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Welfare Impacts of Rural Electrification

A Case Study from Bangladesh

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Abstract

Lack of access to electricity is one of the major impediments to growth and development of the rural economies in developing countries. That is why access to modern energy, in particular to electricity, has been one of the priority themes of the World Bank and other development organizations. Using a cross-sectional survey conducted in 2005 of some 20,000 households in rural Bangladesh, this paper studies the welfare impacts of households' grid connectivity. Based on rigorous econometric estimation techniques, this study finds that grid electrification has significant positive impacts on households' income, expenditure, and educational outcomes. For example, the gain in total income due to electrification can be as much as 30 percent and as low as 9 percent. Benefits go up steadily as household exposure to grid electrification (measured by duration) increases and eventually reach a plateau. This paper also finds that rich households benefit more from electrification than poor households. Finally, estimates also show that income benefits of electrification on an average exceed cost by a wide margin.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to study the rural energy demand and the welfare impacts of rural electrification projects funded by the World Bank. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at skhandker@worldbank.org.

Welfare Impacts of Rural Electrification:

A Case Study from Bangladesh[1]

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Welfare Impacts of Rural Electrification: A Case Study from Bangladesh

1. Introduction

It is universally accepted that electrification enhances quality of life at household level and stimulates economy at a broader level. The immediate benefit of electrification comes through improved lighting, which promotes extended hours of study and in turn contributes to better educational achievements. Lighting can also benefit other household activities, such as sewing by women, social gatherings after dark, and so on. Electric gadgets such as radios and television improve the access to information by rural households and can provide entertainment to family members. In addition, household's economic activities both inside and outside the home benefit a lot from electricity. For example, crop productivity can be increased by the application of electric irrigation pumps, businesses can be operated longer hours in the evening, electric tools and machinery can impart efficiency and productivity to industrial enterprises, and so on. The benefits of electricity have been discussed in a large body of literature (Unnayan Shamannay and Development Design Consultants Ltd. 1996; Barkat et al 2002; Cabraal and Barnes 2006; Barnes, Peskin and Fitzgerald 2003; Kulkarni and Barnes 2004; Khandker 1996; Filmer and Pritchett 1998; Roddis 2000; World Bank 2002; Agarwal 2005).

Rural electrification projects are often justified because they are intended to promote household welfare by providing a better quality of life or more productivity. This view − along with the significance of other sources of modern energy − has resulted in modern energy being recognized as essential to fulfilling the Millennium Development Goals (United Nations 2005). Over the years there have been various studies that have examined the impact of rural electrification on development in Bangladesh (Barakat and et al 2002; Halim 2005; BETS-BUP 2006; Unnayan Shamannay and Development Design Consultants Ltd. 1996). Even though these studies have found significant benefits of electrification, most of them have simply showed the correlation between rural electrification and development. For example, these studies have examined impacts on income. However, examining impacts of electrification on income are problematic because it is well documented that people with lower income either put off adopting electricity once it becomes available, or may not have the money to pay for the connection fees and other costs of electricity. That is, it is not clear what causes what. In general, the common problem with an impact assessment study is the failure to address causality issues, such as endogeneity of program placement and household participation in an electrification development project. This study uses econometric techniques to determine the net effects of rural electrification, after controlling for endogeneity. More specifically, this study estimates benefits of rural electrification of the REB project on various household and individual welfare outcomes using a 2005 survey of rural households.

This paper is organized as follows. An overview of rural electrification in Bangladesh is given in Section 2. This section examines the institutional development and role of the Rural Electrification Board (REB) in providing electricity to rural customers. Since late 1970s the REB has been promoting electricity in rural areas throughout the country. In section 3, the survey methodology and data used for of this study are described. This section also provides some basic information on electricity use patterns in rural areas. In Section 4, we explore the influence of both household and village characteristics on household demand for electricity. The causality issues in estimation of electrification impacts are addressed in Section 5 using two techniques, which are Propensity Score Matching (PSM) and instrumental variable (IV) regression. Both methods are commonly used to address the complicated causality issues that are inherent in impact assessment exercises. Section 5 also reports findings based on these techniques. The impact of having electricity is taken one step further in Section 6 by looking at the benefits of long-term exposure to electricity, and examining whether the benefits tend to decline over time. Section 7 explores if the distribution of the benefits of electricity vary among rich and poor households. Finally, in the last section we conclude the paper with the policy implications of the study.

2. Rural electrification in Bangladesh: The contribution of REB

After the independence of Bangladesh in 1971, the first major initiative to extend grid electricity in rural areas was taken in 1975 under a scheme called 'Total Electrification Programme'. This program looked beyond grid connectivity towards development of the basic distribution facilities for effective delivery of power to rural areas by 1978. At around the same time, establishing an institutional structure was considered, which would develop the technical, economic, financial and social analysis, and organizational requirements for a rural electrification project in Bangladesh. Then at the request of the Bangladesh Government Rural Electrification Project Committee, a decision was taken for the establishment of a new national agency under the Power Ministry to develop and administer a rural electrification program. Accordingly, Rural Electrification Board (REB) was established on 29 October, 1977 and started functioning on 1 January, 1978 with following basic objectives:

- Ensure consumer participation in policy-making.
- Provide reliable, sustainable and affordable electricity to rural people.
- Help improve the economic condition of rural people by providing electricity for agriculture and small industries.
- Help improve the living condition of rural people.
- Expand electrification to entire rural Bangladesh.

The REB program operates through locally organized rural electric associations called *Palli Bidyut Samity* (PBS). The concept of PBS is based on the model of Rural Electric Cooperatives in USA, which operates with cooperatives and ownership of consumers. A PBS is an autonomous organization registered with REB, and it owns, operates and manages a rural distribution system within its area of jurisdiction. Its members are its consumers, who participate in its policy-making through elected representatives in its governing body. REB's role is to provide PBS with assistance in initial organizational activities, training, operational and management activities, procurement of funds, and providing liaison between PBS and the bulk power suppliers like Bangladesh Power Development Board (PDB), Dhaka Electric Supply Authority (DESA), and other concerned Government and Non-Government agencies. The area coverage of one PBS is usually 5-10 *thanas* (sub-districts) with a geographic expanse of 600-700 sq. miles.

The first PBS was established in 1980 to operate in Dhaka, and as of 2007 a total of 70 PBSs are working in some 46,000 villages in 61 districts and serving more than 7 million rural customers all over Bangladesh (REB 2007). Since the inception of REB, rural electrification has grown significantly – starting from less than 10 percent connectivity in 1977, about 61 percent villages have received electricity by 2007.[2] Under REB's program, about 800,000 new rural customers get electricity every year, which is phenomenal for a poor country like Bangladesh. The REB consumers are mostly domestic users of electricity (85 percent), although industrial and commercial customers are also served, including those needing connection for irrigation pumps. REB plans to cover 75,000 villages of Bangladesh by the year 2020.[3] A detailed breakdown of rural electrification rates by region is given later when we discuss the sample data.

The rural electrification program of REB is often viewed as one of the most successful government programs in Bangladesh. A 2004 study of electricity distribution and transmission in Bangladesh found that system loss in 2000 for REB was much lower (16 percent) than that for other major electricity distribution bodies – PDB (28 percent), DESA (30 percent) and DESCO (33 percent) (Alam and others 2004).[4] This is because the usual distributional problems that plague other Bangladeshi distributors (theft, non-payment of bill by influential subscribers, illegal connection, over-billing, etc.) are almost nonexistent in the operation of REB. REB also has an almost perfect bill collection record - over 95 percent of the REB customers pay their bills. REB has improved further since 2000, and reported a 13 percent system loss during 2005-2006 (REB 2007), which compares quite favorably to the system loss in other South Asian countries. The success of REB is due mostly to its autonomy, minimal bureaucracy, strong culture of integrity, donor support and trust, and strong and independent leadership (USAID 2006).

