Does the Quality of Electricity Matter? Evidence from Rural India[†]

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Abstract

This paper estimates the returns to household income due to improved access to electricity in rural India. We examine the effect of connecting a household to the grid and of the quality of electricity, defined as hours of daily supply. The analysis is based on two rounds of a representative panel of more than 10,000 households. We use the district-level density of transmission cables as instrument for the electrification status of the household. We find that a grid connection increases non-agricultural incomes of rural households by about 9 percent during the study period (1994-2005). However, a grid connection *and* a higher quality of electricity (in terms of fewer outages and more hours per day) increases non-agricultural incomes by about 28.6 percent in the same period.

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1 Introduction

In 2009, 288 million people, corresponding to about a fourth of India's population, had no access to electricity (World Energy Outlook 2011). In 2005, 364 million people did not have access, while another 300 million received intermittent supply (Balachandra, 2011). The massive grid failure of July 2012 affected 670 million individuals, almost 10 percent of the world's population and made world headlines (New York Times, 2012). According to the World Bank, unreliable electricity supply has been a major obstacle to Indian economic development, limiting its comparative advantage in labor-intensive products (World Bank, 2010; Rud, 2012). Connecting all households to the grid and providing them assured electricity is likely to have a major impact on the Indian economy.

The aim of this paper is to estimate the economic returns to rural households from a grid connection as well as from the quality of electricity supply. We study the effect on rural household income - we include all income from wages and business income, except income from agricultural assets for which we have insufficient data.[1]

Rural electrification may affect incomes of households in several ways (Oda and Tsujita, 2011; Modi, 2005). It may free members of the household from domestic chores, or let them perform these tasks in the evening. The resulting increase in the labor supply may drive down wages, especially for females. Electrification may also increase the productivity of some activities. The productivity of agricultural labor may improve due to technologies such as sprinkler or drip irrigation, which is likely to have an upward effect on wages. Assured supply of electricity may create opportunities for entrepreneurial activities which can take place within the household, such as rice-milling and production of oil from oilseeds. Other ancillary industries, such as the repair and welding of agriculture implements such as ploughs and tractors, may now be possible. These activities are likely to increase farm incomes, which may result in a general increase in labor supply and wages. Finally, electrification could also affect labor supply by children. The need to collect different kinds of fuels, including animal and agricultural waste and fuelwood may diminish and therefore their labor supply to market activities may increase, or they may allocate their time to other pursuits such as education (Modi, 2005; Oda and Tsujita, 2011).

There are many studies that qualitatively describe the Indian electricity sector (Balachandra, 2011; Khandker et al., 2012a; Bhide and Monroy, 2011). Most papers identifying the effect of rural electrification using econometric techniques such as propensity score matching, difference-in-difference or instrumental variables usually deal with countries other than India. Bensch et al. (2010) focus on the case of Rwanda, while Khandker et al. (2012b and 2013) study Bangladesh and Vietnam, specifically rural electrification

[1] 70 percent of India's population lives in rural areas, the focus of our analysis.

initiatives undertaken by the World Bank. Two recent papers focus on the impact of connecting a household to the electricity grid. Dinkelman (2011) studied the labor market effects of an electrification project in South Africa using an instrumental variable approach. Lipscomb et al. (2013) examine the case of Brazil and, using instrumental variables, find a positive impact of electrification on various development indicators. The main contribution of our paper is the focus on the quality of electricity, which has not been done previously.

A variety of factors may lie behind the electrification of certain areas and the non-electrification of others. Governments usually aim infrastructure investment to already growing areas. Other economic trends may affect the investment decision. For instance, a rich village may be more likely to be electrified than a poor village. The likelihood of being connected to the grid may also depend on the proximity to a big city, or on the population density of the region. For all these reasons, disentangling the impact of infrastructure investments such as electricity on development outcomes has been discussed extensively in the literature (Duflo and Pande, 2007; Roller and Waverman, 2001; Aschauer, 1989; Garcia-Mila and McGuire, 1992; Holtz-Eakin, 1993).

We tackle the endogeneity issue regarding electrification by using an instrumental variable approach. We construct an instrument which measures the difference in the density of transmission cables in each district from the national average. The argument is straightforward. If a household is located in a district served by a higher density of transmission cables the probability of being connected to the network, and of receiving a better quality power supply, is higher than when it is located in a district with a lower cable density (Brown and Sedano, 2004). We then interact this measure with the initial state of electrification in order to capture the possible heterogeneity in the impact of an improvement of the transmission network within a district.

Decisions regarding investments in the Indian transmission network lie with the federal government, while state governments are charged with their implementation (Modi, 2005; Balachandra, 2011). Transmission lines are a major infrastructure investment and require a high voltage pole at their destination. Once the federal government decides to build a transmission line between two points, the planner's problem is to find the shortest and the least costly route between these two points, and the objective of bringing electricity to remote villages is not considered during this stage.[2] For this reason, the objective of rural electrification in India may have played a small role in how the transmission lines were installed and located. Modi (2005) states that federal legislation in India did not explicitly mention rural electrification until 2003.[3] However, state-level

[2]The per kilometer cost of setting up a new transmission network may range from several hundred thousand dollars to several million (Brown and Sedano, 2004).

[3]In the federal planning budget, only about 10 percent of the electricity outlay is spent on distribution, the rest goes towards power generation and transmission.

elected officials have a large incentive to improve rural electrification, but they only control investment in distribution networks, not in transmission networks (Balachandra, 2011). While distribution networks are much less costly, they can only be installed if there is a transmission line within a feasible radius. This paper thus uses the transmission network, rather than the distribution network, as an instrument for the probability of electrification in rural areas.

Our results suggest that the 16% increase in grid connections between 1994 and 2005 increased non-agricultural incomes of rural households by about 9 percent. However, higher quality of electricity (a 32% increase, where quality is measured in terms of fewer outages and more hours per day) increased non-agricultural incomes by about 28.6 percent. The results regarding a new grid connection are comparable in magnitude to those of Dinkelman (2011) and Lipscomb et al. (2013). These results suggest that while bringing new households into the electrical grid is important, providing a high quality electricity with fewer outages has at least an equally significant effect on household incomes.

The remainder of the paper is organized as follows. Section 2 discusses electrification policy in India. Section 3 describes the data used in our analysis and presents some stylized facts. Section 4 outlines the methodology used and presents the results of the estimation. Section 5 concludes the paper.

2 Background

Electricity supply in India is inefficient at all stages of production, transmission and distribution (Modi, 2005). At subsidized prices, supply lags demand, especially during peak periods, leading to frequent outages and voltage fluctuations. In 2010, average per capita consumption in India was 641.3 kilowatt hour (kWh), which is just above Sub-Saharan Africa (530.7 kWh) and well below China (2,943.7 kWh) and the average for OECD countries (about 8,300 kWh).[4] India is home to a third of the world population that is not connected to an electric grid. Cost recovery is low and has actually declined over time (69 percent in 2001-02). These low rates are mainly due to losses during transmission and distribution, which rose from 25% in 1997-98 (Modi, 2005) to about 39% in 2000-01 (Oda and Tsujita, 2011), while the average for neighboring countries is about 10%. Estimates suggest that only 55% of the power supplied is billed and only 41% is paid for (Modi, 2005). Infrastructure theft has led to further declines in coverage (Balachandra, 2011). However, there has been significant improvement in average consumption and production of electricity. The generation capacity grew from 1,362 MW in 1947 to nearly 74,699 MW in 1991. Over the same period, per capita

[4]World Development Indicators (World Bank).

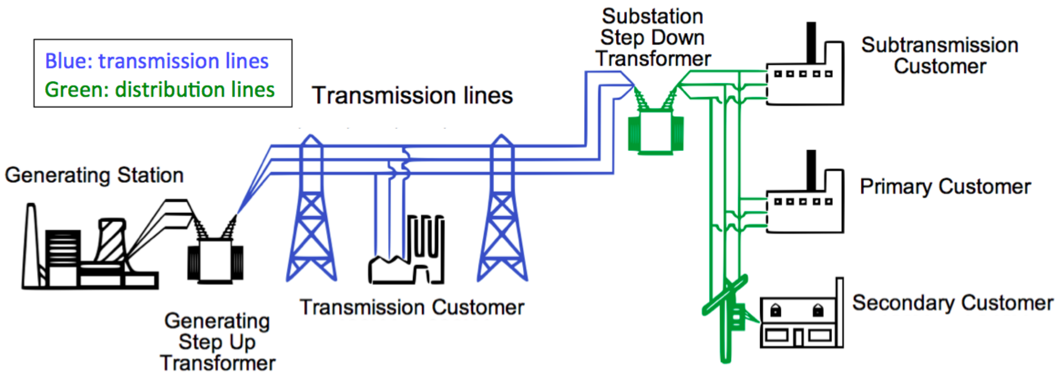
consumption increased from 15.55 kWh to 252.7 kWh (Modi, 2005). Currently, capacity exceeds 170 GW.

