Impacts of Reliable Electricity Supply: Evidence from India

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Abstract

This paper studies the effects of increased access to electricity in rural India on per capita income. We examine outcomes from connecting to the grid as well as the "reliability" of electricity supply. The analysis is based on two rounds of a representative panel of more than 10,000 households. We use the district-level variation in land elevation and the district-level density of transmission cables as instruments for the electrification status of the household. The "reliability" of power supply is instrumented only using the former instrument. The results suggest that per capita income increases subsequent to full electrification may be underestimated by as much as 60% if the level of "reliability" of the power supply is not taken into account.

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1 Introduction

In 2009, 288 million people – about a fourth of India's population, lacked access to basic electricity (World Energy Outlook 2011). In 2005, 364 million people did not have access, while another 300 million only had it sporadically (Balachandra, 2011). The recent grid failure in July 2012 affected 670 million individuals, almost 10 percent of the world's population (New York Times, 2012). According to the World Bank, unreliable energy in India has been a major obstacle to economic development, limiting its comparative advantage in labor-intensive products (World Bank, 2010; Rud, 2012). Connecting all households to the grid is likely to have an important effect on the Indian economy and on its labor market. The aim of this study is to investigate the effects of reliable electricity on economic development in India. Through which channels does electrification impact economic outcomes?

In this paper, we are particularly interested in household income outcomes. We focus not only on the extensive margin of electrification, whether the household is connected to the grid, but also on the intensive margin, i.e., how reliable is the supply of electricity. Reliable power supplies may be as important as the connection to the grid. For instance, even if connected, a household only receiving 5 hours of electricity per day, at random moments, is not likely to be much better off than when it was not connected. That household may actually be worse off after getting linked to the grid, because it reorganizes its day-to-day activities based on the assumption that it will receive an assured supply of power, which it may not receive. The study of the intensive margin of electrification in developing countries, is mostly missing in the development economics literature. Due to a restriction in the data, we can only focus on total household income excluding agricultural income, but including income from wages and salaries paid in the agricultural sector. Income is measured in per-adult equivalent terms.

Rural electrification may affect households' welfare via various channels (Oda and Tsujita, 2011; Modi, 2005). An example of these channels is women's labor supply. The electrification of an household frees its female components form a certain number of domestic chores, or simply allows for the possibility of performing them in the evening. In response to this we shall observe an increase in women labor supply which could drive wages down. Yet, at the same time, electrification renders some activities more productive. For example, productivity of agricultural labor may improve due to technologies such as automatic irrigation, and this could push wages up. A reliable supply of electricity also creates opportunities for many small entrepreneurial activities which can take place within the household, increasing its non-wage income. We could also observe a general increase in labor supply and wages, electrification allows more entrepreneurial activities to take place and renders other activities – for instance agricultural ones – more productive. Finally, electrification could also affect labor supply by children. Thanks to electricity, the need to collect different kinds of fuels diminishes and therefore their labor supply should decrease.

Various papers already approach this topic in relation to the Indian situation (Balachandra, 2011; Khandker et al., 2010; Bhide and Monroy, 2011), yet they limit themselves to a descriptive analysis of the phenomena. Papers identifying the effect of rural electrification using more advanced econometric techniques such as propensity score matching, difference-in-difference or instrumental variables approaches, usually deal with countries other than India. Bensch et al. (2010) focus on the case of Rwanda, while Khandker et al. (2009a and 2009b) focus on Bangladesh and Vietnam, respectively, focusing on the impacts of two specific rural electrification projects by the World Bank. The most sophisticated paper on this topic is by Dinkelman (2012), who studies the labor market effects of electrification in South Africa using an instrumental variable approach by concentrating on a regional electrification project. All of these papers study a particular region in a country, or investigate the impact of a particular electrification program, while the present study is based on a representative sample of the Indian population.