The political appeal of the REB and other worldwide rural electrification programs is that many of the benefits for the countries seem obvious. Because of the electric lighting, household members can engage themselves in useful and productive activities in a way that is not possible or at least very difficult in households without electricity. For example, students can study more easily and comfortably after the dark, adults can postpone chores until the evening, access mass media through TV and radio, and so on and so forth. Besides

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[2] Our data, which were collected in 2005, show a 58 percent connectivity at village level in Bangladesh.

[3] According 1991 census, total number of villages in Bangladesh is about 86,000. The 11,000 villages that are not included in REB's plan are covered by PDB, DESA and other distributors.

[4] System loss is the difference between the quantity produced (generated) and the actual quantity sold, and is expressed as a percentage of the quantity produced. It is a widely accepted measure of the efficiency of the distribution system.

households, business and retail enterprises with electricity can continue operating and keeping their stores open during the evening. It is the purpose of this paper to rigorously examine whether these assumed program benefits are real or not.

3. Research methods and survey data

This study is based on a survey initiated by REB with the financing from the World Bank in 2004. The survey was titled "The Socio-Economic Monitoring and Impact Evaluation of Rural Electrification and Renewable Energy Programme in Bangladesh." The purpose of the survey was to develop practical methods and guidelines to monitor, and evaluate rural electrification programs of REB. The task involved undertaking a large baseline survey to assess the socioeconomic impacts of the rural electrification program of REB and to develop quantitative and qualitative methodologies to assess benefits of rural electrification. In order to carry out the monitoring and evaluation work, the study also aimed to enhance the internal capacity of REB and its affiliated PBSs. The actual survey was carried out in 2005 by Bangladesh Engineering and Technological Services Ltd. (BETS) and Bangladesh Unnayan Parishad (BUP).

The survey administered detailed questionnaires for domestic, commercial, industrial and irrigation units with and without electricity. Domestic questionnaires included information on household characteristics, consumption, income, energy use pattern and appliances. The energy questions in the survey covered electricity use, grid connection and quality of service, use of solar home systems, and also household perception about the quality of services. There were also qualitative questions on women's empowerment and general health awareness. Questions in commercial enterprises and industry survey involved the nature of the businesses including their operation, cost and revenue, and consumption of various types of energy including electricity. For the irrigation survey there were questions on pumps, usage patterns, cost of operation, crop production and energy consumption. All this information is useful to determine the energy use pattern of both domestic and non-domestic units and to assess impacts of rural electrification. However, in this study we concentrate solely on the impacts of household use of electricity.

The survey covers a wide geographical area covering all six divisional regions of Bangladesh that are under the operation of REB. In fact 45 out of a total of 70 PBSs operating in Bangladesh were covered by the survey. A stratified random sample was drawn according to their electrification status. Thus, the sample contains roughly 50-50 split between those with and without electricity. The domestic, commercial, industrial and irrigation samples were selected based on actual distribution within rural Bangladesh – that is 85 percent domestic, 11 percent commercial, 2.5 percent irrigation, and 1.5 percent industrial samples were selected. As for the control group, samples were drawn in equal proportion from three types of areas: villages with electricity, project villages without electricity (these villages were expected to get electricity during the ongoing project period), and non-project villages without electricity (these villages were not expected to get electricity during the ongoing project period). In addition, a small number of households (1,000) were purposely selected in the sample areas that own solar home system (SHS). The final collected sample shown in Table 1, and as usually the case it varied slightly from planned sample (see BETS-BUP 2006 for more detailed description).

Electrification status by village and household in all six regions, as found in the data, is reported in Table 2.[5] While Sylhet region has the highest proportion of villages that have electricity (63.9 percent), proportion of households in electrified villages is highest in Chittagong region (68.2 percent). Chittagong region overall has also the highest proportion of households with electricity (40.3 percent). Barisal region on the other hand has the lowest household electrification rate (23.1 percent). Overall, about 57 percent of Bangladeshi villages have electricity, 58.2 percent of households in those electrified villages have electricity, and 33.1 percent rural households in whole Bangladesh have electricity.[6]

We begin by comparing cases with and without electricity both at village and household-level. The main variables of interest for this study are consumption expenditure and income at household level, and completed schooling years and study hours at individual level. Compared to the households in villages without electricity, those in villages with electricity have significantly better schooling outcomes (Table 3). However, the differences in economic outcomes are not consistent. The village level electricity benefits may also include direct benefits to households and (indirect) spillover benefits, such as street lighting

[5] During data cleaning 16 households were dropped, keeping 20,900 households for analysis. Since electricity users are overdrawn in the sample, all figures and estimations used in this paper are weighted using actual PBS-level distributions of users and nonusers.
[6] This figure is close to the finding of a recent study based on a survey of rural households conducted in 2004 (World Bank 2008).

available to all households.[7] This stresses the need for a close look at the complicated causal factors involved in examining development impacts.

The direct benefits of electrification are those that go directly to the households who have electricity. For households without electricity but located in villages with grid service, there is a possibility of indirect benefits as just mentioned. Finally, there are households in villages without electricity service. Households with electricity have decidedly better levels of income, expenditures, and education than those without electricity (Table 4). However, households without electricity in villages with electricity are worse off than those in villages without electricity. This is not surprising, because households in villages without electricity are expected to be a mix of all socioeconomic classes, but those without electricity in villages with grid service tend to be among the poorest in the community (a bulk of these households cannot afford connection or other costs). Overall, households with electricity are generally better off than those without electricity.

Next we examine if the differences in household welfares by electrification are statistically significant. Table 5 reports the differences in household income, expenditure and education by their electrification status. The households with electricity are compared to households without electricity in both villages with and without electricity. The differences in income and expenditure levels are expressed in log forms. As expected, households with electricity have higher levels of benefits compared to either of the two other groups and these differences are significant. The question can be asked whether this means that having electricity in a household conclusively contributes to better welfare. At this point it is not possible to make such an assertion because we have not yet explored the factors that may have contributed to such differences in welfares. Furthermore, we know that grid electricity service is extended first to more developed and densely populated regions (for revenue maximization), and it is only later that they reach more remote and poorer areas. Therefore, assessing the causal impacts requires an examination of the underlying reasons for electricity program placement and program participation.

[7] Spillover benefits are possible in other ways too. For example, electrification may generate village-wide economic activities and growth which the nonusers of electricity, besides the users, can benefit from.

4. Household characteristics and electricity adoption

The first use of electricity in rural areas is household lighting. The reason is that electric light is much brighter than that provided by kerosene lamps, and the price per unit of light can be hundreds of time cheaper. Because of frequent power outages, people do not discard their kerosene lamps after they have grid connection, but relegate it to a standby energy source. Over time households diversify their electricity consumption by acquiring different electric appliances such television, radio, electric fans, refrigerator, electric pumps (for expanding crop production) and other tools and machinery (for home-based or outside enterprises). According to an earlier analysis of this survey data, the major uses of electricity in rural Bangladesh are reported to be for children's education (83 percent), followed by entertainment (44 percent), information access (22 percent), and home-based businesses (9 percent) (BETS-BUP 2006).