There is a large degree of heterogeneity in the distribution of electrification infrastructure across regions in India. Figure A.2 shows the transmission network in 2005. Large parts of the country have no transmission lines. Regions with poor transmission network connectivity include eastern Karnataka, western Andhra Pradesh, Jammu and Kashmir, Arunachal Pradesh, Assam, Aizawl, Imphal, Nagaland, Gujarat (outside of the Ahmedabad metro region), western Rajasthan and eastern Madhya Pradesh. On the other hand, the corridor that connects Delhi to Kolkata, as well as the southern regions including Kerala and Tamil Nadu are well electrified.

According to Brown and Sedano (2004), the cost of setting up a transmission network ranges from several hundred thousand dollars if there are no geographical obstacles such as hills or mountains, to over a million dollars per km. Figure 1 shows the main components of an electricity network. The *transmission network* carries electricity from production sites to high demand locations. This network is characterized by high voltages (High-Voltage Direct-Current of 765, 500, 345 and 230 kV), as this reduces transport losses. Because of the high voltage, it is not possible to directly connect a house or a firm to the line. A *step-down* transformer must be installed to decrease the voltage and channel the power through a *subtransmission network*, which is characterized by lower voltages, usually 69, 115 or 138 kV. At the end of the sub-transmission network another electrical substation moves electricity into the *distribution network*. This last section of the grid is characterized by even lower voltages (less than 50 kV) and travels very short distances, between 50 and 100 km. The electricity transported by the distribution network is at a voltage that can be consumed by the retail consumer.

Setting up new segments of the transmission network is costly. The cost depends on its length, but also on other factors related to the landscape it must traverse. For example, installing cables over rolling hills is costlier than over flat land because the line will need a higher number of supporting structures. If the line has to bypass a mountain, the cost is likely to increase, as more structures are needed. Because of the high cost of setting up a transmission network, and because it is mainly used to transfer electricity to high demand centers, its route is not designed to serve retail customers between the two points (Brown and Sedano, 2004). The engineer's problem at this stage is to find the route that is shortest and most cost effective. Once the transmission cables are installed, the state government can withdraw power through a step down transformer and build a new distribution network. In our data sample, over 80% of the households live in villages with populations less than 5,000 and out of these, about a quarter live in villages with less than 1,000 inhabitants. These small villages are likely to have only a marginal impact on the location of transmission lines, an observation critical to our

Figure 1: Schematic of the Power Grid



Source: United States Department of Energy.

identification strategy.

We distinguish between connecting to the power grid and the quality of power supply (a measure of outages and average daily hours of supply which are generally correlated).[5] The density of transmission lines thus determines the quality of power supply, as well as the probability of being connected to a grid. A household situated in a district characterized by a high density of transmission cables is more likely to be connected to the grid, and conditional on being connected, is more likely to receive higher quality power.

3 Data and Stylized Facts

The panel data we use contains two survey waves conducted in 1994 and 2005. The first wave is part of the Human Development Profile of India (HDPI) and covers 33,230 rural

[5]We use the term "quality" of power rather than "reliability" which in the engineering literature has a precise meaning relating to voltage fluctuations.

households. A share of these households was then re-interviewed for the India Human Development Survey (IHDS) in 2005, which covered 41,554 rural and urban households. The households to be re-visited in 2005 were chosen by first randomly ranking villages, and then fulfilling a variety of conditions needed for the survey to be representative by starting in the first village and then moving down the list of villages. The survey is thus representative at the country level, but not necessarily at smaller geographical units such as a district. The final data consists of a representative panel comprising 9,791 rural households which were interviewed both in 1994 and 2005. Households are asked whether or not they receive electricity, and if they do, information is obtained regarding the quality of supply. While the definition of power quality varies across rounds, we carry out various robustness tests to ensure that the impact of power quality is correctly identified. The panel also contains a wide variety of information at the individual, household and village levels.

Our main variables are constructed as follows. *House* is a dummy variable which takes a value of 1 if the household owns the house in which the family is currently living. *Children*, *Teen* and *Adult* represent the percentage composition of the household in terms of children (between 0 and 14 years old), teens (between 15 and 21 years) and adults (older than 22 years), respectively. *Size* represents the total number of individuals in the household. *Livestock* is a dummy variable which takes the value 1 if the household owns farm animals. *Hindu* is a dummy variable taking a value of 1 if it is a Hindu household and 0 if it belongs to another religious denomination.

Finally, household income is measured as non-agricultural income in per-adult equivalent terms. It is computed by using the OECD definition of equivalence scale, which is given by $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ where N_{Adults} and $N_{Children}$ are the numbers of adults and children, respectively in the household (OECD, 1982). This expression gives us the number of adult equivalent members of the household. Unfortunately, there is some discrepancy in variable definitions between the two surveys. For example, the questionnaire used in 2005 was much more detailed on agricultural income than the one used in 1994. The latter questionnaire also contains questions about losses, while in the former, agricultural income was not allowed to be negative. Therefore, for the sake of our analysis, data on agricultural income could not be included in household total income. This being said, all of our results should be considered as lower bounds of the actual effect. One of the main effects of electrification is on agriculture through the installation of irrigation pumps.

Table 1 presents the household characteristics considered in the paper. Per adult equivalent income increased significantly over the period studied, and so did its volatility. On average, there were 6.6 individuals per household, which declined to 5.5 by 2004. About one third of the individuals within households were children, 15 percent were

Table 1: Household Characteristics

Variable	1994 Mean	1994 Std. Dev.	2005 Mean	2005 Std. Dev.	$log\Delta$	N
Income per Adult Equivalent	6,472.4	7,639.8	8,722.5	10,895.0	0.130	9791
Household Size	6.577	3.322	5.546	2.759	-0.074	9791
Share of Children	0.341	0.21	0.300	0.222	-0.056	9791
Share of Teenager	0.146	0.166	0.136	0.173	-0.031	9791
Share of Adults	0.513	0.187	0.564	0.216	0.041	9791
Hindu	0.854	0.353	0.848	0.359	-0.003	9791
Home Ownership	0.968	0.175	0.980	0.139	0.005	9791
Livestock Ownership	0.704	0.456	0.845	0.361	0.079	9791

Notes: The table reports descriptive statistics of the household controls used in the estimation. The average of the indicator variables *Hindu*, *Home* and *Livestock*. *Child*, *Teen* and *Adult* represent percentages. The column $log\Delta$ shows the log change between 1994 and 2005.

teenagers and slightly more than half of the household population were adults. The share of adults has increased over time, and the share of children as well as teenagers has decreased. Approximately 85 percent of the households in the sample are Hindus. With respect to asset ownership, almost the entire sample owned the dwelling they were living in. In 1994, 70 percent of the sample owned livestock, increasing to 85 percent in 2005.

3.1 Household Electrification

Table 2 reports household grid connection rates (proportion of households electrified) for the states surveyed in this study. The rate of electrification at the national level increased during the study period from 53 to 69 percent. All states surveyed exhibit an increase in connection rates. States with relatively high income levels, such as Andhra Pradesh, Tamil Nadu and Kerala ended the study period with high electrification rates (of 86%, 88%, and 89%, respectively). Electrification rates in 2005 were significantly lower in poorer states, such as Bihar (21%), Orissa (17%) and Uttar Pradesh (20%).[6]

We next present the 1994 district-level electrification rates in Figure 2. The districts that are not in our sample are presented in white, and the different shades represent different electrification rates across surveyed districts. As can be seen from the map, higher rural electrification rates are observed around Delhi and Gujarat, and in the southern regions of India such as Andhra Pradesh and Tamil Nadu. While the survey used in this paper focuses on rural areas, we can observe a higher electrification rate in these relatively industrialized states. Villages that are in close proximity to industrial

[6] This relationship between income and electrification rates is sharper at the state level. Figure A.1 shows that there is a strong and positive correlation between state-level income and electrification rates in 2005. The same relationship holds for 1994, not presented here for brevity.

regions are likely to benefit more from the higher level of infrastructure in these developed regions.

In Figure 3 we present the change in the electrification rate between 1994 and 2005 which is used in the empirical strategy. Surprisingly, a few districts experienced reductions in the electrification rate. This may be due to theft or deterioration of infrastructure, which is quite common in India (Balachandra, 2011). The increase in electrification rates mainly occurred in the Eastern states such as Jharkhand, rather than the industrial states that had high initial electrification rates. While controlling for all district-level factors through a fixed effects specification in a first difference model, we also run a series of robustness checks to ensure that the exclusion restrictions are not violated by the differential changes in electrification across regions.

Table 2: Proportion of Households Electrified and Average Quality of Power Supply by State (%)

	Electrification			Average Quality of Supply		
	1994	2005	Δ	1994	2005	Δ
Andhra Pradesh	54	86	32	31	78	47
Bihar	10	21	11	7	27	20
Chhattisgarh	36	68	32	27	57	30
Gujarat	71	87	16	44	80	36
Haryana	82	90	8	45	60	15
Himachal Pradesh	91	97	6	69	99	30
Jharkhand	20	64	44	17	71	54
Kerala	76	89	13	44	96	52
Maharashtra	67	78	11	40	80	40
Madhya Pradesh	62	71	9	41	45	4
Orissa	17	34	17	21	94	73
Punjab	77	95	18	45	64	19
Rajasthan	49	54	5	36	49	13
Tamil Nadu	66	88	22	50	98	48
Uttar Pradesh	19	39	20	19	50	31
Uttarakhand	33	66	33	19	61	42
West Bengal	13	36	23	15	86	71
India	53	69	16	39	71	32

Notes: The table shows the percentage of households that reported a grid connection in 1994 and 2005. The household-level quality measure takes the value of 0, 0.5 and 1. The table reports average quality by state after converting quality from a 0 to 1 scale to a 0 to 100 scale. Assam is not reported due to a low number of observations - only three household were surveyed in the state.

