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Who Benefits Most from Rural Electrification?

Evidence in India

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Abstract

This paper applies an econometric analysis to estimate the average and distribution benefits of rural electrification using rich household survey data from India. The results support that rural electrification helps to reduce time allocated to fuelwood collection by household members and increases time allocated to studying by boys and girls. Rural electrification also increases the labor supply of men and women, schooling of boys and girls, and household per capita income and expenditure. Electrification also helps reduce poverty. But the larger share of benefits accrues to wealthier rural households, with poorer ones having more limited use of electricity. The analysis also shows that restricted supply of electricity, due to frequent power outages, negatively affects both household electricity connection and its consumption, thereby reducing the expected benefits of rural electrification.

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1. Introduction

The goal of rural electrification programs in developing countries goes beyond providing rural households affordable modern energy at a cheaper price than inferior alternatives over the long run. Rural electrification is expected to improve rural people's quality of life and spur growth on a range of socioeconomic fronts. Various examples can be given to substantiate such expectations. As a replacement for kerosene-based lighting sources, electric lighting substantially reduces indoor air pollution and carbon emissions. In addition, it allows school-going children to read during evening hours, thus encouraging more hours of study. Furthermore, it benefits income-generation activities through business operations being able to stay open longer and promoting productive uses. The large body of literature on the benefits of rural electrification claims that rural electrification greatly contributes to the welfare growth of rural households (e.g., ADB 2010; Barnes, Peskin, and Fitzgerald 2003; Cockburn 2005; Khandker 1996; Martins 2005; World Bank 2008). But most of these findings are based only on the correlation between rural electrification and development, without taking any selection or program-placement biases into account. Some recent studies, however, have attempted to ascertain the welfare gains caused by rural electrification (e.g., Dinkelman 2008; Khandker, Barnes, and Samad, forthcoming).

To provide further impetus on the welfare gains of electricity, this paper analyzes the impact of electrification on a wider range of household outcomes in rural India and determines who benefits most from rural electrification. With its long history of rural electrification programs, diverse population, and geographic spread, India presents an ideal case for this study, which has benefitted from a large, nationally representative data set. We apply an instrumental variable (IV) method in a fixed-effects (FE) framework to obtain unbiased estimates of the impacts of rural electrification.[1] To quantify electrification's benefits, we explore the outcomes potentially affected immediately after electrification, such as time allocated to fuelwood collection or children's study time and the labor market, to understand how these immediate outcomes may have impacted welfare indicators (e.g., household income, expenditure, and incidence of poverty). More importantly, to determine who benefits most, we estimate a quantile regression model that examines the distributional effects of electrification.

This paper presents an analytical framework that describes the identification strategy used to address the endogeneity of household demand for electricity and household outcomes of interest, including income and expenditure. In addition, the paper examines the effects of both household and village characteristics on household demand for electricity, along with estimates of the average benefits accrued by rural households from providing electricity in rural areas. Since electricity programs receive government subsidies, the paper also examines the distributional benefits of rural electrification. Finally, since electricity reliability is a well-known problem in rural India, we examine its effects on both household adoption and consumption of electricity.

2. Rural Electrification in India: An Overview

The Government of India has long been committed to increasing the country's rural electricity supply. Following independence in the 1950s, the pace of rural electrification was slow, owing to the need to focus on the industrial sector. As a result, by 1960, the number of rural villages with electricity had grown only to 22,000 (from 3,000 in 1950–51). Famine in the mid-1960s prompted the government to shift its focus from rural-village electrification to exploitation of groundwater pumping to increase agricultural yields. To accomplish this, in 1969, the Rural Electrification

[1] Both Dinkelman (2008) and Khandker, Barnes, and Samad (forthcoming) use an IV approach to explore the impact of electrification.

Corporation was put in charge of accelerating the pace of rural electrification and encouraging the use of electricity for irrigation. This emphasis improved irrigation using electric pumps, but the focus on agriculture also deterred household adoption of electricity. Indeed, in 1991, some two-thirds of rural households still remained without electricity (Government of India 1993; World Bank 2001). As agriculture's share of electricity consumption has risen, the financial difficulties of the State Electrification Boards (SEBs) have worsened. In fact, the financial weakness of the SEBs, combined with poor service and low household-connection rates, led to key policy changes in 1995–96, including the establishment of state and central electricity regulatory commissions (World Bank 1999).

At the federal level, India's government initiated a major policy initiative to make electricity generation and supply commercially viable. In April 1998, it issued the Electricity Regulatory Commissions Ordinance (ERCO) for setting up the Central Electricity Regulatory Commission (CERC) and the State Electricity Regulatory Commissions (SERCs) for tariff rationalization and other activities. The CERC sets the bulk tariffs for all central generation and transmission utility companies and decides on issues concerning interstate exchange of electricity. The SERCs have the authority to set tariffs for all types of electricity customers in their respective states; however, state governments are entitled to set policies with respect to subsidies allowed for supply of electricity to any consumer class, and are authorized to cross-subsidize. With the above-mentioned administrative setup in place, the government outlined an ambitious plan for achieving 100 percent village-level electrification by the end of 2007 and total household electrification by 2012 (Cust, Singh, and Neuhoff 2007).

In 2005, India's government set up the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), a program that aimed to provide all villages without electricity a supply within five years. Thanks to the RGGVY program, the rate of village electrification had jumped from 74 percent to 91 by 2011. Yet in 2008, only three-fifths of rural households had gotten a connection. More strikingly, more than two-thirds of increased access went to rich households. Given that the government continued to spend scarce resources for universal access, it is imperative to know the extent of the benefits of rural electrification and who has benefited the most from government-aided rural electrification in India. These questions provide the rational basis for this study.

3. Estimating the Role of Electricity: Model Framework and Estimation Strategy

We are interested in estimating the causal effect of electricity on a set of household outcomes, including farm and non-farm income, food and non-food expenditure, schooling, employment, and other indicators of household welfare. We consider these outcomes conditional on electricity connection status, expressed as follows:

$$Y_{ij} = \alpha^y + \beta^y X_{ij} + \gamma^y V_j + \delta E_{ij} + \mu_{ij}^y + \eta_j^y + \varepsilon_{ij}^y \quad (1)$$

where Y_{ij} denotes the outcome variables of interest, such as income of household *i* from community *j*; X_{ij} is a vector of household-level observed characteristics (e.g., household head's age or gender); V_j is a vector of observable community characteristics; E_{ij} is the electricity-connection status of *i*-th household living in *j*-th community (its value is 1 for households who have electricity and 0 for those without);[2] μ_j represents unobserved household-level characteristics; η_j represents unobserved community-level characteristics; ε_{ij} is the randomly distributed error; and *a*, *β*, *γ*, and *δ* are unknown parameters to be estimated.