Identifying the effect of electrification, as of any other investment in infrastructure, is generally not trivial (Duflo and Pande, 2007; Roller adn Waverman, 2001; Aschauer, 1989; Garcia-Mila and McGuire, 1992; Holtz-Eakin, 1993). A variety of factors may lie behind the electrification of certain areas and the non-electrification of others. Some of these factors are closely related to the labor market situation. Governments usually aim infrastructure investment to already growing areas. Moreover, other economic trends could affect the investment decision. For instance, a richer village is probably 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 again on the population density of the region. For all these reasons our estimation may suffer of an endogeneity bias.

We tackle the possible endogeneity issue regarding electrification using an instrumental variable approach. For this we use a set of two instruments. First, following Dinkelman (2012) we use the district-level variation in land elevation. This variable, measured as the standard deviation of mean elevation is strongly correlated with electrification costs. Setting up a transmission or distribution network on flat land is less costly then setting up the same network in an area characterized by rolling hills or, even worse, by mountain ranges. A high land elevation variability will force the network to contain a higher number of structures, to avoid that the cables hang too loose and to deviate and go around the tallest mountains. In this cases a trade off exists between a longer route characterized by higher electricity losses and a shorter route (for example going over the top of a mountain) which will cost more. Hence, it is more costly for a district situated in a mountainous region to electrify its villages. A high level of variability in land elevation will therefore decrease the probability of electrification. This relationship between the variation in land elevation and the probability of electrification is nonlinear. Therefore, the first stage is modelled using a probit model.

Second, we construct a new instrument which gives a district deviation from the national average transmission cables' density. This instrument is aimed specifically at reliability, but works also for electrification. If a district is characterized by a higher transmission cables density than the rest of the nation, the probability for a rural household to be connected to the grid and to have a more reliable power supply is higher (Brown and Sedano, 2004). We focus on transmission lines, instead of distribution lines, because the transmission network is not laid out in order to electrify rural areas. The transmission network serves to transport electricity over long distances, for example from generating sites (an hydro power plant in the mountains) to high demand areas, taking the shortest possible route. Yet, once the cables are laid out, it is possible to add a transformer and divert some of the power to electrify a small distribution network going through rural villages. Since the transmission is connected to many power plants around the country, the probability of having a reliable access to power when being close to it is higher. By using ArcGIS, we can measure the length of cables crossing a district precisely. The argument behind it is straightforward. If an household is located in a district crossed by many transmission cables the probability of being connected to the network – and especially of receiving a more reliable power supply – is higher than if it is located in a district which does not contain any transmission cable.

The Indian legislation did not explicitly mention rural electrification until 2003 (Modi, 2005). Therefore, up to that point, transmission lines were established with the exclusive purpose of electrifying urban and industrial areas. Yet, once the transmission lines are in place, a step-down transformer might be installed and connected to a distribution network in order to provide power to rural areas. This implies that rural electrification was not targeted directly, but rather happened indirectly as a byproduct of the electrification of urban and industrial areas. Transmission lines are a major infrastructure investment and require as justification a high demand pole at their destination.[1] Distribution lines, on the other hand, could be initiated by local municipalities as they are relatively less costly if there is a transmission line within a feasible radius. These facts justify why we use the transmission network density as an instrument, rather than the density of the distribution network. This choice is dictated by the fact that while the first happens in a random way with respect to rural settlements, the latter does not.

The results suggest that even though having a connection to the grid increases households' income, it is the availability of a reliable power supply which has a stronger impact.

[1]The cost of setting up a new transmission network may range from several hundred thousands dollars to several millions per kilometer.

By not considering the reliability of the supply the effect of full electrification is likely to be underestimated, by as much as 60%. Perhaps surprisingly, we find that the positive effect of power reliability on income derive from an increase in wage and salary income, and not from an increase in small businesses or petty trade income. Access to reliable power does not seem to stimulate household to pick up small entrepreneurial activities, yet it seems to either render production activities more productive (and thus increase wages) or increase labor demand. It could also be the case that both phenomena are taking place at the same time.

The remainder of the paper is organized as follows. Section 2 summarizes the Indian situation with respect to rural electrification. Section 3 describes the main survey and other data used. Section 4 exposes some descriptive statistics and stylized facts. Section 5 presents the methodology used and discusses the results and section 6 concludes.