The quality of power supply at the household level is constructed as follows. The 1994 wave asked whether the household (i) received a continuous power supply, (ii) experienced on average one or two outages per week, or (iii) experienced on average more than two power outages per week. The electricity supply is characterized as high quality if the household selected option (i).[7] The quality measure for the round of 1994 takes value 1 if the power supply was continuous (high quality), 0.5 if it experienced one, two or more than two outages per day (low quality), and 0 if the household is not connected. The 2005 round asked how many hours of electricity per day does the household receive on average, and we assume the threshold for high quality to be 18 hours per day.[8] The quality measure for 2005 takes the value 1 if the household reported 18 or more hours of electricity per day on average (high quality), 0.5 if the household is connected but reported less than 18 hours of electricity per day on average (low quality), and 0 if the household is not connected.

The second panel (Table 2) shows the average quality across states. At the national level, quality increased by 32 points between 1994 and 2005, which is about an 80% increase. The correlation coefficient between the increase in grid connection rates and the quality index is 0.48.

3.2 The Transmission Network

In order to construct the variable for the length of the transmission cables within each district, we use maps of the transmission network published by the Ministry of Power. These maps are then superimposed on the map of Indian districts from Census 2001 using ArcGIS (Government of India, 2001). Next, transmission cables are split along the borders of the districts in order to measure their exact length within each district. The density of the transmission network is then computed by taking the total length of all the line segments within each district, and dividing it by the district surface area. The deviation of this measure from the national average is then defined as the normalized transmission cable density.

Figure 4 shows the map of this normalized cable density measure for 1994, where the darker shades represent higher cable density and horizontal lines indicate negative normalized values, meaning lower than average cable density. The districts marked white are not part of the transmission network as they have no transmission cables. If a household is located in a district characterized by a positive density, then the probability that the household is connected to the grid and receives high quality electricity is higher, while the opposite is true for negative values (Brown and Sedano, 2004).[9]

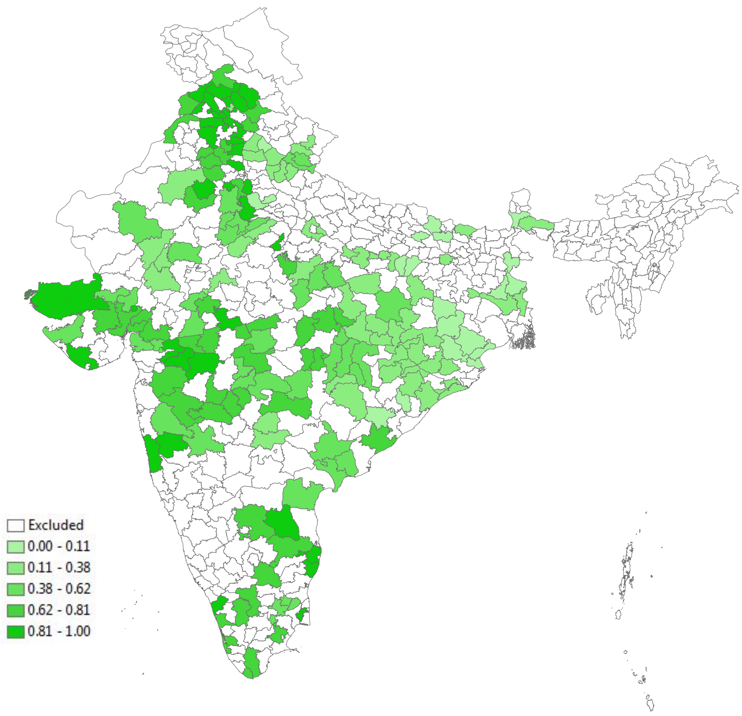
In order to understand how the new infrastructure was distributed across the country during the 11 years of the study period, the difference in the normalized cable density

[7] The results hold if high quality is defined as "at most two outages per week" (i or ii). These results are presented in Table 11.

[8] The model is re-estimated with threshold values of 16, 17, 19 and 20 hours. The main results hold with slight changes in the magnitude of the effects. We use the 18 hours measure in the paper because it approximates the productive hours of a typical agricultural household.

[9] The distribution of cables prior to normalization and the cable network are presented in Figure A.2.

Figure 2: Electrification rate in the survey districts in 1994.

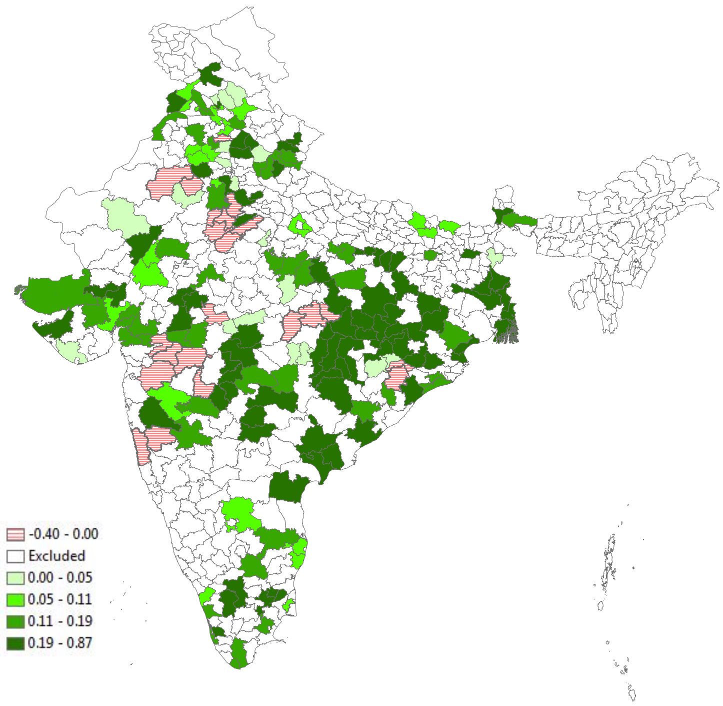


Notes: The information on electrification rates is obtained from the Human Development Profile of India. Districts left white are not part of the survey sample. Source: ESRI ArcGIS World Package and Geocommons.

measure is presented in Figure 5. Note that this does not necessarily reflect an increase or a decrease in overall cable density in the district as the measure is normalized for both years. The negative values indicate that the gap between the district and the national average of transmission cable density has increased, therefore the district did not receive an equiproportionate share of transmission investment given its area. The positive values indicate that the district received more than its share of infrastructure investment. The figure shows that the positive values are clustered in the south and eastern regions. This implies that political connections may be an important factor in attracting infrastructure investment, which we discuss later in the paper.

Table 3 summarizes information on the density of transmission cables by state. During the study period, the transmission network expanded by about 23% (more than 7,000 km). However, there is considerable heterogeneity across states. For example, West Bengal experienced a decline of 3.3%, while the network in Gujarat increased by 96.7%. There was also substantial variation across districts in terms of cable density. The length of transmission cable per km^2 was 42.1 meters in Kerala, and only 2.7 meters

Figure 3: Variation in electrification rate in the survey districts between 1994 and 2005.



Notes: The information on electrification rates is obtained from the Human Development profile for 1994 and India Human Development Survey for 2005. The figure shows the change in the electrification rate in each district. Districts left white are not part of the survey sample. Source: ESRI ArcGIS World Package and Geocommons.

in Chhattisgarh. The states which saw their network size and density increase (Gujarat, Maharashtra, Punjab, Rajasthan and Uttar Pradesh) also experienced large gains in mean real household income. The total transmission cable length was approximately 40 thousand km, corresponding to 12.4 meters of transmission cable per km^2. We can compare this value to China, where the total cable length in 2000 was 157 thousand km with a density of 16.3 meters per km^2. In the United States, the total cable length in 2002 was 254 thousand km with density 25.8 meters per km^2. While a developed nation such as the U.S. is expected to have better infrastructure, we observe that a developing country like China also has a higher cable density than India.[10]

[10]See Yang (2006) and Brown and Sedano (2004) for Chinese and US data, respectively. We computed the above densities from the given data.