Our primary interest is to estimate the impact of electricity, measured by the coefficient (δ). If household electrification occurred randomly (i.e., a household was randomly assigned by an

[2] In addition to a household's electrification status, we use its monthly consumption of electricity (measured in kilowatt hours per month) to evaluate the impact of electricity consumption on outcomes.

agency to receive a connection), then an estimation of model (1) would have provided unbiased estimates of the impact of electrification. However, households are not randomly connected to electricity or villages are not randomly selected for electrification; the decision is often based on both observed and unobserved characteristics, such as an area's productive potential or a household's ability to perceive returns to investment. In this case, if we ignore the possibility of endogenous electricity connection, equation (1) yields biased impact estimates. To address this problem of endogeneity, we need to instrument the household's electricity-connection decision.[3] The estimate of instrumental variables (IVs) is obtained by estimating the following demand equation for electricity:

$$E_{ij} = \alpha^e + \beta^e X_{ij} + \gamma^e V_j + \theta I_{ij}^e + \mu_{ij}^e + \eta_j^e + \varepsilon_{ij}^e \qquad (2)$$

where I_{ij}^e is a vector of instruments that only affect electricity demand but not directly the outcomes of interest, such as income, employment, schooling, and expenditure. Outcomes are affected only indirectly through access to electricity.

For the instruments to be valid, the IV method requires two conditions: (i) θ is not a vector of zeros and (ii) $Cov(I_{ij}^e, \varepsilon_{ij}^y) = 0$. The first condition means that at least one of the instruments must significantly affect a household's electrification decision, while the second implies that the instruments only affect a household's electrification decision and do not directly affect the outcomes of interest, such as household income and expenditure.

We propose that I_{ij} is a vector of instruments that include a variable indicating the proportion of households in a community (*j*) with electricity and its interaction with such household-observed characteristics as household head's age, gender, and education. The proportion of households in a community who have electricity is expected to serve as an instrument because peer pressure or

[3] In our IV estimation, we also instrument a household's monthly electricity, using the same instruments we applied in the electricity-access equation.

demonstration effect is likely to affect a household's electrification decision as households tend to follow their neighbors or other associates in the village. If neighbors obtain electricity, then a household without electricity can signal lower socioeconomic standing, which households would be expected to avoid if they can afford it. There is a large body of literature on peer effects. For example, Akerlof and Kranton (2002) and Munshi and Myaux (2006) analyze peer and neighborhood effects in the context of schooling decision, while Bandiera and Rasul (2006) examine the effect of social networks on technology adoption in Mozambique. Thus, we expect that the higher the percentage of connected households in a village, the greater the likelihood that a household living in that village will adopt electricity, provided it can afford the connection fee and other associated costs.

The second condition can also be expected to hold because the proportion of village households with electricity should not directly impact a household's outcomes, such as time allocated for biofuel collection, whose need depends primarily on household size and availability of alternate energy sources. This condition should also hold for education-related outcomes since school enrollment, time allocated for studying for those enrolled in school, and school completion rate should depend primarily on the quality of schools in the area and the household preference for education, which can be argued not to depend on the proportion of households in a village connected to electricity. Similarly, it can be argued that household income and expenditure do not depend on the proportion of village households with electricity because a household's expenditure decision depends mainly on its size and age composition rather than whether other households in the village have electricity. We perform a number of tests for instrument validity, besides the endogeneity test for electrification and electricity consumption variables, results of which are reported in the appendix and discussed later in the main text.

4. 2005 India Human Development Survey

The 2005 India Human Development Survey (IHDS) is a nationally representative sample of 41,554 urban and rural households covering a wide-ranging set of topics, including energy use, income, expenditure, education, health, time allocation, and irrigation. The 2005 IHDS covers all of India's key states and union territories, with the exception of Andaman/Nicobar and Lakshadweep. The sampled households were selected from 33 states and union territories, 383 districts, 1,503 villages, and 971 urban blocks.

4.1 Household Selection

Urban and rural households were selected using various sampling designs. The urban sample was drawn from all of a state's urban areas, listed according to their size, with the number of blocks drawn from each urban area allocated based on probability proportional to size. Once the number of blocks for each urban area was set, the enumeration blocks were randomly selected with the assistance of the Registrar General of India. From these Census Enumeration Blocks of some 150 households, a complete household listing was formulated, and a sample of 15 households was selected per block. For ease of sampling, some smaller states were combined with larger neighboring states. The final urban sample covered more than 13,000 households.

The rural sample selection was based on both the random sampling design used in the 2005 IHDS and the method used in the 1993–94 Human Development Profile of India (HDPI) survey, which covered 33,320 households in 16 states. About half of the sampled households were newly selected for the 2005 IHDS, while the other half had been interviewed initially as part of the 1993–94 HDPI (Shariff 1999). Both surveys follow a similar sampling design. In states where the 1993–94 survey had been conducted and contact details for future survey were available, 13,593 households were randomly selected for re-interview in 2005. To select the new households, the HDPI was consulted where districts in each state had been divided into high-, medium-, and low-development groups and randomly selected from within this group for survey of rural households. From each district, 7–9 villages were selected, depending on the district's size and listing of India's rural population.[4]

4.2 Survey Features

The IHDS is ideal for estimating the impact of electricity access and consumption on welfare indicators owing to its exhaustive coverage of survey topics and sample representativeness. It is India's first survey for measuring detailed income, as well as consumption and ownership of consumer goods. Income-related questions cover a variety of sources (e.g., wages and salaries, net farm, net family business, property, and pension). The survey also contains education-related questions, including educational outcomes, study hours, school enrollment, and school completion rate, along with household characteristics. Compared to the Demographic and Health Surveys and Living Standards Measurement Surveys, the IHDS covers energy more extensively. It includes elaborate questions on 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 detailed questions related to electricity use, including reliability of power supply and source of household electricity (i.e., whether serviced by the local state electricity board or a neighbor). Such detailed energy questions allow us to investigate the drivers of household demand for electricity and analyze the welfare impacts of household access more comprehensively.

In addition to household-level data, the survey covers key features of the villages where the surveyed households are located (e.g., availability of social development programs in the area or distance to village facilities). Such area characteristics can directly affect outcomes of interest, such as employment, income and poverty indicators, and the probability of electricity presence in the village. Because this survey covers villages with and without electricity, it allows for identifying an

[4] The 2005 IHDS findings are comparable to those of the 2004–05 National Sample Survey, 2005–06 National Family Health Survey (NFHS-3), and the 2001 Census.

unbiased impact of electrification on outcomes affected by electricity. Descriptive analysis was done for both the urban and rural samples; however, for the empirical analysis, we used only the 2005 IHDS rural household-level data, consisting of more than 24,000 households, which were available after the data cleaning.

As expected, the extent of household electrification in India's rural regions—nearly 60 percent on average—is significantly less than in urban areas (more than 94 percent). The highest rates of rural electrification are found in the south and north, while eastern and plains regions exhibit the lowest rates for rural areas and India overall (Table 1). The great variation in rural electrification rates—from only about 40 percent in eastern regions to nearly 88 percent in the north—allows us to empirically investigate the drivers of rural household demand for electricity and the impact of household electrification status on outcomes of interest.