2 Electrification Policy in India

One of the major infrastructure deficiencies of India concerns the power sector. Electricity services across India are affected by severe shortcomings at all stages of production, transmission and distribution. Supply is highly unreliable, outages and voltage fluctuations are frequent. This is not only due to a lack of a sufficient number of power plants, but also to a lack of fuel to run the existing ones. A direct consequence of this is that often peak demand cannot be met. Failure to satisfy electricity demand results in frequent power outages. Last but not least, households cannot easily access electricity, irrespective of living in urban or rural areas, while this problem exacerbates when living in rural areas

Regarding electricity consumption, India is doing worse than the majority of the world. In 2007, average per capita consumption stood at 543 kWh, while average consumption in OECD countries was of 8,477 kWh, in African countries of 578 kWh and in Asian countries of 705 kWh. Even among BRICs countries India is the one doing worst. Its per capita average consumption makes up for just a fourth of chinese consumption (2,346 kWh).[2] According to the World Bank, in 2010 average power consumption in India was still around 566 KWh per capita, compared to a world average of 2,782 KWh per capita. The low average consumption is partly due to the fact that over 35% of the world population without access to electricity lives in India. This lack of access could significantly hinder economic development.

The low development of the Indian power sector is deeply linked to its financial fragility. The rate of cost recovery is extremely low, and dropping. In 1992-93 this rate was around 82%, while in 2001-02 it was around 69%. These low cost recovery

[2] International Energy Agency, 2009.

rates are tied to the huge losses during transmission and distribution, which rose from around 25% in 1997-98 (Modi, 2005) to 38.86% in 2000-01 (Oda and Tsujita, 2011), while the average for neighboring countries is around 10%. As a consequence of these losses and of electricity thefts, it is estimated that, of the power generated, only 55% is billed and only 41% realized. On top of these problems, India experienced over the last years an important rate of de-electrification, due especially to thefts of infrastructure (Balachandra, 2011).

Electrification is a key input for economic development, as recognized by the Millennium Development Goals and the World Summit on Sustainable Development. The rationale behind this is the huge discrepancy in energy consumption levels between developed and developing countries, where more than 1.4 billion people still have no access to modern energy supplies (World Bank, 2010). We observe a strong negative correlation between the fraction of population living below the poverty line and the level of electrification (Srivastava and Rehman, 2005).

The benefits of rural electrification are manyfold, including an increased productivity in agriculture, through technologies such as mills, motors and pumps, and labor, through an improvement in access to information, an enhancement in the delivery of health and education and a better lighting, increasing the probability that women will read and earn income. Many of the effect come through secondary channels, for instance an increase in the productivity of agriculture is likely to lower the prices of locally produced food, therefore improving welfare. The possibility of switching from biomass to electricity for cooking improves the quality of the air within the household and therefore has a positive impact on the health status (Modi, 2005; Oda and Tsujita, 2011).

According to Balachandra (2011), expansion in energy access is declining from the double digits growth rates observed 10 years ago to a meager 4% observed in the last years. Yet, when looking at electrification numbers one has to be extremely careful. One of the big problems in the discussions about the success/failure of electrification policies in India resides in the definition of electrification. As stated by Oda and Tsujita (2011), the criteria to be satisfied in order to declare a village "electrified" changed considerably over time, and have always been lax. Up to 1997, a village was declared electrified if any of its irrigation pumps used electricity. In 1997, the definition was slightly modified and electricity needed to be used in an inhabitant locality for the village to be declared electrified. The currently in use definition, introduced in 2004, states that three conditions have to be fulfilled. *(i)* at least 10% of the village households must be electrified, *(ii)* basic infrastructure such as a transformer and distribution lines must be placed in the inhabited locality as well as the *Dalit Basti* hamlet, and *(iii)* public facilities such as the school and *Panchayat* office must be electrified. For these reasons, it is always better to look at the percentage of electrified households, and not of electrified villages. The

Ministry of Power states that 86% of the rural villages were electrified, yet only 43.5% of rural households were actually connected to the grid (Census 2001, 2001; Srivastava and Rehman, 2005).