Table 3: Density of transmission cables

	1994			2005			
	Length (km)	Length (m/km^2)	Household Income	Length (km)	Length (m/km^2)	Household Income	Number of Districts
Andhra Pradesh	2,057.2	7.4	24,192.8	2,281.9	8.2	27,215.3	11
Assam	465.5	5.5	33,245.5	465.3	5.5	10,921.8	1
Bihar	1,635.1	16.9	25,179.1	1,644.6	17.0	24,842.4	8
Chhattisgarh	368.6	2.7	18,060.5	383.6	2.8	16,857.7	7
Gujarat	1,118.5	6.0	23,179.1	2,186.9	11.8	22,626.3	10
Haryana	736.9	16.7	36,755.6	978.3	22.2	52,558.4	11
Himachal Pradesh	281.7	5.1	33,296.9	292.6	5.3	51,985.8	8
Jharkhand	1,320.0	16.0	39,286.0	1,326.7	16.1	45,039.8	4
Kerala	1,368.0	36.2	30,393.1	1,566.0	41.4	54,139.0	4
Maharashtra	2,337.9	7.6	25,364.8	3,100.4	10.1	28.537.8	16
Madhya Pradesh	2,359.0	7.6	17,754.8	2,965.8	9.6	18.673.2	18
Orissa	3,568.6	22.4	19,556.5	3,621.0	22.7	19,977.2	11
Punjab	1,018.0	20.2	38,883.9	1,673.0	33.2	55,157.2	8
Rajasthan	1,076.2	3.2	30,476.7	2,132.1	6.2	34,403.1	12
Tamil Nadu	3,041.5	23.3	30,620.9	3,422.0	26.2	28,513.2	8
Uttar Pradesh	5,326.9	22.0	28,370.0	6,798.5	28.0	35,848.6	9
Uttarakhand	323.2	6.0	22,342.3	323.1	6.0	29,570.4	3
West Bengal	807.4	9.1	26,830.0	785.6	8.8	28,439.0	8
India	32,432.0	10.1	28,710.6	39,779.3	12.4	22,564.0	157

Notes: Data for transmission cables is obtained from the Indian Ministry of Power. Total cable length within the states is measured using ArcGIS. Household income is computed as real mean income based on the households included in the sample. The transmission cable values for the India row shows the national values for transmission cables, including states that are not in the household survey. The last column shows the number of districts included in the sample for each state.

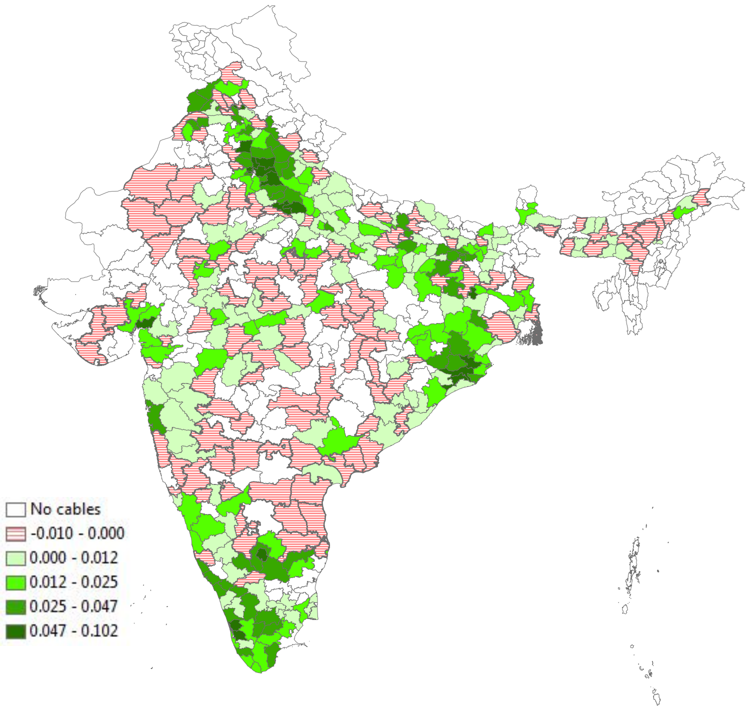
3.3 Description of data

Here we describe the impact of electrification on household income by taking advantage of the panel aspect of the survey and compare households that changed their electrification status from 1994 to 2005. In particular, we compare households that change their status from "not connected" to "connected" and households for which the status remained u changed. Further, those with an electricity connection are divided between low and high quality electricity, where quality is measured as described above. By following households through changes in electrification status, we test whether or not the change in their real income was significant.

Table 4 shows that among 4,613 households in our sample in 1994 who were not connected to the grid, 2,447 remained unconnected, 1,118 were connected but received low quality electricity supply and 978 were connected but received a high quality supply.[11] While the real incomes of the households who remained unconnected increased by 1.9%, this increase was higher (2.8%) for households that received low quality electricity, and

[11] Approximately three quarters of the households report data on the hours of electricity they received. The full sample is used in the analysis wherever possible.

Figure 4: Normalized density of transmission cables per km^2 by district, 1994



Notes: Data is obtained from the Indian Ministry of Power. Cable length within districts is measured using ESRI ArcGIS World Package and Geocommons. The figure represents the cable length divided by the area of the district, normalized with respect to the national mean.

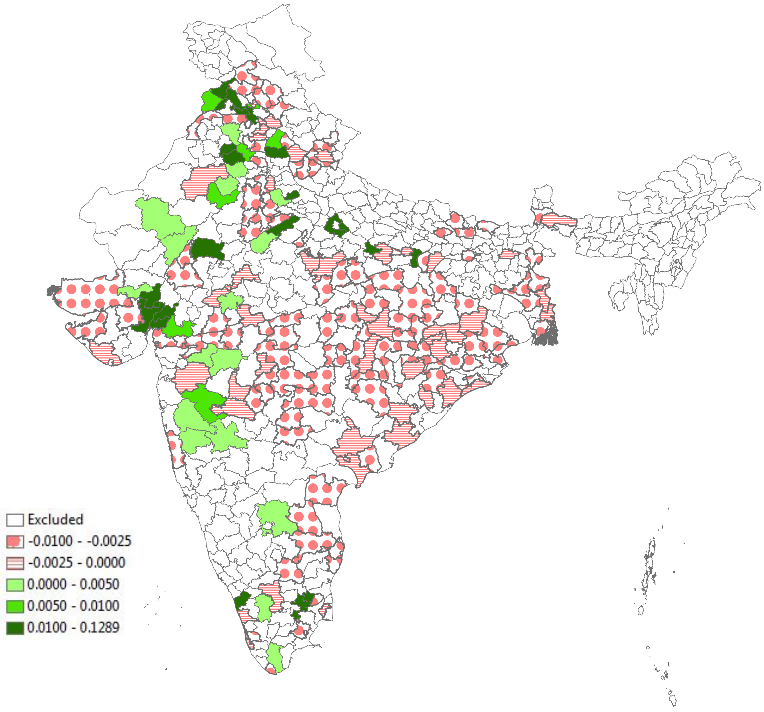
even higher (3.4%) for households that received high quality electricity.[12] Note that the incomes of connected households increased more than for unconnected households: of course we can not yet attribute a causal relationship or rule out other factors that can affect household income.

The households that were connected, but received a low quality supply in 1994 also experience a differential change in income. Those that continued to receive lower quality electricity had a 2.1% increase, and those who experienced improvements in electrification and moved to a high quality electricity supply experienced a higher increase in their income (3.6%). Households that had a high quality supply in 1994 and received a high quality supply in 2005 had the highest increase in their real incomes at 4.6%. However, only 653 out of 9,790 households are in this group, or 6.6% of the sample.

The data also show that some households experienced a regression in quality. Some 532 households with low quality electricity and 83 households with high quality electricity

[12]These differences are statistically significant.

Figure 5: Difference in the normalized density of transmission cables per km^2 between 1994 and 2005.



Notes: Data is obtained from the Indian Ministry of Power. Cable length within districts is measured using ESRI ArcGIS World Package and Geocommons. The figure represents the cable length divided by the area of the district and normalized with respect to the national mean. Districts left white are not part of the survey sample.

in 1994 lost their electricity connection. These households did not experience a significant increase in their income. The reduction in electrification coverage in some states is shown in Figure 3. Finally, 299 households switched from high to low quality electricity. While their incomes increased over the time period, the magnitude is lower than for households that continued to receive high quality supply.

4 Empirical Approach and Results

Let Y denote the logarithm of household income and X be a vector of household-level controls. Define T to be the treatment variable, which represents the quality of power supply received by the household. Our specification in levels takes the following form:

$$Y_{idt} = \alpha + \delta_i + \delta_t + \delta_{dt} + \beta T_{idt} + \gamma X_{idt} + \varepsilon_{idt} \tag{1}$$

Table 4: Household Electrification and Quality of Supply

	Not Connected (2005)	Connected Low Quality Supply (2005)	Connected High Quality Supply (2005)	Total
Not Connected (1994)				
Number of Households	2,447	1,188	978	4,613
Change in Income (%)	1.9***	2.8***	3.4***	
Connected, Low Quality Supply (1994)				
Number of Households	532	1,762	1,848	4,142
Change in Income (%)	0.09	2.1***	3.6***	
Connected, High Quality Supply (1994)				
Number of Households	83	299	653	1,035
Change in Income (%)	2.3	2.1**	4.6***	
Total	3,062	3,249	3,479	9,790

Notes: The table reports the absolute number of households moving from one electricity status to the other between 1994 and 2005 and the change in household income, not including income from agriculture. Asterisks report statistics for a test of two means between 1994 and 2005 income. *** p<0.01, ** p<0.05, * p<0.1. *High Quality Supply* is defined as more than 18 hours of electricity per day on average in 2005 and continuous power supply in 1994.

where subscripts i, t and d denote household, time and district, respectively. The variables δ_i, δ_t and δ_{dt} represent household, time and district-time fixed effects and ε_{idt} is the error term. Time fixed effects account for cyclical changes that are common to all households, household fixed effects control time-invariant characteristics of the household, and district-time fixed effects control for district-specific changes over time. The coefficient of interest is β. In order to eliminate the household fixed effects term and other time invariant factors, we difference over time to get:

$$\Delta Y_{idt} = \Delta\delta_t + \Delta\delta_{dt} + \beta\Delta T_{idt} + \gamma\Delta X_{idt} + \Delta\varepsilon_{idt}. \quad (2)$$

Our panel is composed only of two waves, thus we can re-write equation (2) as:

$$\Delta Y_{idt} = \alpha + \delta_d + \beta\Delta T_{idt} + \gamma\Delta X_{idt} + \Delta\varepsilon_{idt}. \quad (3)$$

The quality of power supply could be improving in districts that tend to grow faster than other districts. In this case $\Delta\varepsilon_{idt}$ is correlated with ΔT_{idt} and an OLS estimation of equation (3) does not identify the causal effect of an increase in the quality of power supply. We deal with this endogeneity issue by using an instrumental variable approach, following the work of Angrist and Imbens.[13] The quality of power supply is instrumented with the increase of the density of transmission cables within the district relative to the

[13]See, for example, Angrist (1990), Angrist and Imbens (1994) and Angrist (1998).

national average, multiplied by the initial level of quality.