5. Energy Use and Electricity Demand in Rural India

Despite rapid urbanization, about three-quarters of India's population still reside in rural areas. Most rural people continue to rely predominantly on traditional biomass fuels to meet most of their energy needs. This is true even for households with electricity. For cooking, most rural households use fuelwood, crop residue, and dung, while some use kerosene. For lighting, kerosene is the primary energy source for households without electricity. Even among households with electricity, kerosene is an important backup lighting source. Thus, it is not surprising that kerosene is used by the vast majority of rural households (Table 2).

India's rural households spend about 10 percent of their monthly income on basic fuel and energy services, which are used primarily for cooking, lighting, and heating activities (ESMAP 2002b). But in urban areas, electricity is the most commonly used fuel, followed by liquefied petroleum gas (LPG), and kerosene. As Table 2 indicates, more than one-third of urban households—primarily the urban poor living in slum areas—continue to rely on fuelwood.

The benefits of replacing kerosene with electricity extend beyond a higher-quality lighting source. Switching to electric lighting also means eliminating the indoor air pollution (IAP) caused by the smoke emitted by kerosene lamps, which in India accounts for about half a million premature deaths annually (ESMAP 2002b; Smith 2000).

Virtually all villages in India have access to electricity, yet only about 60 percent of rural households are connected. Low household-connection rates are often attributed to low incomes, high connection costs, poor-quality housing construction, and unreliable electricity services. Thus, for policy purposes, analyzing the determinants of electricity demand among India's rural households is of interest.

Electricity demand combines interfuel substitution and capital stock adjustments, along with elements that affect the utilization rate of existing stocks. However, demand for electricity is much determined by whether the village has electricity, along with the price of electricity and associated household connection fees. The prices of competing or complementary fuels, such kerosene or LPG, also play an important role. In addition, the price of durable goods that complement household consumption of electricity may influence demand (Bohi 1981). Furthermore, the prices of electric equipments (e.g., irrigation pumps) as well as household wealth and durables also matter.

Household demand for electricity can be estimated by following equation:

$$E_{ij} = a^e + \beta^e X_{ij} + \gamma^e V_j + \mu_{ij}^e + \eta_j^e + \varepsilon_{ij}^e \qquad (3)$$

where E_{ij} represents either household access to electricity (a binary variable with value 1 when household has access and 0 otherwise) or household monthly consumption of electricity (a continuous variable), and control variables include household- and village-level exogenous variables, including a reliability measure of electricity service (average hours of electricity availability at the village level). We implement a maximum likelihood probit model with sample selection for the electricity-access equation and a maximum likelihood regression with sample selection for the electricity-consumption equation.

Table 3 presents the results of the electricity-demand regressions and the summary statistics of the explanatory variables used in the estimation. As expected, education and wealth indicators positively affect electricity demand and use. Demand for electricity declines with its increased price, indicating a negative effect of own price. The cross-price effects of fuelwood and kerosene are significant for electricity consumption. Finally, as the findings clearly show, service reliability plays a major role in household demand for electricity.

Increasing the average availability of electricity at the village level by one hour increases the rate of household adoption by 2.7 percent and electricity consumption by 14.4 percent, suggesting the enormous potential for consumption gains from a modest improvement in service. This finding also underscores that providing electricity access is not enough and must be accompanied by a certain level of service quality.

6. Average Benefits of Rural Electrification

Our outcome variables consist, in part, of time allocated for biofuel collection by household males and females, as well as kerosene (electricity alternate) consumption. Our educational outcomes of interest include school enrollment status of household members ages 7–15 years, study time allocated by school-going children, and years of schooling completed. Additional outcome variables are employment hours, income and food, non-food, and total expenditure. Finally, we use a measure of poverty (moderate poverty headcount) calculated from the per capita household expenditure and state-level poverty line constructed by the organization that conducted the survey.[5]

The differences in means between electricity users and non-users are statistically significant for

[5] A household is considered poor if its per capita expenditure is less than the poverty-line expenditure calculated for its state; otherwise, it is non-poor; thus, poverty headcount is a dummy variable with a value of 1 for the poor and 0 for the non-poor.

all outcome variables (Table 4). In the case of alternate fuels, kerosene is the primary source of household lighting for electricity non-users, while, for electricity users, it serves as a backup lighting source when power outages occur.[6] Electricity non-users consume more kerosene and other biofuels than do electricity users, as evidenced by the time spent collecting such fuels. The findings also suggest that, in terms of biofuel collection, women spend the most time among all household members collecting biofuels, followed by men, boys, and girls.

In households with electricity, children—both boys and girls--spend more time studying than in households without electricity, suggesting a better educational outcome in the future. Also, in households with electricity, compared to those without a connection, both males and females spend more time engaged in productive activities, indicating more productive time use.

Household income and expenditure on food and non-food items are higher for electricity users than non-users. However, higher average value of outcomes for electricity users does not imply a causal impact. As discussed in Section 3, we use regression estimates to obtain an unbiased causal impact of electrification. Before we discuss those results we go over the findings of various tests for instrument validity, which are reported in the appendix. Reported in the appendix are also the first stage regression outputs for the IV estimates (Table A1). As Table A1 shows, most instruments are statistically significant, and they are also jointly significant with a p-value equal to 0 and a high F-statistics, implying that the instruments are strong. There are two important validity tests for instruments that are examined next: instrument exogeneity test and instrument relevance test. The first one determines if the instruments are uncorrelated with the error term of the outcome equation. This test can only be performed if the model is over-identified (that is, number of instruments is higher than the number of endogenous variables) which is true in this case. The test is implemented by Hansen's J statistic, distributed as χ^2 under the null hypothesis that the over-

[6] The data show that more than three-fourths of rural households experience electricity outages for at least 4 hours per day, while one-fifth have intermittent supply for most of the day.

identification restriction is satisfied, that is, instruments are not correlated with the error term of the outcome equation. As Table A2 shows, for majority of the outcomes the null hypothesis cannot be rejected at the 5% significance level, implying that the over-identification restriction is satisfied.

The second test examines whether the instruments are correlated with the endogenous regressor(s). The test is implemented by Kleibergen-Paap's rk LM statistic, distributed as χ^2 under the null hypothesis that the equation is under-identified, that is, instruments do not affect the endogenous variables significantly. As shown in Table A3, null hypothesis is easily rejected for all equations, that is, the instruments are relevant.

Another meaningful test is the weak instrument (or identification) test, which shows if the correlation between the instruments and the endogenous variables is sufficiently strong. The test is implemented by Kleibergen-Paap's rk Wald statistic, distributed as the F statistic, which is then compared against another statistic called Stock-Yogo's critical value for various ratios of IV-to-OLS bias under the null hypothesis that the instruments are weak. For example, if F statistic is greater than Stock-Yogo's critical value defined for an IV bias that is 5 percent of the OLS bias, we can reject the null hypothesis that the bias of the IV estimate due to a weak instrument is greater than 5 percent of the corresponding bias in the OLS estimate. An F value of 11 or higher is considered sufficient to reject the null hypothesis for all practical purposes. Table A3 shows a very high value of F statistic, implying that instruments pass the weak identification test easily.