2.1 History of rural electrification in India

The Indian energy sector has historically been plagued by a variety of problems. The first is the lack of a clear policy framework. Rural energy policy provision has been basically driven by target-oriented and subsidy-driven national programs that have either been technology centric or end-use based without having any inter-linkages. The second is tied to the lack of clarity on the specific roles and responsibilities of various departments/institutions/ministries/agencies involved in disseminating energy services in rural areas. This problem is common to many developing countries (UNDP, 2000). In India, the energy sector is administered by five different ministries. Therefore, even though the planning is done by a single agency, the Planning Commission of India, its implementation is split across different ministries. The third is the overemphasis on connecting every village to the grid irrespective of whether there are consumers in the village and of whether households actually connect. A fourth problem consist in misdirected subsidies regimes. A striking example is that, in some states, agricultural lobbies managed to obtain electricity for agriculture for free (Srivastava and Rehman, 2005; Modi, 2005), further weakening the financial situation of the electricity sector and hindering its development. And the last big problem is a complete lack of research and development initiatives.

As a result, electricity investment has been behind development of other infrastructure in India. Figure B.4 and Figure B.5 plot the transmission network against the rail network and the road network respectively. It can be seen that both rail and road network have a national coverage while the electricity transmission network remained to be clustered in certain parts of the country, especially northern industrial states, while large parts of the country have no transmission lines.

While electricity distribution is the exclusive domain of state governments, both central and state governments enjoy legislative rights on generation and transmission. Within states, generation, transmission and distribution are handled by vertically integrated State Electricity Boards (SEBs). SEBs used to operate under the Electricity Supply Act of 1948 and to be supplemented in their effort by the Central Public Sector Utilities like the National Thermal Power Corporation, the National Hydro-electric Power Corporation and the Power Grid Corporation of India.

During the 1950s and 60s the main effort of the SEBs concerning rural electrification was in connecting cities and towns, in spite of their implied Universal Service Obligation. Universal electrification was expected to be achieved via the gradual electrification of towns and cities. However, the electrification process became a game of numbers for politicians, who in order to get elected wanted to declare "electrified" the maximum number of villages within their constituencies. As a direct result, the number of villages connected to the grid increased, while the number of households connected did not manage to match the pace.

Growth in capacity generation from 1947 to 1991, when reforms were started, has been strong, going from 1,362 MW to nearly 74,699 MW. Over the same period, per capita consumption went from 15.55 kWh to 252.7 kWh (Modi, 2005). Generation is nowadays beyond 170,000 MW. Yet, the financial situation of the SEBs was very weak. For this reason, in 1991 started a lengthy political process to open up SEBs to private participation. Yet, notwithstanding their partial privatization, the financial performance of SEBs across the country resulted in a loss of more than 4.5 billion USD in 2001-02 and more than 14 billion USD in 2010-11. The Electricity Supply Act of 1948 fully protected SEBs from competition, allowing privates to enter only in the generating phase. The new set of regulations, covering generation, transmission, trading and distribution needed ten years to be put together and finally passed in Parliament as the Electricity Act 2003. The Electricity Act 2003 for the first time mentions rural electrification in a law (Modi, 2005).

2.2 The power grid

In order to better understand the mechanisms through which households are connected to a grid, we next look at how electricity travels from a power plant to the final consumer. This is important in order to understand the intuition lying behind our instrument. On its way, electricity goes through three different networks (refer to Figure 1 for a visual description). The *transmission network* is used to carry electricity over large distances, from production sites to high demand locations. This network is characterized by high voltage (HVDC – i.e. High-Voltage Direct-Current – 765, 500, 345 and 230 kV), which reduces transport losses. The entrance and the exit of power from the transmission network necessitates *electrical substations*, the so-called *step-up* transformers at the entrance of the network and the *step-down* transformers at its exit. These transformers take the low voltage electricity coming out of power plants and increase the voltage for the long distance transportation phase. A second electrical substation decreases the voltage and inserts the power in the *subtransmission network*. This network is characterized by lower voltages, usually 69, 115 or 138 kV, and on it electricity travels shorter distances. At the end of the sub-transmission network there is a final electrical substation which canalizes electricity into the *distribution network*. This last section of the grid is characterized by medium to low voltages (less than 50 kV) and travels very short distances. The electricity transported by the distribution network is at the right voltage for the end consumer.