Proximity to the transmission network has two potential effects that are relevant for our analysis. First, proximity to the network increases the probability of a network connection. Second, proximity to the network increases the chance of being closer to generation points and therefore receiving higher quality power supply. We only know the location of the household by district but not their coordinates within it. Interacting the improvement of the transmission network by the initial quality of power supply of a household accounts for the heterogeneity in the distribution of households within a district. The construction of this instrument follows the methodology developed by Bartik (1991), and employed by Blanchard and Katz (1992), Bound and Holzer (2000) and Autor and Dugger (2003). The intuition is that it allows the improvement in the transmission network to vary with the initial state of electrification of the household. The instrument ΔZ is therefore constructed as follows:

$$\Delta Z_{idt} = T_{id0} * \Delta G_{dt} \tag{4}$$

where T_{id0} is the initial value of the quality of power supply and G denotes the district level normalized density of transmission cables. The system of equations to be estimated is therefore:

$$\Delta Y_{idt} = \alpha + \delta_d + \beta \Delta \widehat{T}_{idt} + \Delta X_{idt}\gamma + \Delta \varepsilon_{idt} \tag{5}$$

$$\Delta T_{idt} = \varphi + \delta_d + \eta \Delta Z_{idt} + \Delta X_{idt}\gamma + \Delta u_{idt} \tag{6}$$

where $\Delta \widehat{T}_{idt}$ is the predicted values of the first stage, and standard errors in all regressions are clustered at the district level in order to account for within-region heterogeneity.[14] The same methodology is then applied to the the probability of electrification, where T indicates the connection to the grid.

The expansion of the transmission network is expected to increase the probability of electrification for households that are within a feasible radius of the infrastructure. However, the impact on the quality of electricity is less straightforward. An expansion in the transmission and distribution network could increase the demand for electricity. If this is not complemented by an increase in generation capacity, the quality of power supply for households could decrease. However, if the electricity generation capacity is proportionally expanded, then we would observe an increase in quality. While we are not able to obtain data on the location and capacity of power plants in India, the sign on the first stage would show which of these effects dominate.

[14]The results hold when we cluster the errors at the state or regional level.

A potential threat to this identification strategy comes from the possible correlation between the initial quality of power supply (in 1994), and the income shocks occurring between 1994 and 2005.[15] If the government built disproportionately more transmission lines in the areas that are expected to grow quickly for reasons other than the impact of electrification, then this correlation would be positive. This threat is likely to be mitigated as the federal government primarily targeted industrial activity in urban areas, as discussed in Section 2. Differential levels of electrification in the initial year may affect the change in electrification status, which may lead to underestimation of the first stage effects. For these reasons, we run a series of robustness tests later in the paper to ensure that the effects are properly identified.

The results of the first stage describing the relationship between household electrification and cable density are presented in Table 5. The model described in Equation 6 is first estimated with district fixed effects but no other controls. Household demographic and asset controls are then included in the model one by one and together. The results suggest that cable density has a positive and robust impact on electrification. The numbers in column (1) imply that a one unit increase in the density of transmission lines increases the probability of electrification on average by approximately 10 percentage points at the average initial electrification level. The impact decreases to 9.6 percentage points with the inclusion of demographic controls.

On the right panel, the estimates for the impact on the quality of electricity are shown. A unit increase in the cable density increases quality on average by 15 points at the average initial quality measure.[16] This implies that the increase in electricity demand due to additional transmission cables was not associated with a reduction in quality, and that the increase in demand induced by the expansion in the transmission cables was adequately compensated through increased production. The coefficients on the control variables show that an increase in the household size was associated with a larger probability of electricity connection and a higher quality. On the other hand, an increase in the number of children was associated with lower electricity outcomes while religion and asset ownership did not have a significant impact.

[15]The condition which needs to be satisfied in order for this identification to be consistent is that $E[T_{id0} * \Delta G_{dt} * \Delta\varepsilon_{idt}] = 0$. Taking the limit over districts and individuals, we can show that $\lim_{D,I\to\infty} \frac{1}{D*I}\sum_d \sum_i (T_{id0} * \Delta G_{dt} * \Delta\varepsilon_{idt}) = 0$. Since G_{dt} does not depend on the individual, we can take it out of the brackets and re-write it as $\lim_{D,I\to\infty} \frac{1}{D*I}\sum_d \Delta G_{dt} \sum_i (T_{id0} * \Delta\varepsilon_{idt}) = 0$. In order for this to hold, we only need to argue that $\lim_{I\to\infty} \frac{1}{I}\sum_i (T_{id0} * \Delta\varepsilon_{idt}) = 0$, or equivalently that $E[T_{id0} * \Delta\varepsilon_{idt}] = 0$. This means that income shocks occurring between 1994 and 2005 should not be correlated with the quality of power supply in 1994.

[16]Note that the number of observations is lower in the right-hand panel due to missing information on power quality.

4.1 Electricity and Household Income

We now focus on the impact of the quality of electricity supply on household income as specified in Equation 5. The results for OLS and IV estimations are reported in Table 6, the latter using the normalized density of transmission cables multiplied by the initial state of electrification as an instrument for quality. The OLS results with household controls, shown in columns (5) and (7), indicate that a change in quality from no electricity to high quality is associated with an approximately 8 percent increase in household income. Instrumenting the change in quality with the transmission cable instrument in column (2), increases the coefficient to 87 percent. Inclusion of household assets in the IV specification in column (8), further increases this coefficient to 89.4 percent. From Table 2, we see that the quality of supply improved by 32 percentage points on average over the whole country between 1994 and 2005. These numbers imply that household incomes increased by roughly 28.6 percent over this 11-year period as a result of an increase in the quality of power supply.[17]

The results show that both the OLS and the IV coefficients are robust across specifications, with OLS estimates between 7.6% and 8.6%, while the IV estimates range between 86.7% and 89.8%. All the results consistently show that the impact of electricity quality on income is higher after instrumentation. A potential explanation relates to the type of infrastructure reflected in the coefficients. The IV estimates reflect the impact of the transmission network, while the OLS estimates incorporate the effect of both distribution and transmission networks. The smaller OLS estimates may thus be associated with the efforts of state governments to provide power to poorer areas. The transmission network, on the other hand, substantially improves the household's probability of receiving electricity, but it does not reflect the potential downward bias arising from state policies.[18]

The coefficients on the other control variables have the expected signs. Per-adult equivalent household income is negatively associated with household size, with each additional individual reducing income by roughly 3 percent. The same is true for the proportion of children which also has a negative impact on income. The coefficient on livestock ownership is negative, indicating that the household is less likely to receive income from non-agricultural activities if it owns livestock assets. Home ownership has an insignificant effect as almost the entire sample are home owners, and the real estate rental market is likely to be very small or nonexistent in these small villages in a developing country.

[17] This number is obtained by multiplying the coefficient 0.894 by the improvement in the quality index of power supply, 0.32.

[18] To check if the results are robust to the choice of the 18-hour threshold, the main model is estimated with 16 and 20 hours as thresholds for high quality power supply. The results shown in Table 10 suggest

These results imply that the quality of power supply is an important factor that affects the outcomes from electrification. While the initial connection is important because it can induce reallocation of labor and capital within the household, this impact is expected to increase with quality. The potential benefits of electricity provision are not completely realized by providing a grid connection and low quality power supplies.

We now estimate the same model to investigate the impact of a connection to the grid on household income, shown in Table 7. OLS results predict an impact of a connection to the grid of 6.7%, while IV results predict a higher impact of 55.4% (columns 7 and 8). As before, instrumentation increases the effect several fold. Given that electrification rates increased by 16 percentage points during 1994-2005, these results imply that household non-agricultural incomes increased by 8.9% over this 11-year period as a result of increased access to electricity. The estimates are generally robust to the inclusion of household controls for demographic characteristics and asset ownership.

4.2 Robustness Checks

We check robustness by using an alternative measure for the instrument and by accounting for various factors that may violate the exclusion restriction. These results are shown in Tables 8 through 11 for the baseline specification with demographic controls, asset controls and district fixed effects. All standard errors are clustered at the district level. In each table, the first two columns replicate the results of the specifications reported in columns (9) and (10) of Table 6 for the effect of quality, or Table 7 for the effect of a grid connection.