Finally, Table A4 reports the results of endogeneity test where the test statistic is distributed as χ^2 under the null hypothesis that the specific regressors are exogenous. For most outcomes the exogeneity of the regressors is rejected. It is important to note that all four test statistics reported are robust to heteroskedasticity. Based on the results of these tests, the IV model is found to be reasonably robust.

Regression results for outcome equations are reported in Tables 5-7. We incorporate district-level FE in the regression to control for unobserved district-level effects that may bias the outcomes.

The results of the IV-FE estimation strategy show that household electrification lowers domestic kerosene consumption by 35 percent, while a 10-percent increase in electricity consumption reduces it by about 0.5 percent (Table 5). Household electrification also means less time spent collecting biofuels for all household members. For both men and women, biofuel collection time decreases by more than 3.3 hours per month. The results indicate that the impact of electrification is greater for those who spend the more time collecting biofuels.

In terms of education, electrification access increases school enrollment by about 6 percent for boys and 7.4 percent for girls (Table 6). It also increases weekly study time by more than an hour, and the increase is slightly more for girls than boys. As a result of more study hours, children from households with electricity can be expected to perform better than their peers living in households without electricity. This is reflected in schooling outcomes: Owing to household electrification, the average completed schooling year increases by about 0.3 and 0.5 for boys and girls, respectively.

The impact of electrification on labor supply is positive for both men and women; that is, household access to electricity increases employment hours by more than 17 percent for women and only 1.5 percent for men (Table 7).[7]

Household access to electricity increases household per capita income by nearly 38.6 percent, which is a cumulative effect of electricity over time. In addition, a 10-percent increase in electricity consumption raises income by 0.6 percent. It seems the increase in income due to electricity is primarily due to increase in nonfarm income, but not so much on farm income. Electrification increases household per capita food expenditure by 14 percent, non-food expenditure by 30 percent, and total expenditure by more than 18 percent. Not surprisingly, household

[7] This finding differs from that of Dinkelman (2008), who also used an IV method to estimate the impact of electrification on employment outcomes in South Africa but found no significant impact on male labor employment.

electrification also decreases poverty. The poverty rate (also known as headcount for moderate poverty) declines by 13.3 percentage points as a result of household access to electrification (Table 7).

All of these findings indicate electrification's substantial positive effect on overall household welfare. This is possible when benefits accumulate through various channels. In the case of income, the cost of household lighting with electricity is much less expensive than with kerosene lamps. As a result, people can use more lighting when they have electricity, meaning that, during evening hours, children can study more and have better school performance, resulting in a higher income potential over the long run. Electric lighting also allows household members to extend hours of operation for home-based businesses and engage in other income-generating activities after completing household chores, such as sewing or making handicrafts (ESMAP 2002a). Electricity-powered televisions and radios provide better access to information and business knowledge, giving households with electricity a competitive advantage.

In addition to its various consumption roles, household electrification has a distinctive productive role since electricity-powered machinery and tools can replace inefficient manual ones, resulting in more revenue and profit. Various studies have shown that more home businesses are created in households with electricity than in those without (ESMAP 2002a; Barkat et al. 2002). In addition, households simply living in a community with electricity can reap certain spillover effects. A recent study on rural electrification's benefits in South Africa, for example, shows that women's employment rate grows by 13.5 percent because of community electrification (Dinkelman 2008). Thus, conceptually at least, household income can benefit in multiple ways from electricity connection, and the cumulative effects can result in substantial income growth over the long run. Thus, it comes as no surprise that electrification has a large impact on the income and expenditure of India's rural households.

7. Distributional Effects of Rural Electrification

While the primary goal of electrification is to provide improved lighting at a low cost, it is also intended that electrification, particularly rural electrification, improve the livelihoods of the poor. The electrification impacts estimated thus far in this paper assess the average impacts of grid electricity without distinguishing among electricity users. However, we observe that access to electricity is highly dependent on a household's physical and human capital endowments (Table 3). Furthermore, wealthier households can diversify their electricity use more than can poorer ones by adopting a broad array of modern appliances and amenities.

This then raises a question: Does this unequal consumption of electricity and appliance ownership result in unequal distribution of electrification benefits among households with access to electricity? The average impacts of an intervention, as shown in Table 7, for example, reveal nothing about how it affects various segments of the population. This is a critical issue for policy makers since critics may contend that rural electrification projects may not benefit the poor much and thus resources might be better allocated to other types of projects that might yield better returns for the poor. In this section, we investigate how electrification benefits accrued to richer households vary from those accrued to poorer ones in terms of income and expenditure impacts.

7.1 <u>Quantile Regression</u>

One way to estimate electrification benefits for household groups (based on their welfare outcomes, such as income or expenditure) is to use quantile regression. While an OLS regression estimate calculates change in the mean of the outcome variable (e.g., income) as some function of a set of covariates, a quantile regression fits other parts (quantiles) of the distribution of the outcome, allowing us to observe the changes in impacts from one quantile to another. For example, if electricity users are categorized into different groups based on their income status, a quantile regression can estimate which income group benefits most from electrification. Here we estimate quantile treatment effects (QTEs) of household electrification (assumed endogenous) on household income and expenditure, using the IV model.

Formally, the quantile regression equation for the distributional effects of electricity connection on household outcome *Y* of household *i* of village *j* can be expressed as follows:

$$Q^{\tau}_{Y_{ij}} = \alpha + \beta^{\tau} X_{ij} + \delta^{\tau} E_{ij}, \quad \tau \in (0,1) \qquad (4)$$

where Q^{τ}_{Y} denotes the quantile τ of *Y*, *X* is a vector of household and village exogenous attributes, *E* is the electrification variable, β^{τ} and δ^{τ} are parameters to be estimated, and δ^{τ} is the QTE. We assume unconditional endogeneity (when QTE is not sensitive to changes in covariates *X*, which is more useful for policy-making purposes), with QTE expressed as follows:

$$\delta^{\tau} = \Delta^{\tau} = Q^{\tau}_{Y^1} - Q^{\tau}_{Y^0}$$

where $Q^{\tau}_{Y^1}$ and $Q^{\tau}_{Y^0}$ are the respective τ quantiles of Y^1 and Y^0, and Y^1 and Y^0 are the respective outcomes with and without electricity. Frölich and Melly (2007) propose the following estimator for estimating Δ^{τ}:

$$(\hat{\alpha}_{IV}, \hat{\Delta}^{\tau}_{IV}) = \sum\nolimits_{\arg\min \alpha,\Delta} W_{ij} . \rho_{\tau}(Y_{ij} - \alpha - \Delta^{\tau} E_{ij}) \qquad (5)$$

where $\rho_{\tau}(u) = u.\{\tau - 1\,(u < 0)\}$ and W_{ij} is defined by

$$W_{ij} = \frac{Z_{ij} - \Pr(Z = 1 \mid X_{ij})}{\Pr(Z = 1 \mid X_{ij})(1 - \Pr(Z = 1 \mid X_{ij}))}(2E_{ij} - 1) \qquad (6)$$

Details of these derivations are provided in Frölich and Melly (2007); their development of the IV implementation of the quantile regression requires that the instrument variable be a dummy variable. Since the main instrument variable used in this paper (share of households with electricity in the village) is a continuous variable, we convert it into a dummy variable whose value is 1 if the majority of households (over 50 percent) in the village has electricity and 0 otherwise. And we implement FE in the quantile regression by using district-level dummy variables.