Given these benefits, it is important to examine what determines electricity adoption at the household level. To accomplish this, we look at a number of factors at the household and village level, including household's physical endowments (such as land) and human capital (such as adults' education), price of different fuels in the village and others. Since household electrification can only be observed in villages that have electricity, the issue of sample selection needs to be addressed in estimating household's access to electricity.[8] Under this condition, instead of a simple probit model, a maximum likelihood probit model with sample selection is implemented using a two-stage procedure that involves a latent equation and a selection equation (Van de Ven and Van Pragg 1981). The selection equation that determines village electrification is of following form:

$$V_j = a^v + \beta^v Z_j + \varepsilon^v{}_j \qquad (1)$$

And household electrification (latent equation) is given by,

$$E_{ij} = a^e + \beta^e X_{ij} + \gamma^e U_j + \varepsilon^e{}_{ij} \qquad (2)$$

[8] Of course village electrification is only a necessary but not a sufficient condition for household electrification, as there are many households without grid connection in electrified villages.

where, X_{ij} is a vector of household level characteristics (for example, head's age, gender, household landholding, etc.); U_j and Z_j are vectors of village characteristics where Z_j contains at least one variable that is not in U_j; ε_{ij}^{e} and ε_{j}^{v} are unobserved random errors; and β^e, and γ^e are parameters to be determined. Here, household electrification is observed ($E_{ij} = 1$) only if village electrification is observed ($V_j = 1$), and error terms satisfy the following conditions:

$$\varepsilon_{ij}^{e} \sim N(0,1)$$

$$\varepsilon_{j}^{v} \sim N(0,1)$$

$$corr(\varepsilon_{ij}^{e}, \varepsilon_{j}^{v}) = \rho$$

When $\rho \neq 0$, a simple probit estimation applied to equation (2) gives biased results, but a maximum likelihood probit model gives consistent and asymptotically efficient estimates of household electrification. We use regional dummies and village infrastructure variables in the selection equation (in Z_j), but not in U_j. The idea behind this formulation is, once village electrification is determined by regional and community characteristics, it is mostly the household characteristics that will determine household's grid connectivity.

The summary statistics of dependent and explanatory variables used in the electrification demand and subsequent impact equations are presented in Table 6. The table shows that households with electricity are clearly better off than those without electricity in terms of general characteristics.[9] For example, households with electricity have more land asset and more educated adult members than their counterpart households without electricity. These variables are used to predict whether or not a household adopts electricity. Household landholding is included as a proxy for income to denote household's welfare status because, unlike income, it does not change in the short term and therefore is not likely

[9] An exception is household's landholding. Our data show that within villages with electricity, average landholding of electrified households (118.22 decimals) is much more than that of non-electrified households (74.74 decimals). However, households in non-electrified villages have more land (average value of 150.50 decimals) than the electrified households, causing the overall average landholding of non-electrified households to be higher than that of electrified households.

to be changed due to the adoption of electricity. Results shown in Table 7 indicate the relationship between the household characteristics and the adoption of electricity.

In general, both the descriptive statistics in Table 6 and the impacts in Table 7 are very consistent. Again, households with members having a better education, greater land assets, and better housing conditions are more likely to adopt electricity. Residents of brick houses are 68 percent more likely to have electricity than those living in inferior homes. At village level, higher firewood prices increase the likelihood of electricity adoption by village residents, while the prices of kerosene or diesel play no role. In summary, households with better physical and human endowments are more likely to have electricity than those without such endowments.

Estimation also shows that $\varrho < 0$, meaning the unobserved factors that determine the program placement at the village level do not necessarily determine household's access to electricity. In other words, there are unobserved household factors relevant to household electrification which may be quite different from the productive potential of a village that attract investment in electricity at village level.

5. The impact of rural electrification

The main difficulty in project impact evaluation is to find a counterfactual. This means examining the scenario as to what would have happened to the households with electricity if they did not have electricity. One way to deal with this counterfactual is to make electricity available in a randomized fashion and then observe how households similar in all characteristics except electricity compare with one another. But randomization is very difficult to implement for most infrastructure projects (such as rural electrification) because of policy and economic reasons. In order to be financially viable, electricity providing entities generally follow a plan to reach more developed and densely populated communities first before moving the services out to more remote and less developed areas. As a result, it is necessary to statistically create (or simulate) a counterfactual situation in order to compare similar households with and without electricity.

There are two methods commonly used to deal with the counterfactual issue. One is to identify close matches for household with and without electricity that are similar in most other ways. Over a large sample such as the one available for our study, it is quite possible to match a large number of households. The most widely used matching technique for this purpose is the propensity score matching (PSM). The second method estimates an outcome equation conditional on program participation. The reasoning behind this approach is that some factors related to adoption of electricity may not be directly related to the outcome variables. For example, price of electricity can be a potential candidate for such factor, because it affects the adoption of electricity by a household but does not directly affect its income. The method that uses this type of estimation is the instrumental variable (IV) method. We will use both methods in assessing the impacts of household electrification.

Propensity score matching (PSM) technique:

As discussed earlier, a simple comparison of households with and without electricity just gives a snapshot of the outcomes without any consideration as to what causes them. These households may vary fundamentally in initial characteristics and also their ability to access to electricity. The calculated benefits may be due to the differences in household or village characteristics rather than in having electricity. We address this problem in part by using a matching technique. At the heart of any matching technique lies the identification of a counterfactual, which identifies households with no intervention to compare with households with similar characteristics but with intervention. Essentially this is a simulation of with and without scenarios. This technique involves first by matching households with and without electricity based on observed pre-intervention characteristics. After this matching is done, this is possible to observe the difference of average outcome values between these two groups (just like the single difference method). Households that cannot be matched are discarded from this comparison process.

Propensity score matching (PSM), is the most commonly used matching technique which goes further than directly matching observable characteristics. The PSM technique calculates for both treated (with electricity) and untreated (without electricity) samples, the probability of treatment or electrification as a function of household or village characteristics from a logit or probit model. This probability of adopting electricity, calculated for households both with and without electricity, is called propensity score. The outcomes of treated units are then compared with those of untreated units. Rosenbaum and Rubin (1983) show that if treatment is random within cells defined by X, it is also random within cells defined by the values of the propensity score $p(X)$. So, if the propensity score $p(X_i)$ is known, the impact of the treatment (which they call Average effect of Treatment on the Treated or ATT) can be estimated as follows:

$$\begin{aligned}\tau &\equiv E\{Y_{1i} - Y_{0i} \mid D_i = 1\} \\ &= E\{E\{Y_{1i} - Y_{0i} \mid D_i = 1, p(X_i)\}\} \\ &= E\{E\{Y_{1i} \mid D_i = 1, p(X_i)\} - E\{Y_{0i} \mid D_i = 0, p(X_i)\} \mid D_i = 1\}\end{aligned} \quad (3)$$

where the outer expectation is over the distribution of ($p(X_i) \mid D_i = 1$) and Y_{1i} and Y_{0i} are the outcomes in the two counterfactual situations of (respectively) treatment and no treatment.[10]

One disadvantage of PSM method is that matching process may discard a significant number of observations from the original sample non-randomly, making the working sample unrepresentative. We will discuss two alternative uses of propensity score that can take care of this problem. First, the estimated propensity score, instead of the actual treatment variable, can be added in an OLS regression of the outcome variable:

$$Y_{ij} = \alpha^y + \beta^y X_{ij} + \gamma^y V_j + \delta^y P_{ij} + \mu_j + \eta_{ij} + \varepsilon^y{}_{ij} \quad (4)$$

where, Y_{ij} is the welfare outcome of the *i*-th household of the *j*-th village, X_{ij} and V_j are vectors of household and village characteristics as defined before, P_{ij} is the propensity score (household's probability of adopting electricity) which replaces the actual electrification variable indicating household's access to electricity, β^y, γ^y, δ^y are parameters to be estimated, μ and η are unobserved determinants of household outcome at village- and household-level respectively, and ε^y is an unobserved random error. This procedure can remove any omitted variable bias that would have resulted using a simple OLS regression (Ravallion 2005, Imbens 2004). A disadvantage of this method is it assumes a functional form which standard PSM technique does not. A second way is to use in the OLS regression of the outcome variable a weight variable constructed from the propensity score: the weight

[10] More on PSM technique can be found in Becker and Ichino (2002).

is defined as $1/\sqrt{P_{ij}}$ for treated households and $1/\sqrt{(1-P_{ij})}$ for control households.[11] The resulting equation looks like:

$$Y_{ij} = \alpha^{y} + \beta^{y} X_{ij} + \gamma^{y} V_{j} + \delta^{y} E_{ij} + \mu_{j} + \eta_{ij} + \varepsilon^{y}{}_{ij} \tag{5}$$

where, E_{ij} is the actual treatment variable indicating household's access to electricity and this equation is estimated using a weight variable calculated. A study by Hirano, Imbens and Ridder (2003) shows that by using propensity score to calculate weight balances the covariates and results in fully efficient estimates. We implement all three approaches of propensity score for comparison and to check the robustness of the results.