In these baseline specifications, we define the transmission cable density as the total length of transmission lines in a district divided by the area of the district. It may be the case that larger districts have unpopulated areas with no cables, which can make our density measure smaller, but the populated areas may be well electrified. We thus alternatively define the transmission variable as the total length of cables per person instead of per square km. The district population from the 2001 census is used for this computation. We then normalize this density measure with respect to the national average as in the baseline specification. The results are shown in columns (3) and (4) of Tables 8 and 9 for the effect of electrification quality and grid connection, respectively. The magnitude of the estimates is largely robust to this change, while the first stage F-statistics are larger. This indicates that cable length per person is a stronger instrument for the quality and grid connection, while the estimated impact on household income was not affected by this change.

Our results may be contaminated by other reforms that took place over the eleven

that our estimates are quite robust to this change.

years (1994-2005) with differential impacts on a subset of households. Specifically, the long run effects of trade liberalization that took place in 1991 may have had an effect on markets by 1994 and continued through the period of this study. The reduction in prices due to tariff cuts may have specifically affected agricultural households that live in coastal states.[19] These states also tend to be more industrial and thus have a higher density of transmission cables, which can be seen from Figure A.2. As a robustness check, we present results by excluding the coastal states of Gujarat, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal, shown in columns (5) and (6) of Tables 8 and 9. The magnitude of the coefficient for quality increased to 0.985, while the magnitude for grid connection increased to 0.853 when compared to the baseline specification. The larger estimates imply that the effect is higher for inland states, as is to be expected.

The political connections of the local government may bias our results if they actively lobby for higher investments in the transmission network. Regions with stronger political connections to the federal government may be more likely to receive electricity, and also grow faster due to better access to other resources as well. In order to check whether this is driving our results, we have excluded the states whose chief minister (head of the state) in 1994 belonged to the same party as the Indian prime minister at the federal level. The prime ministers of Andhra Pradesh, Assam, Haryana, Himachal Pradesh, Kerala, Maharashtra, Madhya Pradesh and Punjab belonged to the Indian National Congress party in 1994, which was also in power in the federal government. We repeated the estimation by excluding these states. The results shown in columns (7) and (8) of Tables 8 and 9 suggest that the effect of electricity quality is higher in the states while the effect of a connection is similar. The larger marginal effects can indicate lower levels of initial quality in these states. However, our central result that an improvement in quality has a larger effect than a grid connection is robust to this change.

In India, there are large disparities across states in terms of income levels and rates of economic growth. If high growth states experienced a relatively smaller improvement in electrification rates, then the estimates could be biased. We exclude the three states where income per capita has increased the most between 1994 and 2005 according to the HDPI-IHDS surveys, i.e. Haryana, Himachal Pradesh and Kerala, shown in columns (9) and (10). The estimates are higher when high-growth states are excluded, implying that the marginal impact of grid connection and quality is higher in slower-growing areas.[20]

The model is re-estimated by excluding households that live in districts that are more urbanized. Incomes in these districts may be growing faster for reasons that are

[19] Ural Marchand (2012).

[20] We also took out the five states with the highest growth rates, i.e. Haryana, Himachal Pradesh, Kerala, Punjab and Uttarakhand. The results are consistent with slightly larger IV coefficients for both quality and connection.

not related to electricity. The quality of power supply may be higher in these areas due to a higher number of power plants or higher investments in power transmission. We test this by first focusing only on urban areas. Second, we exclude the the districts that include the 10 largest cities. We then pick the districts that are neighbors of these districts and also exclude them in order to capture the full extent of their area of influence. The 10 biggest cities in India in decreasing order of size are: Mumbai, Delhi, Bangalore, Hyderabad, Ahmedabad, Chennai, Kolkata, Surat, Pune, and Jaipur.[21] This test captures parts of the transmission network that is likely not impacted by demand from urban and industrial centers. The resulting network may represent the most cost effective route between a generation site and a high demand location or between two high demand locations. Thus the outcomes we observe should come from the transmission network only through the channel of electrification.

See columns (3) and (4) of Tables 10 and 11. Excluding the districts with the largest cities increases the impact of grid connection as well as quality. The urbanized areas already have high grid connection rates and good quality electricity in the initial period. The increased coefficients after excluding these areas imply that the marginal returns to additional improvements are higher at low levels of electrification. The exercise is repeated by excluding only the districts with the 10 largest cities, presented in Columns (5) and (6).[22]

The high quality cutoff for the 2005 survey was taken as 18 hours of electricity per day. We estimate the model using different threshold values for this variable. The results in columns (7) and (8), reflecting a 16-hour cutoff, and in columns (9) and (10), reflecting a 20-hour cutoff shows that the magnitude of the coefficients increases with a higher cutoff, while the sign and the significance is not affected. The definition of high quality electricity in the 1994 round was taken as no power outages. We estimated the model one more time with a slightly different definition of at most two outages per week. These results are presented in columns (7) and (8) of Table 11 and show that the coefficient is smaller under this definition. The larger coefficients with more strict definitions, and smaller coefficients with weaker definitions of high quality electricity may indicate that the relationship is not linear and the marginal impact increases along

[21]This results in elimination of the following districts from the sample: Maharashtra: the districts of Dhule, Pune, Ahmednagar, Solapur and Satara; Haryana: the districts of Sonipat, Gurgaon and Faridabad; Karnataka: the district of Bangalore rural, Tumkuru and Kolar; Tamil Nadu: the districts of Dharmapuri and Kancheepuram; Andhra Pradesh: the district of Medak; Gujarat: the districts of Ahmedabad, Kheda, Gandhinagar, Bharuch, Mahesana and Surendernagar; Rajasthan: the districts of Sikar, Alwar, and Sawai Madhopur; and finally West Bengal, the districts of South 24 Parganas and North 24 Parganas.

[22]We repeated this exercise by excluding districts with the 15 largest cities, which includes Lucknow, Kanpur, Nagpur, Indore and Thane. Again, after excluding districts with 20 largest cities, that included Bhopal, Visakhapatnam, Pimpri-Chinchwad, Patna and Vadodara. The magnitude of these coefficients are similar to the baseline estimation.

the quality dimension. In all cases, the results show that the coefficients are robust and the main implication of the paper holds under alternative definitions of quality.

5 Concluding Remarks

The provision of reliable electricity is key to economic growth in the developing world. Previous studies of the effects of electrification have focused on new connections to the grid. In this paper we examine the effect of a grid connection as well as the quality of power supply on household incomes in rural India. These estimates can help determine spending priorities, for example between improving and maintaining existing infrastructure or extending the grid to cover new areas.

Identifying the impact of electrification on income is difficult because of reverse causality and other endogeneity concerns. We use the variation in infrastructure, specifically, transmission lines, in order to isolate the causal relationship between electricity provision and economic outcomes. We use a nationally representative dataset to show that the impact of electrification on households varies greatly by the quality of the electricity supply. A grid connection increases non-agricultural incomes of rural households by about 9 percent during the study period (1994-2005). However, higher quality of electricity (in terms of fewer outages and more hours per day) increases non-agricultural incomes by about 29 percent during the same time span. This highlights the importance of providing a high quality supply of power, as the potential benefits of electricity are not completely realized by only connecting households to the grid.

Our results suggest that policies that aim to provide reliable electricity to households may bring about significant economic benefits. These estimates can be used to perform cost-benefit analysis on infrastructure improvements, which can guide scarce capital assets into sectors that yield the highest returns.

Although several recent studies have examined the impact of grid connections, this is the first paper providing an estimate of the effect of the quality of electricity supply on household incomes. However, significant work is still needed in order to fully understand the impact of electrification on welfare. Because of data limitations we were not able to precisely disentangle the various channels through which electrification may operate. For example, it will be useful to see how households change their labor allocation when they get reliable electricity and understand the spillover effects when the whole village receives a connection to the grid.

Table 5: First Stage Regression on Grid Connection and Quality

	Dependent variable:							
	Grid Connection				Quality of Supply			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ*Cable*Connection*	0.100***	0.096***	0.100***	0.096***				
	(0.024)	(0.024)	(0.024)	(0.024)				
Δ*Cable*Quality*					0.152***	0.149***	0.152***	0.149***
					(0.053)	(0.052)	(0.053)	(0.052)
Δ*Size*		0.010***		0.010***		0.005***		0.005***
		(0.002)		(0.002)		(0.002)		(0.002)
Δ*Children*		−0.104***		−0.104***		−0.074***		−0.073***
		(0.020)		(0.020)		(0.015)		(0.015)
Δ*Hindu*		0.024		0.024		−0.013		−0.012
		(0.035)		(0.035)		(0.026)		(0.026)
Δ*Home*			−0.009	−0.016			−0.000	−0.004
			(0.033)	(0.032)			(0.023)	(0.023)
Δ*Livestock*			0.014	0.005			0.017	0.012
			(0.012)	(0.012)			(0.011)	(0.011)
District F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	9,785	9,785	9,785	9,785	7,181	7,181	7,181	7,181
F-stat first stage	17.32	16.34	17.28	16.34	8.30	8.12	8.26	8.08
K-P F-stat (weak ident)	17.33	16.35	17.28	16.34	8.30	8.12	8.26	8.08

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Δ*Cable* is the change in the normalized cable density. This is interacted with the initial value of electrification variable, which is *Connection* for columns (1) to (4) and *Quality* for columns (5) to (8). *Hindu*, *Home* and *Livestock* are indicator variables.