7.2 Distributional Impacts

The impacts of electrification across income and expenditure quantiles vary, with richer households tending to benefit more than poorer ones (Table 8). Also, the inter-quantile variation in impacts is greater for expenditure than income. In fact, households in the lower two expenditure quantiles (15^{th} and 25^{th} percentiles) accumulate no electrification benefits (i.e., coefficients are not statistically significant). For households in the highest quantile (85^{th} percentile), the electrification impact on per capita expenditure is nearly twice that of those in the middle quantile (50^{th} percentile) (i.e., 30 percent versus 16 percent). In terms of income, households from all quantiles benefit from electrification; for those in the lowest quantile (15^{th} percentile), the impact is about 26 percent, compared to nearly 46 percent for the richest households (85^{th} percentile).[8]

These results are not surprising since wealthier households consume more electricity in many more ways compared to poorer ones, whose electricity consumption is limited mainly to lighting. As mentioned previously, households can accrue electrification benefits through multiple channels (e.g., extended hours of business operation, growth of businesses that use electricity for production purposes, and exposure to television and other electronic media). Obviously, richer households can exploit these channels to an extent that poorer ones cannot. Finally, the findings from quantile regression point to a somewhat disturbing picture with regard to priorities of poverty alleviation projects. If rural electrification projects benefit the wealthier segment of the population more, then policy makers and stakeholders may need to revisit the focus and details of such interventions.

8. Reliability of Electricity Supply and Effects on Household Welfare

[8] The question may arise as to why the income effects of household electrification are spread out for all quantiles, while expenditure effects are limited to higher-quantile households. This finding is not surprising since it is expected that poorer households will be somewhat conservative in their spending, even as their incomes rise.

Estimates of rural electrification's benefits are highly subject to the reliability of electricity supply. If supply is constrained due to a host of factors, the effects will be sub-optimal, meaning that beneficiaries would not reap the maximum benefits possible from household electrification. The 2005 IHDS data show that lack of reliable electricity service is pervasive in rural areas of India, which may have kept electricity access and consumption low. The effects of service quality on electricity access and consumption, discussed previously (Table 3), clearly demonstrate the substantial consumption gains that can accrue from small improvements in reliability. Similarly, villages without power outages have an electrification rate of 81 percent, while those with more than 20 hours of power outages per day have an access rate of only about 38 percent, which affects their electricity consumption (Table 9).

Households without power outages consume up to 69 kWh per month, compared to only about 46 kWh per month for those that experience severe outages. Clearly, the amount of electricity consumed depends not only on whether service is available but also on how long service is available, and the extent of impacts depends on the level of consumption. With improved reliability, electricity may play a stronger role in improving income and productivity, as ensuring only access is not enough. In short, electricity access, in conjunction with service reliability, is what matters in improving household welfare in rural India.

9. Conclusion

The analysis in this paper unpacks the causal chain from provision of electricity to the various benefits it is claimed to bring and quantifies these benefits. The estimation results indicate that electrification has significant positive effects on time allocation for fuel collection, as well as income, expenditure, and poverty incidence. It also has a positive impact on children's schooling, which can increase future income; thus, electricity not only alleviates poverty in the near term but also holds the potential to do so over the longer run. The policy implication of these findings is that rural electrification should be used as a complement to other educational investments to further improve schooling and educational attainment.

Despite such significant benefits of electrification, the household access rate in rural India is substantially lower (about 60 percent) than that for village electrification (about 90 percent). Possible reasons for households not adopting electricity are high connection costs and lack of service reliability. Rural households in India depend mainly on agriculture-based seasonal income, from which saving enough for the connection cost may be difficult. Therefore, it may be advisable to spread the connection cost over a longer period.

We have observed that the kerosene consumed by households with electricity is not much less than for households without electricity. At the very least, the money households with electricity spend on kerosene equals what they pay for unreliable electricity service, not accounting for the loss of productivity and appliance damage due to power outages, suggesting that access without reliability may be counter-productive. Policy makers must focus on this key issue.

Quintile regression estimates show that electrification benefits are, not unexpectedly, higher for wealthier households. The greater benefits to richer households accrue through higher consumption and more diversification of electricity service. This too is an issue that policy makers keen on the poverty-alleviation aspects of electrification should address.

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Tables

Table 1: Extent of electrification in India

Region	Household electrification (%)		
	Rural	**Urban**	**All**
North	86.7	94.1	88.1
Plains	51.3	93.7	63.4
West	71.5	96.9	81.0
South	86.6	96.5	89.5
East	39.9	88.9	49.4
Northeast	62.3	95.6	71.0
All regions	59.8	94.3	69.4

Source: 2005 IHDS.

Table 2: Household energy-use patterns in India, by source

Factor	Traditional source				Modern source			
	Fuel wood	Dung	Crop residue	Coal/ charcoal	Kerosene	LPG	Electricity	All sources
Rural areas (N = 24,191)								
Household users (%)	89.1	55.9	22.1	4.8	91.0	15.9	59.8	100.0
Quantity used[1]	131.7	71.9	30.1	3.9	2.7	1.6	32.5	-
Energy used (kgOE/mo.)	49.3	24.4	11.0	2.4	2.2	1.7	2.7	3.8
Energy expenditure (Rs./mo.)	190.8	75.1	44.0	7.9	39.5	35.6	73.9	466.8
Share in total household energy use (%)	56.7	22.2	7.3	2.5	3.5	3.6	4.2	100.0
Urban areas (N = 13,176)								
Household users (%)	34.8	14.1	1.8	7.0	54.6	70.4	94.3	100.0
Quantity used[1]	31.7	9.4	1.3	4.5	2.6	8.9	81.4	-
Energy used (kgOE/mo.)	11.7	3.1	0.5	2.7	2.1	9.2	6.8	36.0
Energy expenditure (Rs./mo.)[2]	54.8	11.1	2.1	9.9	37.5	192.5	234.0	541.9
Share in total household energy use (%)	21.0	4.5	0.6	4.3	7.7	38.1	23.8	100.0

Source: 2005 IHDS.

[1] Measured in kilograms (kg) for fuelwood; dung, crop residue, coal/charcoal, and LPG; liters (l) for kerosene; and kilowatt hours (kWh) for electricity.

[2] Since rural households often do not report expenditures on non-commercial fuels (e.g., fuelwood or crop residue), we impute them using regression models.