Setting up new segments of the transmission network is an extremely costly operation. The cost of a new transmission line per kilometer can go from several hundred thousand dollars up to several million. The cost does not only depend on the capacity of the line but especially on the shape of the land it has to go through. For example, setting up the new segment over rolling hills will be much more expensive than over flat land because the line will need a higher number of structures sustaining the cables. In the same line of argument, if the line has to take a deviation in order to avoid a big mountain, the cost will equally go up. The reason of the increase in cost is the same as before, in order to take a turn, more structures are needed. Given the high set up cost of a transmission line, everything is done to keep it running. This means that it will be highly interconnected, and connected to virtually all major power plants in the country. The high interconnection level makes it highly reliable (Brown and Sedano, 2004). The transmission network is the most reliable part of the whole grid, and for this reason an household situated in a district characterized by a high density of transmission cables' is more likely to receive a reliable power supply.

3 Data

The panel contains two survey waves, one collected in 1994 and one in 2005. The first wave is part of the Human Development Profile of India (HDPI). This database was constructed in 1994 and comprises over 33,000 rural households. A share of these households was then re-interviewed for the India Human Development Survey (IHDS) in 2005, which contained in total over 41,000 rural and urban households. The households to be re-visited were chosen by first selecting a simple random sample of villages within each district, and selecting a random sample of households among the surveyed households within each village. The panel data then consists in a representative panel comprising more than 12,000 rural households which were interviewed in 1994 and 2005. The panel contains a wide variety of information at the individual, household and village level.

When the first wave of data was collected in 1994, the survey was not designed as the first wave of a panel, therefore there are some discrepancies between variable definitions in 1994 and in 2005. One of the many examples of this phenomena are data on agricultural income. The questionnaire used in 2005 was much more detailed on agricultural income than the one used in 1994. For instance, the 2005 questionnaire also contains questions about losses, while in the 1994 one agricultural income was not allowed to be negative. Therefore, for the sake of our analysis, data on agricultural income cannot be included in households' total income. Another example concerns data on the reliability of power supply. The 1994 wave only asked if the household's power supply was continuous, if the household experienced on average one power break per week, or more than one power break per week. Instead, the 2005 wave asked how many hours of electricity does the household receive on average per day.

Table (1) reports state-wise households' electrification rates for the 18 states surveyed in this study. The majority of the states studied experiences an increase in its electrification rate.[3] The table shows that the richest states, for instance Andhra Pradesh, Tamil Nadu and Kerala are also those doing best in terms of electrified rural households. Poorer and more corrupted states, such as Bihar, Orissa and Uttar Pradesh are doing considerably worse. Figures B.1 and Figure B.2, in the appendix, provide a visual illustration of the district-level electrification rates in 1994 and 2005. Figure 2, shows the evolution of the electrification rate in each district between 1994 and 2005. This map clearly shows that the highest growth in electrification rates happened in the already stronger areas in India. This pattern confirms what we know about rural electrification: for the period considered it was not a clearly stated policy objective but it just happened as a byproduct of the electrification of more sensible areas.

Our main variables are constructed as follows. *Home* is a dummy variable which takes value of 1 if the household owns the house in which the family is currently living. *Child*, *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 old) and adults (older than 22 years old), respectively. *Size* simply represents the total number of individuals forming the household. *Livestock* is a dummy variable which takes value 1 if the household owns any farm animal. We expect the coefficient on this variable to be negative. Agricultural income is not included in our definition of income, and the ownership of farm animals indicates that the household is more likely to get part of its income from agricultural activities. Therefore, this should decrease income coming from other activities. *Hindu* is a dummy variable taking value of 1 if the household is of Hindu religion and 0 if it belongs to another religious denomination. Finally, the occupational dummies *Agriculture*, *Low Skill* and *High Skill* indicates whether the head of the household belongs respectively to agricultural, low skill or high skill occupations, with *Other* occupations as the control group. This last group corresponds to any kind of home based activity, including students and unemployed. While the two rounds of survey use different classifications for occupational categories, we are able to group them under these broad categories. Table A.1 presents the list of occupations under each category.