Table 6: Effect of Quality of Power Supply on Income

	Dependent variable: Log of income per adult equivalent							
	OLS	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ *Quality*	0.081	0.867^{**}	0.076	0.873^{**}	0.086^{*}	0.898^{**}	0.079^{*}	0.894^{**}
	(0.049)	(0.407)	(0.047)	(0.391)	(0.049)	(0.413)	(0.047)	(0.395)
Δ *Size*			-0.030^{***}	-0.034^{***}			-0.028^{***}	-0.033^{***}
			(0.005)	(0.006)			(0.005)	(0.006)
Δ *Children*			-0.361^{***}	-0.297^{***}			-0.368^{***}	-0.303^{***}
			(0.052)	(0.058)			(0.052)	(0.058)
Δ *Hindu*			0.145	0.147			0.140	0.141
			(0.096)	(0.094)			(0.096)	(0.094)
Δ *Home*					0.074	0.074	0.078	0.081
					(0.068)	(0.073)	(0.067)	(0.072)
Δ *Livestock*					-0.105^{***}	-0.121^{***}	-0.085^{***}	-0.097^{***}
					(0.026)	(0.029)	(0.025)	(0.028)
District F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	7,181	7,181	7,181	7,181	7,181	7,181	7,181	7,181
F-stat first stage		8.30		8.12		8.26		8.08
K-P F-stat (weak ident)		8.30		8.12		8.26		8.08

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Income represents total household income excluding agriculture expressed in per adult equivalent terms. The instrument used is normalized density of transmission cables multiplied by the initial quality of power supply. *Hindu*, *Home* and *Livestock* are dummy variables. The *Quality* index takes a value of 0 for no electricity, 0.5 for low and 1 for high quality supply. The threshold for high quality power supply in 2005 is fixed at an average of 18 hours of power per day.

Table 7: Effect of Grid Connection on Income

	Dependent variable: Log of income per adult equivalent							
	OLS	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ *Connection*	0.064**	0.507**	0.066**	0.534**	0.067**	0.538**	0.067**	0.554**
	(0.028)	(0.253)	(0.028)	(0.258)	(0.028)	(0.261)	(0.028)	(0.263)
Δ *Size*			−0.032***	−0.037***			−0.031***	−0.036***
			(0.004)	(0.005)			(0.004)	(0.005)
Δ *Children*			−0.372***	−0.318***			−0.377***	−0.322***
			(0.045)	(0.052)			(0.045)	(0.052)
Δ *Hindu*			0.104	0.090			0.101	0.086
			(0.080)	(0.078)			(0.080)	(0.077)
Δ *Home*					0.049	0.053	0.047	0.055
					(0.052)	(0.056)	(0.051)	(0.056)
Δ *Livestock*					−0.105***	−0.114***	−0.081***	−0.085***
					(0.023)	(0.024)	(0.022)	(0.023)
District F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	9,785	9,785	9,785	9,785	9,785	9,785	9,785	9,785
F-stat first stage		17.32		16.34		17.28		16.34
K-P F-stat (weak ident)		17.33		16.35		17.28		16.34

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the district level. *** p<0.01, ** p<0.05, * p<0.1. Income represents total household income excluding agriculture expressed in per adult equivalent terms. The instrument used is normalized density of transmission cables multiplied by initial quality. *Hindu*, *Home* and *Livestock* are dummy variables.

Table 8: Effect of Quality of Power Supply on Income – Robustness Tests I

	Dependent variable: Log of income per adult equivalent									
	Baseline		Population		No Coast		Political Conn.		High Growth	
	OLS	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Δ *Quality*	0.079*	0.894**	0.079*	0.882**	0.083	0.985**	0.163	1.643***	0.096*	1.039**
	(0.047)	(0.395)	(0.047)	(0.346)	(0.065)	(0.413)	(0.075)	(0.378)	(0.049)	(0.423)
Δ *Size*	−0.028***	−0.033***	−0.028***	−0.032***	−0.029***	−0.034***	−0.033***	−0.039***	−0.031***	−0.036***
	(0.005)	(0.006)	(0.005)	(0.006)	(0.005)	(0.007)	(0.003)	(0.004)	(0.005)	(0.006)
Δ *Children*	−0.368***	−0.303***	−0.368***	−0.304***	−0.324***	−0.268***	−0.379***	−0.256***	−0.389***	−0.308***
	(0.052)	(0.058)	(0.052)	(0.057)	(0.067)	(0.069)	(0.039)	(0.046)	(0.056)	(0.062)
Δ *Hindu*	0.140	0.141	0.140	0.141	0.173	0.181	0.018	−0.032	0.126	0.142
	(0.096)	(0.094)	(0.096)	(0.094)	(0.144)	(0.138)	(0.097)	(0.050)	(0.112)	(0.107)
Δ *Home*	0.078	0.081	0.078	0.081	0.058	0.062	0.127	0.170**	0.106	0.116
	(0.067)	(0.072)	(0.067)	(0.072)	(0.102)	(0.107)	(0.076)	(0.073)	(0.070)	(0.079)
Δ *Livestock*	−0.085***	−0.097***	−0.085***	−0.097***	−0.140***	−0.165***	−0.061	−0.084***	−0.046*	−0.057*
	(0.025)	(0.028)	(0.025)	(0.028)	(0.038)	(0.043)	(0.028)	(0.032)	(0.026)	(0.031)
District F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	7,181	7,181	7,181	7,181	4,422	4,422	2,895	2,895	5,660	5,660
F-stat first stage		8.08		43.52		7.40		15.42		6.90
K-P F-stat (weak ident)		8.08		43.54		7.39		4.63		6.90

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the district level. *** p<0.01, ** p<0.05, * p<0.1. Income represents total household income excluding agriculture expressed in per adult equivalent terms. The instrument used is normalized density of transmission cables multiplied by the initial quality of power supply. *Hindu*, *Home* and *Livestock* are dummy variables. The *Quality* index takes a value of 0 for no electricity, 1 for high quality supply and 0.5 for low quality. The threshold for high quality power supply in 2005 is fixed at an average of 18 hours of power per day.

Table 9: Effect of Grid Connection on Income – Robustness Tests I

	Baseline		Population		No Coast		Political Conn.		High Growth	
	Dependent variable: Log of income per adult equivalent									
	OLS	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Δ*Connection*	0.067**	0.554**	0.067**	0.566**	0.085**	0.853**	0.086	0.852***	0.067**	0.681**
	(0.028)	(0.263)	(0.028)	(0.265)	(0.036)	(0.413)	(0.065)	(0.269)	(0.029)	(0.287)
Δ*Size*	−0.031***	−0.036***	−0.031***	−0.036***	−0.027***	−0.036***	−0.038***	−0.044***	−0.034***	−0.040***
	(0.004)	(0.005)	(0.004)	(0.005)	(0.005)	(0.007)	(0.005)	(0.003)	(0.004)	(0.006)
Δ*Children*	−0.377***	−0.322***	−0.377***	−0.321***	−0.369***	−0.296***	−0.386***	−0.296***	−0.391***	−0.314***
	(0.045)	(0.052)	(0.045)	(0.053)	(0.059)	(0.068)	(0.021)	(0.032)	(0.048)	(0.059)
Δ*Hindu*	0.101	0.086	0.101	0.085	0.153	0.153	0.041	−0.005	0.084	0.061
	(0.080)	(0.077)	(0.080)	(0.077)	(0.133)	(0.121)	(0.046)	(0.057)	(0.089)	(0.086)
Δ*Home*	0.047	0.055	0.047	0.055	0.036	0.036	0.065	0.094**	0.061	0.074
	(0.051)	(0.056)	(0.051)	(0.056)	(0.087)	(0.091)	(0.051)	(0.044)	(0.053)	(0.061)
Δ*Livestock*	−0.081***	−0.085***	−0.081***	−0.085***	−0.131***	−0.141***	−0.062*	−0.059***	−0.050**	−0.052**
	(0.022)	(0.023)	(0.022)	(0.023)	(0.034)	(0.038)	(0.020)	(0.021)	(0.023)	(0.025)
District F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	9,785	9,785	9,785	9,785	5,707	5,707	4,924	4,924	8,173	8,173
F-stat first stage		16.34		50.49		10.93		7.31		14.03
K-P F-stat (weak ident)		16.34		50.51		10.93		10.35		14.04

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the district level. *** p<0.01, ** p<0.05, * p<0.1. Income represents total household income excluding agriculture expressed in per adult equivalent terms. The instrument used is normalized density of transmission cables multiplied by the initial connection. *Hindu*, *Home* and *Livestock* are dummy variables.