Table 3: Estimated household electricity demand and access in rural India (N = 24,191)

Selected explanatory variable	Household access to electricity	Log household demand for electricity (kWh/mo.)	Mean and standard deviation of explanatory variables
Age of household head (years)	0.0001	0.008**	47.2
	(0.33)	(2.37)	(13.6)
Sex of household head (M = 1, F = 0)	-0.013	-0.175	0.907
	(-0.78)	(-1.10)	(0.290)
Highest education among household adult males (years)	0.012**	0.123**	5.94
	(7.16)	(9.85)	(4.90)
Highest education among household adult females (years)	0.015**	0.185**	3.42
	(7.65)	(13.36)	(4.35)
Log household agricultural land (acre)	0.049**	0.337**	2.00
	(5.92)	(4.68)	(4.50)
Village fuelwood price (Rs./kg)	0.028**	0.331**	1.64
	(2.40)	(3.28)	(0.79)
Village kerosene price (Rs./l)	0.001	0.028*	15.97
	(0.22)	(1.47)	(5.72)
Village LPG price(Rs./kg)	-0.002	-0.036	22.42
	(-0.24)	(-0.57)	(1.73)
Average availability of electricity in village (hrs./day)	0.027**	0.144**	12.3
	(5.64)	(7.04)	(6.4)
State price of electricity (Rs./kWh)	-0.224**	-0.275**	3.05
	(-4.50)	(-5.12)	(0.93)
Wald χ^2 (42)	8,395.68	4,305.77	-
$p > \chi^2$	0.000	0.000	-
Mean and standard deviation of dependent variables	0.598	32.5	
	(0.490)	(53.0)	

Source: 2005 IHDS.

Note: The access equation is implemented as a maximum likelihood probit model with sample selection, and the consumption equation is implemented as a maximum likelihood regression model. Marginal effects are reported. Figures in parentheses are t-statistics, based on robust standard errors (corrected for village-level clusters), except for the last column, where they are standard deviations. * and ** refer to significance levels of 10% and 5% or better, respectively. Explanatory variables, in addition to those reported here, include village-level prices of consumer goods and wages and a variety of infrastructure variables (e.g., village distance to paved roads or whether village has NGOs, food for work and other employment- and skills-development programs, and primary and secondary schools). In addition, state-level dummy variables are included to control for unobserved bias at that level.

Table 4: Summary statistics (means and standard deviations) of outcome variables (N = 24,191)

Outcome variable	Electricity users	Electricity nonusers	t-statistics of the difference	Whole rural sample
Consumption and collection of alternate fuels				
Kerosene consumption (liters/mo.)	2.63	2.73	-3.04	2.67
	(2.49)	(2.21)		(2.38)
Biofuel collection time (hours/mo.)				
Men	5.07	5.93	-5.84	5.41
	(11.03)	(11.47)		(11.21)
Women	10.05	12.22	-10.62	10.92
	(15.32)	(16.05)		(15.66)
Boys	0.54	1.09	-10.22	0.76
	(3.69)	(4.77)		(4.17)
Girls	0.29	0.72	-10.66	0.46
	(2.39)	(3.85)		(3.07)
Educational outcomes (children ages 5–18)				
School enrollment				
Boys	0.799	0.654	29.55	0.750
	(0.401)	(0.476)		(0.433)
Girls	0.751	0.570	33.61	0.691
	(0.432)	(0.495)		(0.462)
Study time at home (hours/week)				
Boys	6.41	4.16	30.10	5.65
	(6.85)	(5.81)		(6.61)
Girls	5.95	3.58	30.82	5.16
	(6,83)	(5.63)		(6.55)
Completed schooling (years)				
Boys	4.62	3.14	38.01	4.12
	(3.56)	(3.06)		(3.47)
Girls	4.50	2.63	46.40	3.88
	(3.59)	(2.91)		(3.50)
Employment (hours/mo.)				
Men	77.2	62.0	7.77	71.2
	(187. 7)	(55.5)		(149.5)
Women	30.6	22.2	8.34	27.2
	(91.6)	(45.9)		(76.7)
Per capita income and expenditure (Rs./year) and poverty				
Farm income	4,769.5	2,475.7	8.20	3,847.2
	(27,418.9)	(3,870.5)		(21,372.4)
Nonfarm income	5,982.9	3,030.3	16.46	4,795.7
	(16,366.0)	(8,203.5)		(13,758.5)
Total income	10,752.4	5,506.0	15.75	8,642.9
	(32,054.7)	(8,806.7)		(25,536.9)
Food expenditure	4,578.2	3,781.4	26.94	4,257.8
	(2,446.0)	(1,936.6)		(2,288.6)
Non-food expenditure	5,171.7	2,612.0	30.24	4,146.0
	(7,893.2)	(3,385.1)		(6,590.8)
Total expenditure	9,755.8	6,393.5	33.76	8,403.8
	(9,120.9)	(4,443.8)		(7,771.5)
Moderate poverty headcount	0.155	0.330	-32.64	0.225

	(0.362)	(0.470)		(0.418)

Source: 2005 IHDS.
Note: Figures in parentheses are standard deviations.

Table 5: Household electrification impacts on consumption and collection of alternate fuels (IV with district FE) (N = 24,191)

Outcome variable	Household access to electricity	Log household demand for electricity (kWh/month)
Log household kerosene consumption (liters/mo.)	-0.348**	-0.049**
	(-4.27)	(-4.88)
Biofuel collection time (hours/mo.)		
Males	-3.32**	-0.446**
	(-7.98)	(-8.74)
Females	-3.34**	-0.464**
	(-5.98)	(-6.79)
Boys	-0.38*	-0.044*
	(-1.94)	(-1.84)
Girls	-0.20	-0.026
	(-1.48)	(-1.61)

Source: 2005 IHDS.
Note: Marginal effects are reported. Figures in parentheses are t-statistics based on robust standard errors (either heteroskedastic or corrected for village-level clusters). * and ** refer to significance levels of 10 percent and 5 percent or better, respectively. Controls include household demographic characteristics (e.g., age and sex of household head, maximum education of household males and females, land and non-land assets, and access to tap water and flush toilet) and village-level characteristics (e.g., population density; distance to district headquarters, paved road, and market; presence of social programs [NGO, food-for-work, government employment, and adult education]; and prices of alternate fuels and consumer goods). Instruments include proportion of village households with electricity and the interactions of electricity with amount of household agricultural land and the age, sex, and education of household head.

Table 6: Household electrification impacts on education outcomes of children (IV with district FE) (N = 23,88 for boys; N = 22,484 for girls)

Outcome variable (children ages 5–18)	**Household access to electricity**	**Log household demand for electricity (kWh/month)**
School enrollment		
Boys	0.060**	0.009**
	(3.51)	(4.23)
Girls	0.074**	0.011**
	(4.19)	(4.93)
Study time at home (hours/week)		
Boys	1.359**	0.186**
	(5.63)	(6.17)
Girls	1.579**	0.214**
	(6.35)	(6.92)
Completed schooling (years)		
Boys	0.284**	0.038**
	(3.34)	(3.66)
Girls	0.489**	0.068**
	(5.17)	(5.85)

Source: 2005 IHDS.

