represent a statistical significance of 10 percent and 5 percent (or better), respectively, for the difference in the outcome variable between households that have electricity available for at least 20 hours a day and those that have electricity available for less than 20 hours a day. Monetary figures are adjusted by the consumer price index (2005=100). Rs. = rupees.

Table 6. Effect of household electrification on consumption of kerosene and fuel collection time (*N* = 24,191)

	(1)		(2)		(3) Aggregate electrification impacts calculated from (2)	
	Simple fixed effects	*p*-weighted fixed effects	Simple fixed effects	*p*-weighted fixed effects	Simple fixed effects	*p*-weighted fixed effects
Log kerosene consumption (liters/month)						
Household has grid electricity	-0.041	-0.121**	0.007	-0.141**	-0.051	-0.126**
	(-0.98)	(-2.18)	(0.08)	(-2.01)	(-1.18)	(-2.08)
Household has grid electricity × duration of power outages per day (hours)			-0.004	0.001		
			(-0.71)	(0.01)		
Time spent on biomass fuel collection (hours/month)						
Household has grid electricity	-0.838	-1.582*	-2.492*	-3.533**	-0.483	-1.804*
	(-1.03)	(-1.69)	(-2.23)	(-3.03)	(-0.58)	(-1.89)
Household has grid electricity × duration of power outages per day (hours)			0.141**	0.170*		
			(2.10)	(-1.64)		

Note: Figures in parentheses are *t*-statistics based on robust standard errors clustered at the village level. ** represents statistically significant at the 5 percent level. * represents statistically significant at the 10 percent level. Regression controls for survey round (2004-05 = 0, 2011-12 = 1), household characteristics (age, sex, and education of the household head, number of adult males, number of adult females, log of agricultural land, access to piped water or tube well, access to flush toilet), village-level infrastructure (paved roads, schools, markets, banks, NGOs, development programs, and so on), and village prices of fuels (firewood and , kerosene and LPG) and of essential food items (staples, meat, fish, vegetables, and so on). Rs. = rupees.

Table 7. Effect of household electrification on income, expenditure, and poverty (*N* = 24,191)

	(1)		(2)		(3) Aggregate electrification impacts calculated from (2)	
	Simple fixed effects	*p*-weighted fixed effects	Simple fixed effects	*p*-weighted fixed effects	Simple fixed effects	*p*-weighted fixed effects
Log per capita farm income (Rs./year)						
Household has grid electricity	-0.009	0.061	0.171**	0.108	-0.048	0.049
	(-0.16)	(0.64)	(2.14)	(0.66)	(-0.81)	(0.56)
Household has grid electricity × duration of power outages per day (hours)			-0.015**	-0.004		
			(-3.15)	(-0.47)		
Log per capita nonfarm income (Rs./year)						
Household has grid electricity	0.138*	0.149**	0.266**	0.373**	0.110	0.094
	(1.81)	(2.27)	(2.50)	(2.38)	(1.44)	(0.80)
Household has grid electricity × duration of power outages per day (hours)			-0.011*	-0.020**		
			(-1.86)	(-2.20)		
Log per capita total income (Rs./year)						
Household has grid electricity	0.054**	0.110**	0.102**	0.167**	0.043*	0.096*
	(2.26)	(2.25)	(3.12)	(2.70)	(1.80)	(1.94)
Household has grid electricity × duration of power outages per day (hours)			-0.004**	-0.005*		
			(-2.19)	(-1.70)		
Log per capita food expenditure (Rs./year)						
Household has grid electricity	0.044**	0.061**	0.047**	0.084**	0.043**	0.056**
	(4.23)	(4.51)	(3.31)	(4.76)	(4.09)	(3.94)

Household has grid electricity × duration of power outages per day (hours)			-0.0003 (-0.37)	-0.002* (-1.89)		
Log per capita nonfood expenditure (Rs./year)						
Household has grid electricity	0.166** (8.18)	0.161** (4.83)	0.146** (4.91)	0.149** (3.43)	0.170** (8.23)	0.164** (4.82)
Household has grid electricity × duration of power outages per day (hours)			0.002 (0.95)	0.001 (0.44)		
Log per capita total expenditure (Rs./year)						
Household has grid electricity	0.091** (7.51)	0.108** (5.15)	0.087** (4.80)	0.120** (4.31)	0.092** (7.49)	0.105** (4.98)
Household has grid electricity × duration of power outages per day (hours)			0.0004 (0.36)	-0.001 (-0.67)		
Moderate poverty rate						
Household has grid electricity	-0.066** (-6.74)	-0.074** (-5.68)	-0.078** (-6.49)	-0.095** (-5.24)	-0.063** (-6.39)	-0.068** (-5.28)
Household has grid electricity × duration of power outages per day (hours)			0.001* (1.75)	0.002* (1.87)		

Note: Figures in parentheses are *t*-statistics based on robust standard errors clustered at the village level. ** represents statistically significant at the 5 percent level. * represents statistically significant at the 10 percent level. Regression controls for survey round (2004–05 = 0, 2011–12 = 1), household characteristics (age, sex, and education of the household head, number of adult males, number of adult females, log of agricultural land, access to piped water or tube well, access to flush toilet), village-level infrastructure (paved roads, schools, markets, banks, NGOs, development programs, and so on), and village prices of fuels (firewood, kerosene and LPG) and of essential food items (staples, meat, fish, vegetables, and so on). Rs. = rupees.