Table 10: Effect of Quality of Power Supply on Income – Robustness Tests II

	Dependent variable: Log of income per adult equivalent									
	Baseline		Urban areas		10 Cities		16 Hours		20 hours	
	OLS	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Δ *Quality*	0.079*	0.894**	0.062**	1.272**	0.079	0.901**	0.074	0.902**	0.098**	0.990**
	(0.047)	(0.395)	(0.022)	(0.617)	(0.048)	(0.398)	(0.048)	(0.391)	(0.049)	(0.481)
Δ *Size*	−0.028***	−0.033***	−0.030***	−0.035***	−0.028***	−0.032***	−0.028***	−0.032***	−0.028***	−0.033***
	(0.005)	(0.006)	(0.005)	(0.007)	(0.005)	(0.006)	(0.005)	(0.006)	(0.005)	(0.006)
Δ *Children*	−0.368***	−0.303***	−0.346***	−0.259***	−0.365***	−0.301***	−0.368***	−0.299***	−0.367***	−0.305***
	(0.052)	(0.058)	(0.048)	(0.095)	(0.052)	(0.058)	(0.052)	(0.058)	(0.052)	(0.058)
Δ *Hindu*	0.140	0.141	0.064	0.085*	0.129	0.130	0.139	0.124	0.138	0.123
	(0.096)	(0.094)	(0.065)	(0.051)	(0.096)	(0.094)	(0.096)	(0.092)	(0.096)	(0.093)
Δ *Home*	0.078	0.081	0.090	0.086	0.071	0.070	0.079	0.084	0.079	0.091
	(0.067)	(0.072)	(0.072)	(0.091)	(0.068)	(0.073)	(0.067)	(0.071)	(0.067)	(0.075)
Δ *Livestock*	−0.085***	−0.097***	−0.088*	−0.116***	−0.088***	−0.099***	−0.085***	−0.097***	−0.086***	−0.107***
	(0.025)	(0.028)	(0.035)	(0.034)	(0.026)	(0.029)	(0.025)	(0.029)	(0.025)	(0.030)
District F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	7,181	7,181	6,072	6,072	7,023	7,023				
F-stat first stage		8.08		24.81		8.01		8.10		8.20
K-P F-stat (weak ident)		8.08		4.69		8.01		8.10		8.20

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the district level. *** p<0.01, ** p<0.05, * p<0.1. Income represents total household income excluding agriculture expressed in per adult equivalent terms. The instrument used is the normalized density of transmission cables multiplied by the initial quality of power supply. *Hindu*, *Home* and *Livestock* are dummy variables. The *Quality* index takes a value of 0 for no electricity, 1 for high quality supply and 0.5 for low quality. The threshold for high quality power supply in 2005 is fixed at an average of 18 hours of power per day.

Table 11: Effect of Grid Connection and Quality of Power Supply on Income - Robustness Test

	Dependent variable: Log of income per adult equivalent							
	Connection						Quality	
	Baseline		Urban areas		10 Cities		Change in outages 1994	
	OLS	IV_C	*OLS*	IV_C	*OLS*	IV_C	*OLS*	IV_C
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ*Connection*	0.067**	0.554**	0.062	0.640*	0.065**	0.554**	0.061**	0.395*
	(0.028)	(0.263)	(0.034)	(0.381)	(0.028)	(0.263)	(0.018)	(0.216)
Δ*Size*	−0.031***	−0.036***	−0.032***	−0.038***	−0.030***	−0.035***	−0.028***	−0.030***
	(0.004)	(0.005)	(0.006)	(0.007)	(0.004)	(0.005)	(0.005)	(0.005)
Δ*Children*	−0.377***	−0.322***	−0.373***	−0.309***	−0.379***	−0.326***	−0.369***	−0.340***
	(0.045)	(0.052)	(0.036)	(0.075)	(0.046)	(0.053)	(0.043)	(0.052)
Δ*Hindu*	0.101	0.086	0.076*	0.064*	0.093	0.079	0.140**	0.138***
	(0.080)	(0.077)	(0.028)	(0.035)	(0.080)	(0.077)	(0.034)	(0.034)
Δ*Home*	0.047	0.055	0.049	0.0547	0.039	0.046	0.079	0.082*
	(0.051)	(0.056)	(0.057)	(0.056)	(0.052)	(0.056)	(0.042)	(0.042)
Δ*Livestock*	−0.081***	−0.085***	−0.077*	−0.085***	−0.079***	−0.083***	−0.085*	−0.092***
	(0.022)	(0.023)	(0.032)	(0.031)	(0.023)	(0.024)	(0.032)	(0.033)
District F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	9,785	9,785	8,383	8,383	9,585	9,585	7,181	7,181
F-stat first stage		16.34		39.97		16.33		50.06
K-P F-stat (weak ident)		16.34		13.42		16.34		26.49

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the district level. *** p<0.01, ** p<0.05, * p<0.1. Income represents total household income excluding agriculture expressed in per adult equivalent terms. The instrument used is the normalized density of transmission cables multiplied by the initial connection. *Hindu*, *Home* and *Livestock* are dummy variables.

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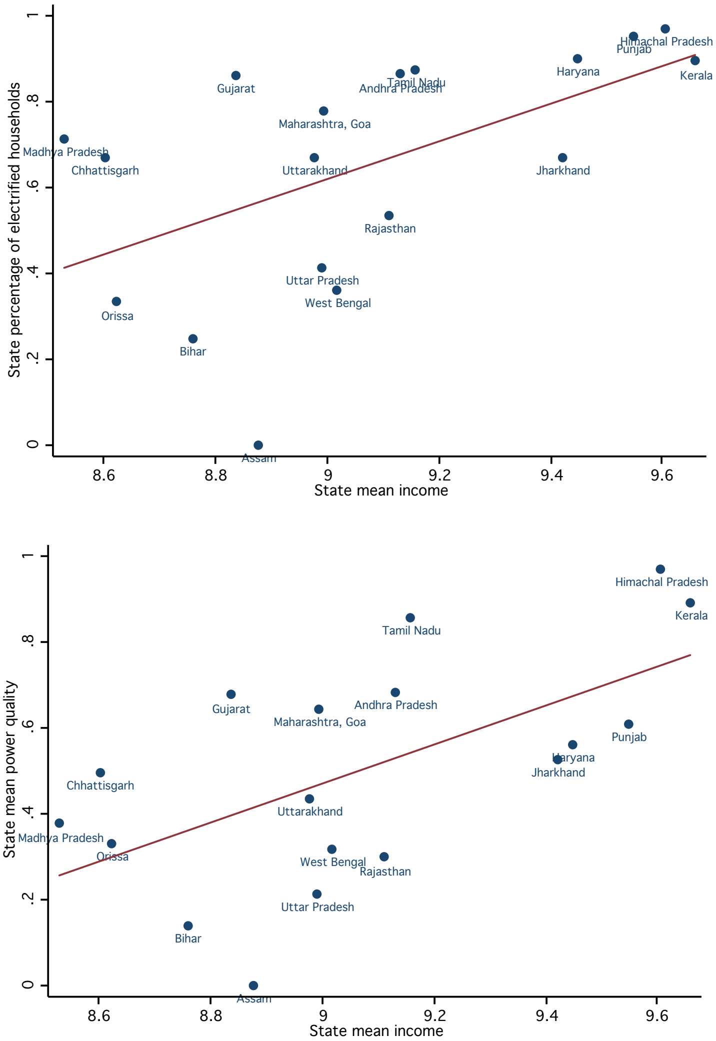
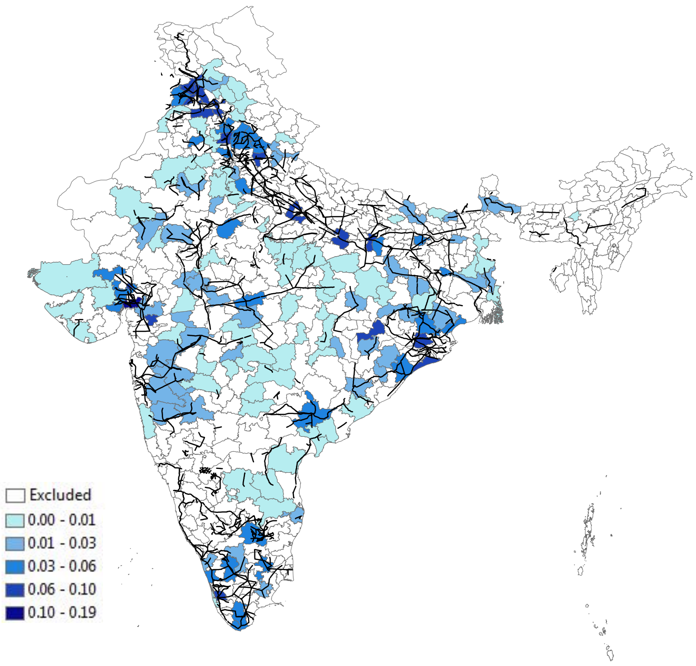
A Appendix Figure

Figure A.1: Household Electrification Rate vs Mean Income by State, 2005



Notes: We show the state-wise correlation between electricity outcomes and average household income in 2005. A linear fit for the scatter diagram is provided.

Figure A.2: Density of transmission cables per km^2 by district, 2005



Notes: The figure shows the Indian transmission network, and the density of transmission cables in 2005 in the survey districts. The density is computed as the cable length divided by the area of the district. The districts that are left white are not included in our sample. Source: Indian Ministry of Power, ESRI ArcGIS World Package and Geocommons.