Implementations of the PSM technique show that rural electrification has a significant and generally positive impact on income, expenditures and education (Table 8). The figures in the second column show standard PSM estimates with Kernel matching.[12] The third column includes regression estimates in which the propensity score or likelihood of having electricity is used instead of the actual electrification status of the household in OLS outcome regression. In the last column shows a regression estimate that uses a weight derived from the propensity score, as defined before.

The results show that, in almost all cases, reported impacts for economic outcomes are highest in standard PSM implementation and lowest in the first alternate implementation. For example, electrification impact on per capita expenditure is 15.4 percent in standard PSM, 6.0 percent in first alternative, and 9.2 percent in second alternative. Educational impacts are also highest in standard PSM, except for girls' schooling years where impact in first alternative is the highest. Girls schooling years increase by 0.23 grade, 0.36 grade and 0.12 grade due to electrification in standard PSM, first alternative and second alternative respectively. Overall, we see that different implementations of PSM are very consistent among themselves in the direction of impacts.

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[11] A variation of the formula for weight (without the square root sign) is also used. However we prefer the square-rooted version because it scales down the variation in weight.

[12] In Kernel matching, each unit (household in our case) in the treatment group is matched to a weighted average of *all* units (as opposed to fewer units used in some other matching) in the control group, with greater weight being given to units with scores that are closer.

Instrumental variable (IV) technique:

Although PSM technique controls for biases due to observed characteristics, it still cannot correct biases due to unobserved characteristics or endogeneity. For example, some people are more motivated than others, and this may cause them to be early adopters of electricity. The degree of this motivation or dynamism is not observable, but it can still bias estimates obtained through PSM technique. The problem of endogeneity might also arise from criteria used for program placement and this is typically not a random process. For example, the REB does not just randomly select a village for electrification, but conducts feasibility studies before making a decision to extend electricity to villages. As a consequence, it is likely to select a village for electrification that is very different from the unselected villages. This section addresses the issue of such endogeneity bias and a possible estimation strategy to control for it.

Let us assume that outcome of a particular kind (such as consumption or income) measured by Y_{ij}, conditional on the treatment of household electrification (E_{ij}), can be expressed by equation similar to equation 5, which is repeated here:

$$Y_{ij} = \alpha^y + \beta^y X_{ij} + \gamma^y V_j + \delta^y E_{ij} + \mu_j + \eta_{ij} + \varepsilon^y{}_{ij} \qquad (5)$$

where, Y_{ij}, X_{ij}, V_j and E_{ij} have the same definition as mentioned before, β^y, γ^y, δ^y are parameters to be estimated, μ and η are unobserved determinants of household outcome at village- and household-level respectively, and ε^y is an unobserved random error.

If all variables are observable (that is, μ and η are absent), δ^y would determine, without bias, the impact of household electrification. In that case, we can use a reduced form ordinary least squared (OLS) regression to estimate δ^y. However, since μ and η are unobserved, the estimated impacts of electrification would be biased if household's access to electricity is influenced by those unobserved variables. As a consequence, a household's decision to have electricity may be correlated with the error term ε^y, giving rise to possible endogeneity.

One way to resolve the endogeneity bias is to use household fixed-effect regressions. But with cross-sectional data that is not possible. Another way to resolve the endogeneity is to use instrumental variables (IV) estimation. The idea is to first identify *suitable* instruments that can influence household's access to electrification (E_{ij}) but *not* the error term (ε^{y}). In other words, instruments should not directly influence the outcome Y_{ij}, but only through the intervention (access to electricity). Household's access to electricity (E_{ij}) is predicted using instrumental variables in a probit regression, and then the predicted value of that access ($\hat{E}_{ij}$), instead of actual E_{ij}, is used in the second stage outcome equation (5). This works because instrument variables break the correlation between the treatment and the error term, thereby eliminating the endogeneity bias.

Selecting appropriate instruments is crucial. One possible way of finding good instruments is to apply demand theory. According to demand theory, the prices of endogenous variables could be good candidates for instrumental variables if the market is competitive, and we also mentioned briefly the price of electricity as a potential instrument. However, the price of electricity is fixed and the demand for electricity is more conditioned by the availability of electricity rather than the price of electricity, and so electricity price cannot be used as an instrument. Instead, the presence of electricity in the village can be a possible instrumental variable. However, the presence of electricity in a village (or its allocation) is itself endogenous and can be determined by several factors including the general wellbeing of the village, which may also influence household welfare outcomes we are trying to estimate (for example, income). So we need more than village electrification – something which is exogenous to this whole process. We take a closer look at household's decision making to connect, as village electrification by itself does not ensure the access of electricity by a household.

After REB expands its electrification program to a village, a household has to make a conscious choice to adopt electricity. The connection cost is probably the most significant factor influencing a household's decision to adopt electricity. In Bangladesh, the process works as follows. For households living within 100 feet of the electricity line or lines that run through a village, connection cost for obtaining electric service is highly subsidized and therefore low. By contrast, the connection cost charged by the electric cooperatives for households beyond 100 feet from the line is much higher as they have to bear the full cost of connection. For all practical purposes, we can say that households living within 100 feet of electric line have a choice in getting electricity, while those living farther or in villages without electricity do not. Thus, a household's location within or beyond 100 feet of an electricity line can be used as an instrument, since it influences household's grid electricity adoption but not directly their outcomes.

REB prioritizes villages for grid electricity connection based on the potential revenue generated by market conditions. The revenue criteria require that each kilometer of line constructed generates roughly US$400 per month to cover the operating costs (Waddle 2007). Once a village is so identified, REB selects a location to lay out the electric line and poles – a location with enough population to generate desired revenue. A densely populated location does not imply that the location is economically prosperous, particularly in Bangladesh. The PBSs optimized the line placement on the basis of population density to enhance revenue. So we contend that a household's choice for grid electrification, which is determined by its location relative to the electric line, is fairly independent of the household's income. Our data also finds very little correlation between the choice variable (determined by household's proximity to electric line) and household's welfare outcomes.[13] So we use this choice variable (which is 1 if a household is in a village with electricity and either has adopted electricity or is located within 100 ft of electric line, and 0 otherwise) for instrumentation in the IV estimation.

We interact this choice variable (let us call it C_{ij}) with X_{ij} and V_j variables to get the set of household level instruments. The first stage equation now can be written as,

$$E_{ij} = \alpha^e + \beta^e X_{ij} + \gamma^e V_j + \phi^e C_{ij} + \lambda^e (C_{ij} X_{ij}) + \rho^e (C_{ij} V_j) + \varepsilon^e_{ij} \qquad (6)$$

Both PSM and IV methods have their own advantages and disadvantages. An IV method controls for both observed and unobserved characteristics, while PSM cannot control for unobserved characteristics. But unlike IV or any regression technique, PSM does not assume a functional form, which is certainly an advantage.