Note: Marginal effects are reported. Figures in parentheses are t-statistics based on robust standard errors (either heteroskedastic or corrected for village-level clusters). * and ** refer to significance levels of 10 percent and 5 percent or better, respectively. Controls include household demographic characteristics (e.g., age and sex of household head, maximum education of household males and females, land and non-land assets, access to tap water and flush toilet) and village characteristics (e.g., population density; distance to district headquarters, paved road, and market; presence of social programs [NGO, food-for-work, government employment, and adult education]; and prices of alternate fuels and consumer goods). Instruments include proportion of village households with electricity and the interactions of electricity with amount of household agricultural land and the age, sex, and education of household head.

Table 7: Household electrification impacts on employment and economic outcomes (IV with district FE) (N = 24,191)

Outcome variable	Household access to electricity	Log household demand for electricity (kWh/month)
Log men's labor supply (hours/mo.)	0.015**	0.001
	(3.43)	(1.49)
Log women's labor supply (hours/mo.)	0.173**	0.019**
	(7.47)	(6.50)
Log per capita farm income (Rs./mo.)	0.402	-0.025
	(1.28)	(-0.73)
Log per capita nonfarm income (Rs./mo.)	0.688**	0.139**
	(1.85)	(3.27)
Log per capita income (Rs./mo.)	0.386**	0.061**
	(3.52)	(4.83)
Log per capita food expenditure (Rs./mo.)	0.137**	0.032**
	(3.01)	(5.98)
Log per capita nonfood expenditure (Rs./mo.)	0.298**	0.059**
	(3.53)	(6.01)
Log per capita total expenditure (Rs./mo.)	0.180**	0.042**
	(3.24)	(6.45)
Moderate poverty headcount	-0.133**	-0.017**
	(-5.73)	(-6.97)

Source: 2005 IHDS.
Note: Marginal effects are reported. Figures in parentheses are t-statistics based on robust standard errors (either heteroskedastic or corrected for village-level clusters). * and ** refer to significance levels of 10 percent and 5 percent or better, respectively. Controls include household demographic characteristics (e.g., age and sex of household head, maximum education of household males and females, land and non-land assets, and access to tap water and flush toilet) and village characteristics (population density; distance to district headquarters, paved road, and market; presence of social programs [NGO, food-for-work, government employment, and adult education]; and prices of alternate fuels and consumer goods). Instruments include proportion of village households with electricity and the interactions of electricity with amount of household agricultural land and the age, sex, and education of household head.

Table 8: Quantile regression estimates of household electrification impacts on income and expenditure (N = 24,191)

Quantile (percentile)	Log per capita total income (Rs./month)	Log per capita total expenditure (Rs./month)
15th	0.259**	0.115
	(2.13)	(0.89)
25th	0.297**	0.147
	(2.21)	(1.50)
50th	0.361**	0.162*
	(3.42)	(1.72)
75th	0.404**	0.253**
	(2.89)	(2.03)
85th	0.457**	0.302**
	(2.19)	(2.49)

Source: 2005 IHDS.
Note: Marginal effects are reported. Figures in parentheses are t-statistics based on analytical standard errors. * and ** refer to significance levels of 10 percent and 5 percent or better, respectively. Controls include household demographic characteristics (e.g., age and sex of household head, maximum education of household males and females, land and non-land assets, and access to tap water and flush toilet) and village characteristics (population density; distance to district headquarters, paved road, and market; presence of social programs [NGO, food-for-work, government employment, and adult education]; and prices of alternate fuels and consumer goods). Instruments include proportion of village households with electricity and the interactions of electricity with amount of household agricultural land and the age, sex, and education of household head.

Table 9: Household access to electricity in rural India by average village-level outage (N = 22,675)

Average outage at village level (hours/day)	Household access to electricity (%)[1]	Average household electricity consumption (kWh/month)[2]
0	81.0	69.0
1–5	71.6	58.5
6–10	73.1	49.5
11–15	69.7	53.1
16–20	56.4	58.5
21–24	37.9	45.9

Source: 2005 IHDS.
[1] Sample is restricted to villages with electricity.
[2] Sample is restricted to households with electricity.

Appendix

Table A1: First stage regressions for the IV estimates reported in Tables 5-7 (N = 24,191)

Selected explanatory variable	Household access to electricity	Log household demand for electricity (kWh/mo.)
Instruments		
Proportion of households in village with electricity	0.383**	2.607**
	(10.92)	(7.00)
Proportion of households in village with electricity*Age of household head (years)	-0.001*	-0.003
	(-1.77)	(-0.49)
Proportion of households in village with electricity*Sex of household head ((M = 1, F = 0)	0.051**	0.518**
	(2.13)	(2.04)
Proportion of households in village with electricity* Highest education among household adult males (years)	-0.006**	-0.002
	(-3.50)	(-0.12)
Proportion of households in village with electricity* Highest education among household adult females (years)	-0.019**	-0.108**
	(-9.93)	(-5.14)
Proportion of households in village with electricity* Log household agricultural land (acre)	-0.004	0.057
	(-0.44)	(0.54)
Other control variables		
Age of household head (years)	0.001**	0.010**
	(2.13)	(2.42)
Sex of household head (M = 1, F = 0)	-0.032*	-0.285
	(-1.64)	(-1.48)
Highest education among household adult males (years)	0.013**	0.121**
	(10.06)	(8.69)
Highest education among household adult females (years)	0.023**	0.212**
	(14.34)	(12.16)
Log household agricultural land (acre)	0.030**	0.345**
	(3.76)	(4.05)
Village fuelwood price (Rs./kg)	0.010**	0.126**
	(3.04)	(3.26)
Village kerosene price (Rs./l)	-0.001	-0.003*
	(-1.25)	(-0.38)
Village LPG price(Rs./kg)	0.001	0.034
	(0.28)	(1.35)
Average availability of electricity in village (hrs./day)	0.004**	0.028**
	(8.10)	(4.44)
R^2	0.154	0.178

Joint significance of all instruments	F=25.64 (p>F=0.00)	F=15.40 (p>F=0.00)

Source: 2005 IHDS.
Note: Figures in parentheses are t-statistics, based on robust standard errors (corrected for village-level clusters). * and ** refer to significance levels of 10% and 5% or better, respectively. Explanatory variables, in addition to those reported here, include village-level prices of consumer goods and wages and a variety of infrastructure variables (e.g., village distance to paved roads or whether village has NGOs, food for work and other employment- and skills-development programs, and primary and secondary schools).