Table 8. Effect of household electrification on education outcomes (ages 5–18)

	(1)		(2)		(3) Aggregate electrification impacts calculated from (2)	
	Simple fixed effects	***p*-weighted fixed effects**	**Simple fixed effects**	***p*-weighted fixed effects**	**Simple fixed effects**	***p*-weighted fixed effects**
Time spent in studies by boys (hours/week) (*N* = 22,773)						
Household has grid electricity	0.125	0.354**	0.436**	1.006**	0.082	0.270**
	(0.94)	(3.13)	(2.40)	(5.89)	(0.61)	(2.37)
Household has grid electricity × duration of power outages per day (hours)			-0.024**	-0.051**		
			(-2.51)	(-5.10)		
Time spent in studies by girls (hours/week) (*N* = 20,970)						
Household has grid electricity	0.077	0.346**	0.304*	0.644**	0.042	0.301**
	(0.58)	(3.08)	(1.66)	(3.85)	(0.31)	(2.64)
Household has grid electricity × duration of power outages per day (hours)			-0.018*	-0.024**		
			(-1.81)	(-2.41)		
Grade completion by boys (years) (*N* = 22,773)						
Household has grid electricity	-0.019	-0.035	-0.034	0.138**	-0.017	-0.057
	(-0.43)	(-0.85)	(-0.56)	(2.23)	(-0.39)	(-1.37)
Household has grid electricity × duration of power outages per day (hours)			0.001	-0.013**		
			(0.36)	(-3.73)		
Grade completion by girls (years) (*N* = 20,970)						
Household has grid electricity	-0.036	-0.006	-0.075	0.102	-0.030	-0.022
	(-0.73)	(-0.13)	(-1.13)	(1.54)	(-0.60)	(-0.49)
Household has grid electricity × duration of power outages per day (hours)			0.003	-0.009**		
			(0.87)	(-2.20)		

Note: Figures in parentheses are *t*-statistics based on robust standard errors clustered at the village level. ** represents statistically significant at the 5 percent level. * represents statistically significant at the 10 percent level. Regression controls for survey round (2004–05 = 0, 2011–12 = 1), household characteristics (age, sex, and education of the household head, number of adult males, number of adult females, log of agricultural land, access to piped water or tube well, access to flush toilet), village-level infrastructure (paved roads, schools, markets, banks, NGOs, development programs, and so on), and village prices of fuels (firewood, kerosene and LPG) and of essential food items (staples, meat, fish, vegetables, and so on).

Table 9. Effect of household electrification on employment (ages 15–65)

	(1)		(2)		Aggregate electrification impacts calculated from (2)	
	Simple fixed effects	***p*-weighted fixed effects**	**Simple fixed effects**	***p*-weighted fixed effects**	**Simple fixed effects**	***p*-weighted fixed effects**
Men's labor force participation (*N* = 43,766)						
Household has grid electricity	0.008	0.009*	0.024**	0.011*	0.004	0.001*
	(1.46)	(1.81)	(3.50)	(1.69)	(0.80)	(1.66)
Household has grid electricity × duration of power outages per day (hours)			-0.001**	-0.0002		
			(-3.84)	(-0.58)		
Women's labor force participation (*N* = 45,953)						
Household has grid electricity	0.014**	0.008*	0.033**	0.008	0.009	0.009
	(2.15)	(1.67)	(4.14)	(1.09)	(1.45)	(1.55)
Household has grid electricity × duration of power outages per day (hours)			-0.002**	0.00002		
			(-3.98)	(0.03)		
Log men's employment (hours/month) (*N* = 24,191)						
Household has grid electricity	0.071**	0.049	0.112**	0.033	0.062**	0.053
	(2.63)	(1.01)	(3.06)	(0.460)	(2.28)	(1.10)
Household has grid electricity × duration of power outages per day (hours)			-0.003*	0.001		
			(-1.65)	(0.35)		
Log women's employment (hours/month) (*N* = 24,191)						
Household has grid electricity	0.114**	0.156**	0.215**	0.312**	0.093	0.117*
	(2.85)	(2.40)	(3.75)	(3.33)	(2.27)	(1.77)
Household has grid electricity × duration of power outages per day (hours)			-0.009**	-0.014**		
			(-2.49)	(-2.36)		

Note: Figures in parentheses are *t*-statistics based on robust standard errors clustered at the village level. ** represents statistically significant at the 5 percent level. * represents statistically significant at the 10 percent level. Regression controls for survey round (2004–05 = 0, 2011–12 = 1), household characteristics (age, sex, and education of the household head, number of adult males, number of adult females, log of agricultural land, access to piped water or tube well, access to flush toilet), village-level infrastructure (paved roads, schools, markets, banks, NGOs, development programs, and so on), and village prices of fuels (firewood, kerosene and LPG) and of essential food items (staples, meat, fish, vegetables, and so on).

Table 10. Fixed-effects quantile regression estimates of effects of household electrification on per capita expenditure (rupees/year) (*N* = 24,191)

	(1)	(2)	(3) Aggregate electrification impacts calculated from (2)
20th quantile			
Household has grid electricity	0.130**	0.168**	0.160**
	(9.21)	(15.53)	(15.09)
Household has grid electricity × duration of power outages per day (hours)		-0.001*	
		(-1.67)	
40th quantile			
Household has grid electricity	0.102**	0.154**	0.149**
	(8.35)	(12.56)	(11.06)
Household has grid electricity × duration of power outages per day (hours)		-0.002**	
		(-3.50)	
60th quantile			
Household has grid electricity	0.080**	0.114**	0.101**
	(7.98)	(14.57)	(8.20)
Household has grid electricity × duration of power outages per day (hours)		0.00001	
		(0.01)	
80th quantile			
Household has grid electricity	0.072**	0.064*	0.061*
	(4.21)	(1.82)	(1.66)
Household has grid electricity × duration of power outages per day (hours)		0.001	
		(0.79)	

Note: Figures in parentheses are *t*-statistics based on bootstrapped standard errors. ** represents statistically significant at the 5 percent level. * represents statistically significant at the 10 percent level.