Even with the compelling reasons for using IV estimation, it is a good idea to test whether an OLS or an IV approach is the more appropriate estimation technique with the data at hand. To examine this issue, the results from both OLS and IV approach are

[13] Correlation between choice and household's land, income or expenditure is less than 10 percent.

presented in Table 9 along with results of an endogeneity test.[14] The results of the Hausman test for endogeneity reject the null hypothesis in 5 out of 8 outcomes at 5 percent level, confirming that IV estimation is the better method for this situation. We report the OLS results for comparison nevertheless. Most of our earlier findings still hold, and it is mainly the magnitude of the impact that changes. Household per capita expenditure increases by 8.2 percent and overall total income goes up by 12.2 percent due to electrification. Examining the components of income, it appears that having electricity improves both farm and non-farm income. In addition, the impact of household electrification on educational outcomes is quite positive, improving school completion rates as well as study time of both boys and girls. So we can summarize our findings by saying that electrification has a significant positive impact on household's socio-economic welfare, and various impact assessment techniques yield very similar results.

6. The growth and persistence of the benefits of household electricity

The welfare impacts estimated so far report the average value of benefits accrued to all households that have electricity. However, another important issue to investigate is how these benefits grow over time as the households add electricity appliances and increase the use of electricity. It is quite likely that the benefits vary according to the length of time that a household has electricity. For example, a household with electricity service for 5 years would be expected to benefit more than the one having it for just a few months. Over time, households are expected to consume more electricity, diversify its use through accumulation of various appliances, and make more productive use of electricity.

To examine the relationship between the benefits of electricity and household's exposure to electricity, households are grouped according to the length of time they have had electricity. Form Table 10, a trend of increased use of electricity from prolonged exposure to electrification is obvious. Because the rural electrification program in Bangladesh has been growing rapidly during the last five years, households that have grid for 5 years or less are the most common, accounting for about 40 percent of all households with electricity. Also, as expected, the demand for electricity goes up with the length of time that

[14] Here the null hypothesis is that both OLS and IV estimates are consistent, and the alternate hypothesis is that only the IV estimate is consistent. If the null hypothesis is true, OLS model should be used because it is more efficient. Otherwise, IV model should be used.

a household has had electricity. On an average, there is roughly an increase of 5.0 kWh per month in electricity consumption for every 5 years that a household has electricity.

The next question is, does this increase in the time lead to an increase in household benefits, and if so, how much? To answer this question we examine the relationship between time of electricity adoption and income, expenditures and education. The descriptive results in Table 11 verify that most welfare outcomes improve steadily with the duration of household's electricity use. For example, households having electricity for more than 15 years have a 17 percent higher consumption expenditure and 43 percent higher income than those using electricity for 5 years or less. Given this trend, it is a good idea to explore a quantitative relationship between the length of a household's electricity use and its welfare. At the same time, another question arises - does the electrification benefit keep going up indefinitely or slow down after some time? To examine these issues, we model a regression similar to equation (5) and replacing the household's access to electricity, E_{ij}, with duration of electricity use (D_{ij}) and also adding the squared term of the duration:

$$Y_{ij} = a^{y} + \beta^{y} X_{ij} + \gamma^{y} V_{j} + \delta^{y} D_{ij} + \lambda^{y} D_{ij}^{2} + \mu_{j} + \eta_{ij} + \varepsilon^{y}{}_{ij} \qquad (7)$$

We use the same instruments for duration and its squared term as we did in the model for electrification benefit equation. However, for simplicity, we limit the analysis to household income among all outcomes. As Table 12 shows, it is apparent that an additional year of exposure to electricity increases household's income by 6.9 percent but squared duration shows a 0.4 percent decrease, implying a saturation in income growth due to electrification in the long run. Adjusting for the negative effect of the squared term, the net impact of duration on total income becomes less than 6.9 percent and is given by the expression (δ-2λ), which is 6.1 percent.

The results indicate that impact of electrification on household income slows down in the long run and eventually flattens out once benefits are fully realized. This is when the marginal impact of duration on income changes from positive to zero, and it can be calculated by differentiating income Y in equation (7) with respect to duration *D* and setting $\frac{dY}{dD}$ to 0. So the time at which return to household income diminishes to zero is given by the expression: $D_c = \frac{\delta}{2\lambda}$. From the results shown in Table 12, this duration is found to be 8.6 years for benefits in income. This scenario is depicted in Figure 1, where outcome (Y) is plotted against duration (D). As the figure shows, the outcome increases as duration increases until a point is reached (point C on the curve) when outcome becomes flat. The tangent on the curve at this point is horizontal (parallel to X-axis) and $\frac{dY}{dD}$ turns from positive to zero.

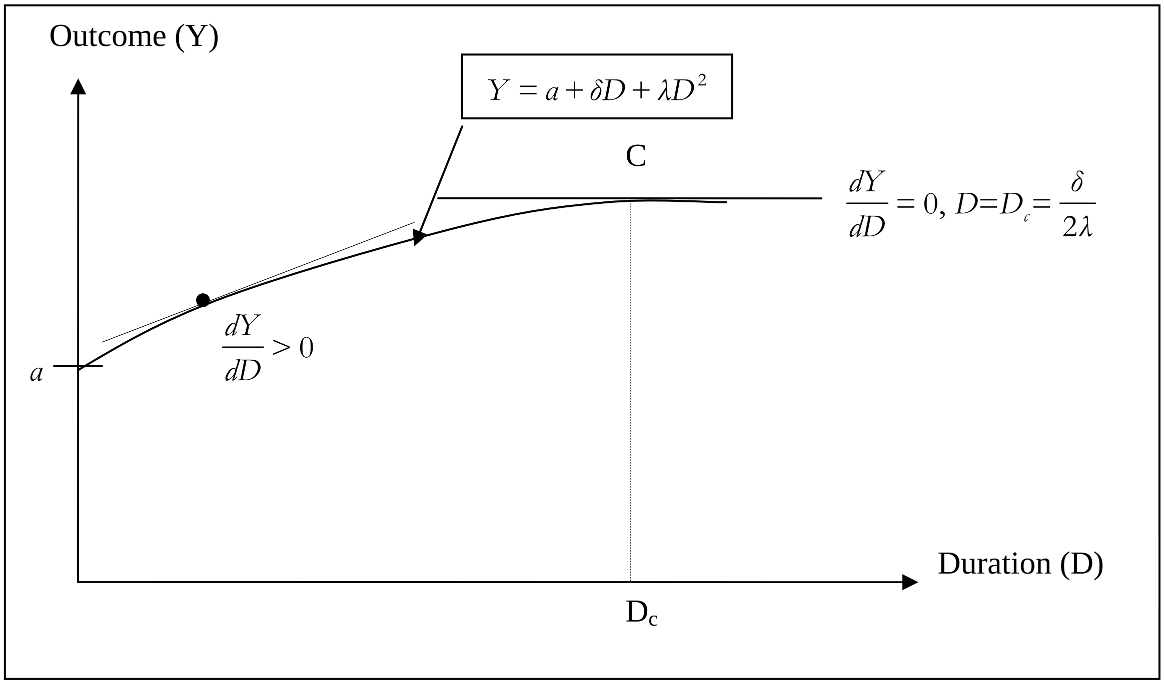

Figure 1: Long-term relationship of household outcome and duration of electricity

7. Are the benefits of electricity equitable?

One of the major objectives of any major development projects such as rural electrification is to improve the livelihood of the poor. Access to electricity is highly dependent on household's physical and human capital endowments (as shown in Table 4). Furthermore, rich people are expected to diversify electricity use with the adoption of a greater number of modern appliances and amenities. This raises the questions as to whether this unequal consumption of electricity and appliance ownerships results in unequal distribution of electrification benefits among the households that have electricity. This is a critical issue for policy-makers, because critics may contend that rural electrification projects may not benefit the poor much, and money allocated to these projects, if allocated to alternate projects, might impart more benefits to poor households. In this section, we investigate whether electrification benefits of rich households are different from that of poor households.