Table A2: Results from overidentification tests of the instruments

(H0: Overidentification restriction is valid based on Hansen J statistic)

Outcome variable	Household access to electricity	Log household demand for electricity (kWh/month)
Log household kerosene consumption (liters/mo.)	$\chi^2(5) = 14.378$, $p = 0.001$	$\chi^2(5) = 13.226$, $p = 0.001$
Biofuel collection time (hours/mo.)		
Men	$\chi^2(5) = 2.423$, $p = 0.298$	$\chi^2(5) = 4.466$, $p = 0.107$
Women	$\chi^2(5) = 5.529$, $p = 0.063$	$\chi^2(5) = 6.140$, $p = 0.046$
Boys	$\chi^2(5) = 4.467$, $p = 0.107$	$\chi^2(5) = 4.973$, $p = 0.083$
Girls	$\chi^2(5) = 3.724$, $p = 0.155$	$\chi^2(5) = 3.872$, $p = 0.144$
School enrollment		
Boys	$\chi^2(5) = 10.444$, $p = 0.005$	$\chi^2(5) = 11.807$, $p = 0.003$
Girls	$\chi^2(5) = 2.642$, $p = 0.267$	$\chi^2(5) = 3.575$, $p = 0.167$
Study time at home (hours/week)		
Boys	$\chi^2(5) = 15.108$, $p = 0.001$	$\chi^2(5) = 18.538$, $p = 0.000$
Girls	$\chi^2(5) = 20.694$, $p = 0.000$	$\chi^2(5) = 22.420$, $p = 0.000$
Completed schooling (years)		
Boys	$\chi^2(5) = 43.061$, $p = 0.000$	$\chi^2(5) = 43.844$, $p = 0.000$
Girls	$\chi^2(5) = 2.864$, $p = 0.239$	$\chi^2(5) = 4.288$, $p = 0.117$
Log employment (hours/mo.)		
Men	$\chi^2(5) = 2.437$, $p = 0.297$	$\chi^2(5) = 2.740$, $p = 0.254$
Women	$\chi^2(5) = 3.869$, $p = 0.145$	$\chi^2(5) = 4.642$, $p = 0.098$
Log per capita income or expenditure (Rs./mo.)		

Farm income	$\chi^2(5) = 0.467$, p = 0.792	$\chi^2(5) = 0.557$, p = 0.757
Nonfarm income	$\chi^2(5) = 10.254$, p = 0.006	$\chi^2(5) = 8.372$, p = 0.015
Total income	$\chi^2(5) = 21.447$, p = 0.000	$\chi^2(5) = 18.232$, p = 0.001
Food expenditure	$\chi^2(5) = 1.616$, p = 0.446	$\chi^2(5) = 1.825$, p = 0.402
Non-food expenditure	$\chi^2(5) = 0.315$, p = 0.854	$\chi^2(5) = 0.001$, p = 0.999
Total expenditure	$\chi^2(5) = 1.613$, p = 0.446	$\chi^2(5) = 1.198$, p = 0.549
Moderate poverty headcount	$\chi^2(5) = 9.139$, p = 0.010	$\chi^2(5) = 14.240$, p = 0.001

Source: 2005 IHDS.

Table A3: Results from underidentification and weak instruments tests

Tests and sample type	**Household access to electricity**	**Log household demand for electricity (kWh/month)**
Underidentification test (H0: Model is underidentified based on Kleibergen-Paap LM statistics)		
For household level outcome equation	$\chi^2(6) = 629.037$, p = 0.000	$\chi^2(6) = 374.091$, p = 0.000
For individual level outcome equation (education outcomes)	$\chi^2(6) = 3191.573$, p = 0.000	$\chi^2(6) = 1841.265$, p = 0.000
Weak instrument test (H0: Instruments are weak based on Kleibergen-Paap Wald statistics)		
For household level outcome equation	F = 112.563, Stock-Yogo critical value for 5% maximal IV relative bias= 19.28	F = 64.519, Stock-Yogo critical value for 5% maximal IV relative bias= 19.28
For individual level outcome equation (education outcomes)	F = 1115.321, Stock-Yogo critical value for 5% maximal IV relative bias= 19.28	F = 481.314, Stock-Yogo critical value for 5% maximal IV relative bias= 19.28

Source: 2005 IHDS.

Table A4: Results from endogeneity test for outcome variables

(H0: Electricity access and consumption variables are exogenous)

Outcome variable	**Household access to electricity**	**Log household demand for electricity (kWh/month)**
Log household kerosene consumption (liters/mo.)	$\chi^2(1) = 4.637$, p = 0.031	$\chi^2(1) = 9.041$, p = 0.000

Biofuel collection time (hours/mo.)		
Men	$\chi^2(1) = 34.152$, $p = 0.000$	$\chi^2(1) = 54.561$, $p = 0.000$
Women	$\chi^2(1) = 13.079$, $p = 0.000$	$\chi^2(1) = 23.810$, $p = 0.000$
Boys	$\chi^2(1) = 0.472$, $p = 0.492$	$\chi^2(1) = 1.750$, $p = 0.186$
Girls	$\chi^2(1) = 0.790$, $p = 0.374$	$\chi^2(1) = 2.619$, $p = 0.106$
School enrollment		
Boys	$\chi^2(1) = 0.280$, $p = 0.596$	$\chi^2(1) = 5.111$, $p = 0.024$
Girls	$\chi^2(1) = 2.572$, $p = 0.109$	$\chi^2(1) = 9.515$, $p = 0.002$
Study time at home (hours/week)		
Boys	$\chi^2(1) = 2.351$, $p = 0.125$	$\chi^2(1) = 7.521$, $p = 0.006$
Girls	$\chi^2(1) = 8.806$, $p = 0.003$	$\chi^2(1) = 13.322$, $p = 0.000$
Completed schooling (years)		
Boys	$\chi^2(1) = 1.101$, $p = 0.294$	$\chi^2(1) = 0.003$, $p = 0.958$
Girls	$\chi^2(1) = 2.726$, $p = 0.099$	$\chi^2(1) = 11.060$, $p = 0.001$
Log employment (hours/mo.)		
Men	$\chi^2(1) = 26.60$, $p = 0.000$	$\chi^2(1) = 4.56$, $p = 0.033$
Women	$\chi^2(1) = 68.05$, $p = 0.000$	$\chi^2(1) = 60.57$, $p = 0.000$
Log per capita income or expenditure (Rs./mo.)		
Farm income	$\chi^2(1) = 5.704$, $p = 0.017$	$\chi^2(1) = 0.193$, $p = 0.661$
Nonfarm income	$\chi^2(1) = 0.765$, $p = 0.382$	$\chi^2(1) = 6.371$, $p = 0.012$
Total income	$\chi^2(1) = 3.172$, $p = 0.075$	$\chi^2(1) = 11.974$, $p = 0.001$
Food expenditure	$\chi^2(1) = 12.392$, $p = 0.0004$	$\chi^2(1) = 16.416$, $p = 0.000$
Non-food expenditure	$\chi^2(1) = 9.054$, $p = 0.003$	$\chi^2(1) = 9.808$, $p = 0.002$
Total expenditure	$\chi^2(1) = 9.731$, $p = 0.002$	$\chi^2(1) = 10.619$, $p = 0.001$
Moderate poverty headcount	$\chi^2(1) = 4.610$, $p = 0.032$	$\chi^2(1) = 11.200$, $p = 0.001$

Source: 2005 IHDS.