For this exercise, we consider household's land asset as proxy for household's economic welfare, because it is a common practice in rural Bangladesh besides the fact that household's land does not vary in the short-term. To make a meaningful use of this variable, we create two dummy variables. The first dummy captures those households that have more than or equal to half an acre of land, and the second one captures those having less than half an acre of land. The choice of half and acre as the threshold value is guided by the fact that half an acre is often used as a cut-off point for poverty level of rural Bangladeshi households. We interact these dummy variables with household's access to electricity and use those interactions, instead of original electrification variable, in the regression model similar to that used to estimate general impacts of electricity. The idea is to separate the electrification benefits for two groups of households. The resulting equation looks like this,

$$Y_{ij} = a^{y} + \beta^{y} X_{ij} + \gamma^{y} V_{j} + \lambda^{y}(L_{ij1} * E_{ij}) + \chi^{y}(L_{ij2} * E_{ij}) + \mu_{j} + \eta_{ij} + \varepsilon^{y}_{ij} \qquad (8)$$

where L_1 (household has at least half an acre of land) and L_2 (household has less than half an acre of land) are the dummy variables from household's landholding, and λ and χ are parameters to be estimated.[15] The interaction parameters can be interpreted as the electrification benefits for land-rich and land-poor households respectively, and Table 13 shows the results.

From the results it is obvious that rich households benefit more than poor households from electrification. Electrification impacts on per capita expenditure for rich households (12.4 percent) are four times more than that for poor households (3.1 percent). Having electricity improves farm income a lot for rich households (almost 50 percent) without any significant impact on farm income of poor households. Obviously farmers with larg landholdings make more investments in their farm activities than do poor farmers – a fact which reaps greater returns for rich farmers once they have electricity. Electrification

[15] We use a two-stage instrumental variable model (as before) by instrumenting the interaction variables.

benefits on non-farm income do not vary much by landholding. Overall, only rich households accrue significant positive impacts in total income (21.2 percent).

The trend is somewhat similar when it comes to educational outcomes. Schooling years for both boys and girls improve as a result of electrification, but such benefits for land-rich households are slightly higher than that for land-poor households. For example, while boys' schooling years for rich households go up by 0.16 grade due to electrification, that for poor households go up by 0.13 grade. As for children's study hours, it is only land-rich households that post significant gains from electrification – 16.3 minutes and 20.5 minutes per day for boys and girls respectively, with no significant impacts for land-poor households.

What we can infer from this discussion is that physical capital makes a difference in the distribution of electrification benefits, and it matters more for rich households than for poor households. We have seen before that households with more physical assets are the ones to access electricity first when it is available in the community and they also consume more electricity than poor households. So it is not surprising that rich households would reap more electrification benefits than the poor households.

8. Discussion and Conclusion

The benefits of rural electrification have long been debated in the development literature. Although a large number of studies have found positive associations between rural electrification and development outcomes, there have been few studies that have tackled the issue of causality after taking care of endogeneity biases. This study is one of the few that have addressed the issue of correlation versus causation head on. This has been made possible by employing robust econometric techniques that tackle counterfactual and endogeneity issues which often limit the quality of impact assessment exercises. However, in the end it must be admitted that all cross-sectional analysis have their shortcomings, and moreover, assessed impacts may be short-term. The patterns observed today may not hold in the future. Panel analysis gives a better opportunity for evaluation of longer term impacts of development projects. REB in Bangladesh is now conducting a follow-up survey of the same households. Once that data is available for analysis, the findings of this study may be put to test.

According to the findings in this study, the rural electrification program has a strong and robust impact for both economic and educational outcomes. For example, the gain in total income due to electrification can be as much as 30 percent. Electricity also leads to a significant improvement in both completed schooling years and study time for children in rural households. And, not only does household electrification result in income improvement, but this impact is sustained for as long as 8 years, after which the benefits level off.

Last but certainly not least, the questions as to whether rural electrification benefits well-off households more than it does poor households has been analyzed. For rich households that adopt electricity, the impacts are often higher than that for poor households. Certainly, rural electrification programs that have a policy to reach as many households as possible without putting undue financial strain on electricity distribution companies have to deal with this issue.

Let us now consider the benefits against the cost of connectivity. The marginal distribution and connection costs incurred by the REB for each household range between US$600 to US$1,200 depending on the distance of communities from the medium or high voltages lines. This cost covers the poles, lines, transformers, and other related costs necessary to reach rural households in communities without electricity. Since most of the new equipments last about 30 years, the marginal connectivity cost is then between about US$1.50 to US$3.00 per household per month depending on the average distance from the grid. On the other hand, the marginal cost associated with generation and transmission of electricity is assumed to be about US$0.03 per month per kWh, so the cost works out to be about $1.00 per month for a household consuming 30 kWh per month and about US$1.50 for a household consuming 50 kWh per month. Hence, the high cost scenario for serving a new rural household is about US$4.50 per month and this includes all marginal costs for bringing grid service to community that does not yet have electricity. With the estimated average income gains of 12 percent per annum, the per capita income gain due to connectivity is about $12 per month.[16] This means benefits exceed cost by more than 150 percent. This is indeed a huge benefit accrued to the society because of electrification.

Given the substantial income gains from electrification, programs that do not reach a good number of households in communities that receive electricity do not seem be exploiting their full development potential. For instance, a strict policy to only connect

[16] This is based on an average household income of Tk.76,809 per year (Table 3), using the gains from IV estimates (Table 9), and assuming US $1 equals to Bangladesh Tk.65 (2005 conversion figure).

households within a certain distance from the electricity lines may very well have less development benefits than those with a more expansive approach. This is not to diminish the importance of maintaining financially viable electricity distribution companies, but rather to emphasize that pricing and subsidy policies should be more inclusive. Certainly, the findings would support a strong effort to reduce connection costs for the poorest households while ensuring that they pay for the electricity they consume.

In Bangladesh, the REB for the most part has been very successful in expanding electricity in rural areas all over the country through local electric cooperative distribution companies (Waddle 2007). The electric cooperatives generally have low system losses, better billing and collection systems, and good theft prevention. Although there have been some problems with electricity outages, the electric cooperatives are generally trusted by their customers. The rural electrification programs are big, expensive, and institutionally complex, but they also appear to have rather large benefits when managed in a proper way. There are still many challenges to be overcome, but an expansion of electricity coverage that is equitable and institutionally and financially viable will have significant development benefits in rural Bangladesh and will balance growth in the country as a whole.

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Tables

Table 1: Distribution of the sample

User	Domestic	Commercial	Irrigation	Industrial	Total
Electricity users	9,793	1,549	1,325	1,343	14,063
Electricity non-users	10,088	1,466	1,051	263	12,815
Solar home system users	1,035	-	-	-	1,035
Total Sample Size	20,916	3,015	2,376	1,606	27,913

Table 2: Extent of electrification in rural Bangladesh

Region	Village electrification (%)	Household electrification (%)	
		In villages with electricity	In whole sample
Dhaka	51.6	55.1	29.7
Chittagong	57.0	68.2	40.3
Khulna	61.4	62.4	35.7
Rajshahi	54.1	56.2	31.8
Barisal	60.1	41.3	23.1
Sylhet	63.9	55.8	34.2
All regions	57.0	58.2	33.1
Observations	13,829	7,071	20,900

Table 3: Descriptive statistics of household outcomes by village electrification

Outcome variables	Villages with electricity	Villages without electricity	Difference
Economic outcomes (N=20,903)			
Yearly per capita yearly expenditure (Tk.)	11,438.2	11,394.4	43.8
	(5,236.9)	(6,375.1)	(0.54)
Yearly farm income (Tk.)	24,541.1	32,708.2	-8,167.1
	(43,907.8)	(49,087.9)	(-12.65)
Yearly non-farm income (Tk.)	58,244.5	52,843.3	5,401.2
	(56,551.4)	(105,073.1)	(4.77)
Yearly total income (Tk.)	82,785.5	85,551.5	-2,765.9
	(77,139.5)	(114,046.2)	(-2.09)
Education outcomes (age 5-18)			
Boys' completed schooling years	4.28	4.05	0.24
	(3.27)	(3.30)	(4.86)
Girls' completed schooling years	4.51	4.04	0.57
	(3.28)	(3.28)	(10.93)
Boys' study time (minutes/day)	127.5	124.1	3.4
	(126.3)	(125.9)	(1.79)
Girls' study time (hours/day)	133.8	129.5	9.4
	(121.4)	(122.8)	(4.83)
Observations	N_H=13,829, N_M=11,806, N_F=10,884	N_H=7,071 N_M=6,343, N_F=5,633	

Note: Figures in parentheses are standard deviations in second and third columns, and t-statistics in last column. N_H=Number of households, N_M=Number of boys, and N_F=Number of girls.

Table 4: Descriptive statistics of household outcomes by household electrification

Outcome variables	Households with electricity	Households without electricity		
		In villages with electricity	In villages without electricity	All villages
Economic outcomes				
Yearly per capita expenditure (Tk.)	12,543.5	9,988.3	11,394.4	10,863.8
	(5,437.1)	(4,514.9)	(6,375.1)	(5,827.6)
Yearly farm income (Tk.)	30,051.0	16,869.1	32,708.2	27,086.6
	(51,113.5)	(29,557.7)	(49,087.9)	(43,838.3)
Yearly non-farm income (Tk.)	68,449.2	44,035.6	52,843.3	49,717.3
	(61,464.3)	(45,214.5)	(105,073.1)	(88,683.7)
Yearly total income (Tk.)	98,500.2	60,904.7	85,551.5	76,803.9
	(87,223.1)	(53,112.5)	(114,046.2)	(97,621.6)
Education outcomes (age 5-18)				
Boys' completed schooling years	4.77	3.64	4.05	3.90
	(3.38)	(3.01)	(3.30)	(3.21)

Girls' completed schooling years	5.06	3.99	4.04	4.02
	(3.38)	(3.16)	(3.28)	(3.24)
Boys' study time (minutes/day)	141.8	108.4	124.1	118.6
	(130.4)	(117.9)	(125.9)	(123.4)
Girls' study time (minutes/day)	154.1	117.9	129.5	125.4
	(129.5)	(114.6)	(122.8)	(117.0)
Observations	N_H=9,782, N_M=8,287, N_F=7,704	N_H=4,047, N_M=3,519, N_F=3,180	N_H=7,071, N_M=6,343, N_F=5,633	N_H=11,118, N_M=9,862, N_F=8,813

Note: Figures in parentheses are standard deviations. N_H=Number of households, N_M=Number of boys, and N_F=Number of girls.

Table 5: Benefits of household electrification (single difference)

Outcome variables	Comparison of electrified households with households without electricity in		
	In villages with electricity	In villages without electricity	All villages
Economic outcomes			
Yearly per capita expenditure (Tk.)	0.234	0.112	0.155
	(35.76)	(17.99)	(26.61)
Yearly farm income (Tk.)	1.227	-0.733	-0.037
	(14.05)	(-9.51)	(-0.50)
Yearly non-farm income (Tk.)	0.993	1.322	1.205
	(15.64)	(21.18)	(20.42)
Yearly total income (Tk.)	0.433	0.177	0.268
	(45.44)	(18.89)	(30.92)
Education outcomes (age 5-18)			
Boys' completed schooling years	1.134	0.725	0.867
	(18.91)	(12.97)	(16.66)
Girls' completed schooling years	1.068	1.015	1.034
	(16.72)	(17.47)	(18.99)
Boys' study time (minutes/day)	33.4	17.7	23.1
	(14.32)	(8.24)	(11.54)
Girls' study time (minutes/day)	36.2	24.6	28.7
	(15.10)	(11.17)	(14.04)
Observations	N_H=13,829, N_M=11,806, N_F=10,884	N_H=16,853, N_M=14,630, N_F=13,337	N_H=20,900, N_M=18,149, N_F=16,517

Note: Figures in parentheses are t-statistics. Income and expenditure variables are expressed in log form. N_H=Number of households, N_M=Number of boys, and N_F=Number of girls.

Table 6: Summary statistics of electricity access and (major) explanatory variables used regression estimates (N=20,901)

Variables	Electricity users	Nonusers	Whole sample
Household has electricity (1=Yes, 0=No)	1	0	0.33
	(0)	(0)	(0.47)
Age of household head (years)	44.68	42.65	43.32
	(12.16)	(11.56)	(11.80)
Sex of household head (Male=1, female=0)	0.95	0.97	0.96
	(0.21)	(0.18)	(0.19)
Education of household head (years)	6.35	4.54	5.14
	(4.49)	(4.46)	(4.55)
Highest education among household males (years)	8.28	6.30	6.96
	(3.93)	(4.20)	(4.21)
Highest education among households females (years)	6.82	5.19	5.73
	(3.57)	(3.76)	(3.77)
Household land asset (decimals)	118.22	150.50	139.82
	(210.60)	(427.05)	(370.07)
Household dwelling is brick-built (1=Yes, 0=No)	0.06	0.02	0.03
	(0.24)	(0.12)	(0.17)
Household's drinking water is from tube-well (1=Yes, 0=No)	0.97	0.97	0.97
	(0.16)	(0.17)	(0.17)
Village price of firewood (Tk./kg)	1.77	1.66	1.70
	(0.56)	(0.55)	(0.55)
Village price of kerosene (Tk./liter)	25.88	25.73	25.78
	(1.63)	(1.78)	(1.73)
Village price of diesel (Tk./liter)	24.45	24.39	24.41
	(1.24)	(1.38)	(1.33)
Proportion of village land that is irrigated	0.60	0.59	0.59
	(0.36)	(0.37)	(0.36)
Observations	9,782	11,118	20,900

Note: Figures in parentheses are standard deviations.

Table 7: Probit estimates of household's access to electricity

Explanatory variables	Estimates
Sex of HH head (M=1, F=0)	-0.153
	(-2.32)
Age of HH head (years)	0.004
	(2.98)
Education of HH head (years)	0.030

	(5.69)
Highest education among HH males (years)	0.053
	(9.90)
Highest education among HH females (years)	0.039
	(8.68)
Log of HH landholding (decimals)	0.116
	(10.72)
HH dwelling is brick-built (1=Yes, 0=No)	0.681
	(7.62)
HH's drinking water is from tube-well (1=Yes, 0=No)	-0.097
	(-1.16)
Village price of firewood (Tk./kg)	0.122
	(3.80)
Village price of kerosene (Tk./liter)	-0.011
	(-1.15)
Village price of diesel (Tk./liter)	0.008
	(0.37)
ϱ (rho)	-0.473
	(-26.69)
Wald $\chi^2(17)$	1238.34
	p> χ^2=0000
Observations	20,900

Note: Figures in parentheses are t-statistics. Explanatory variables additionally include regional dummies.

Table 8: Impacts of household electrification (PSM estimates)

	PSM with kernel matching	First alternate implementation of p-score	Second alternate implementation of p-score
Economic outcomes			
Yearly per capita expenditure (Tk.)	0.154	0.060	0.092
	(9.29)	(7.54)	(16.74)
Yearly farm income (Tk.)	0.729	-0.024	0.241
	(5.52)	(-0.31)	(3.93)
Yearly non-farm income (Tk.)	0.903	0.564	0.737
	(7.37)	(6.66)	(12.71)
Yearly total income (Tk.)	0.300	0.090	0.167
	(13.72)	(8.91)	(19.85)
Education outcomes (age 5-18)			
Boys' completed schooling years	0.276	0.162	0.171
	(1.91)	(2.32)	(3.02)
Girls' completed schooling years	0.226	0.355	0.117
	(1.603)	(5.04)	(2.12)
Boys' study time (minutes/day)	18.2	4.9	10.4
	(4.94)	(1.65)	(4.95)
Girls' study time (minutes/day)	17.0	11.7	12.9
	(5.71)	(3.85)	(5.94)
Observations	N_H=12,123, N_M=10,263, N_F=9,547	N_H=20,900, N_M=18,149, N_F=16,517	N_H=20,900, N_M=18,149, N_F=16,517

Note: Figures in parentheses are t-statistics. Income and expenditure variables are expressed in log form. N_H=Number of households, N_M=Number of boys, and N_F=Number of girls. Regressions additionally include household (head's age, sex and education, maximum education of adult males and females, landholding, sanitation, and so on) and village level variables (infrastructure and price). The first alternate implementation of p-score uses an OLS regression to estimate electrification impacts where p-score replaces the original treatment variable. The second alternate implementation of p-score uses a weighted OLS regression where weight is calculated based on section 5.

Table 9: Impacts of household electrification (OLS and IV estimates)

Outcome variables	OLS estimates	IV estimates	Endogeneity test (Durban-Wu-Hausman χ^2)
Economic outcomes			
Yearly per capita expenditure (Tk.)	0.095 (15.95)	0.082 (7.24)	$\chi^2(1)=5.961$ Prob>χ^2==0.015
Yearly farm income (Tk.)	0.175 (2.77)	0.521 (4.13)	$\chi^2(1)=0.054$ Prob>χ^2==0.816
Yearly non-farm income (Tk.)	0.615 (10.15)	0.229 (1.97)	$\chi^2(1)=10.995$ Prob>χ^2==0.001
Yearly total income (Tk.)	0.163 (20.65)	0.122 (8.09)	$\chi^2(1)=33.763$ Prob>χ^2==0.000
Education outcomes (age 5-18)			
Boys' completed schooling years	0.180 (5.36)	0.092 (1.47)	$\chi^2(1)=5.596$ Prob>χ^2==0.037
Girls' completed schooling years	0.148 (4.88)	0.133 (2.36)	$\chi^2(1)=0.056$ Prob>χ^2==0.812
Boys' study time (minutes/day)	10.0 (4.46)	6.0 (1.67)	$\chi^2(1)=4.347$ Prob>χ^2==0.044
Girls' study time (minutes/day)	13.7 (5.98)	8.9 (2.17)	$\chi^2(1)=0.58$ Prob>χ^2==0.455
Observations	N_H=20,900, N_M=18,149, N_F=16,517	N_H=20,900, N_M=18,149, N_F=16,517	

Note: Figures in parentheses are t-statistics. Income and expenditure variables are expressed in log form. N_H=Number of households, N_M=Number of boys, and N_F=Number of girls. Regressions additionally include household (head's age, sex and education, maximum education of adult males and females, landholding, sanitation, and so on) and village level variables (infrastructure and price).

Table 10: Electricity use pattern by duration of electricity connection (N=9,782)

Duration	Percentage of households	Electricity use (kwh/month)
5 years or less	39.6	35.5
5 to 10 years	27.4	39.8
10 to 15 years	17.3	47.2
More than 15 years	15.7	50.4
All electrified households (Average duration=8.8 years)	100.0	41.0

Table 11: Descriptive statistics of welfare indicators by duration electricity connection

Outcome variables	5 years or less	5 to 10 years	10 to 15 years	More than 15 years
Economic outcomes				
Yearly per capita expenditure (Tk.)	11,781.9	12,550.1	13,145.9	13,785.5
	(5,321.4)	(4,852.1)	(5,271.2)	(6,487.0)
Yearly farm income (Tk.)	27,690.0	28,567.4	31,043.2	37,500.2
	(46,464.0)	(51,280.9)	(46,286.0)	(64,658.0)
Yearly non-farm income (Tk.)	60,257.7	66,687.3	72,019.9	88,238.2
	(50,140.8)	(55,994.4)	(61,247.8)	(86,875.0)
Yearly total income (Tk.)	87,947.7	95,254.7	103,063.1	125,738.4
	(76,004.3)	(75,732.2)	(79,864.4)	(125,781.8)
Education outcomes (age 5-18)				
Boys' completed schooling years	4.38	4.77	5.31	5.16
	(3.26)	(3.41)	(3.45)	(3.40)
Girls' completed schooling years	4.72	5.12	5.47	5.38
	(3.29)	(3.34)	(3.48)	(3.50)
Boys' study time (minutes/day)	132.3	140.1	156.6	152.6
	(128.3)	(130.5)	(133.5)	(130.0)
Girls' study time (minutes/day)	141.2	156.8	167.6	168.9
	(124.7)	(129.8)	(128.6)	(139.2)
Observations	N_H=3,802, N_M=3,280, N_F=3,024	N_H=2,623, N_M=2,224, N_F=2,148	N_H=1,816, N_M=1,515, N_F=1,425	N_H=1,541, N_M=1,515, N_F=1,107

Note: Figures in parentheses are standard deviations. N_H=Number of households, N_M=Number of boys, and N_F=Number of girls.

Table 12: Impacts of household electrification duration on income

Explanatory variables	Estimates
Duration of household's electricity connection (years)	0.069
	(5.32)
Duration of household's electricity connection squared	-0.004
	(-4.36)
Sex of HH head (M=1, F=0)	-0.188
	(-7.29)
Age of HH head (years)	0.007
	(17.66)
Education of HH head (years)	0.012
	(4.19)
Highest education among HH males (years)	0.031
	(23.60)
Highest education among HH females (years)	0.021
	(15.47)
Log of HH landholding (decimals)	0.110
	(33.27)
HH dwelling is brick-built (1=Yes, 0=No)	0.334
	(11.08)
HH's drinking water is from tube-well (1=Yes, 0=No)	-0.016
	(-0.58)
Village price of firewood (Tk./kg)	0.195
	(19.65)
Village price of kerosene (Tk./liter)	0.019
	(7.32)
Village price of diesel (Tk./liter)	0.010
	(2.88)
R^2	0.346
Observations	20,900

Note: Figures in parentheses are t-statistics. Explanatory variables additionally include regional dummies.

Table 13: Estimates of differential electrification benefits for land-rich and land-poor households

Endowments variables	Yearly per capita expenditure (Tk.)	Yearly farm income (Tk.)	Yearly non-farm income (Tk.)	Yearly total income (Tk.)	Boys' completed schooling years	Girls' completed schooling years	Boys' study time (minutes/ day)	Girls' study time (minutes/ day)
Electrification of land-rich HHs (HH land asset is 0.5 acre or more*HH has access to grid)	0.124 (8.96)	0.489 (5.75)	0.543 (3.85)	0.212 (11.42)	0.164 (2.02)	0.202 (2.69)	16.3 (3.31)	20.5 (4.27)
Electrification of land-poor HHs (HH land asset is less than 0.5 acre*HH has access to grid)	0.031 (2.24)	0.053 (1.40)	0.575 (3.63)	0.024 (1.31)	0.130 (1.85)	0.188 (3.12)	-2.7 (-0.59)	6.9 (1.55)
R^2	0.236	0.419	0.152	0.407	0.694	0.784	0.250	0.292
N	20,900	20,900	20,900	20,900	18,149	16,517	18,149	16,517

Note: Figures in parentheses are t-statistics. Income and expenditure variables are expressed in log form. Regressions additionally include household (head's age, sex and education, maximum education of adult males and females, landholding, sanitation, and so on) and village level variables (infrastructure and price).