The district-level variation in land elevation is computed thanks to Global Land Cover Facility data (USGS, 2004), which provides maps of global land elevation at 90 meters

[3]Assam seems to be going up to a 100% connection rate, yet only three households located there were interviewed.

resolution. This means that every district is divided into squares of 90m by 90m, and we know the elevation with respect to the sea surface of each square. Using ArcGIS, we were able to compute mean, standard error and range of elevation within each Indian district. While the range only informs us about the difference between the lowest and the highest point within the district, the standard deviation gives us a better idea of the behavior of land elevation. For instance rolling hills will generate a higher variation than a gently upward sloping piece of land. The variation is important in determining the cost of electrification. Figure B.6 gives a visual image of land elevation in India.

In order to construct the variable for the length of the transmission cables within each district, we use the maps of the Indian transmission system published by the Indian Ministry of Power. We then overlie these maps onto the map of Indian districts from Census 2001 (Government of India, 2001) using ArcGIS. Figure B.7 presents two different stages of development of the Indian transmission network, district borders have been removed in order to facilitate the reading of the map. After obtaining the overlaid map, it is easy to split the transmission cables along districts borders and measure the exact length of the transmission cable within each district. The density of the transmission network is then computed by taking the total length of all the transmission line segments for each district, and dividing it by the district surface. The normalized density of the transmission network for each district is then defined as the deviation from the national average density, henceforth we will call this measure the normalized transmission cables' density. Figure B.3 presents the map of the normalized transmission cables' density for 2005 (Figure 3 in the appendix, portrays the same map for 1994). In both maps the three lighter shades represent values below the national average, the darker shades show instead a higher district density with respect to the national average. If a household is located in a district characterized by a positive normalized density, i.e. having a higher transmission density than the national average, then the probability that the household is connected to the grid, and has a reliable power supply, is higher (Brown and Sedano, 2004). On the other hand, if the household lives in a district distinguished by a negative value of the normalized density, then the probability of electrification and good reliability is lower.

4 Stylized Facts and Descriptive Statistics

Table 3 exhibits the evolution of households from non-connected to the grid, to connected but with an unreliable supply of electricity and to connected with a reliable supply of power between 1994 and 2005. Over this period, the amount of households connected to the grid increased by 29.9%, going from 52.9% of electrified households, to 68.7%. Table 3 also shows the variation in real income per adult equivalent between 1994 and 2005.

Households experiencing the highest increase in income per adult equivalent are those who got connected to the grid within that time period. This data, strongly suggests a positive effect of electrification on income.[4] The table shows that the amount of households having an unreliable power supply went down by 21.6%, while the amount of households with a reliable power supply went up by 236.1%. A small number of households moved backward, i.e. either from a reliable supply to an unreliable one, from an unreliable supply to no connection or from a reliable supply to no connection. This phenomenon finds an explanation in the widespread and growing thefts of infrastructure which occur regularly all over the Indian territory (Balachandra, 2011).

Both, connection to the grid and an increase in the reliability of electrification, have a positive effect on income. This result may be observed in Table (3), Figure 4 and Figure 5. Focusing first on Table (3), we can observe that moving from no connection in 1994 to a connection, irrespectively of reliability in 2005, seems to lead to an increase in the household real income of around 3%. These increases are statistically significant at the 1% level. Looking at the second line of the table we observe that moving from an unreliable power supply to a reliable one leads to an increase in income of around 4% statistically significant at the 1% level. These very preliminary numbers tend to indicate the relevance of studying not only what happens when an household is connected to the grid, but also what happens when the power received becomes more reliable.

Figure 4 and Figure 5 tell a similar story at the state level.[5] Figure 4 shows the positive correlation between the percentage of households connected to the grid and the state mean household income. Figure 5 exhibits the same positive correlation between the state mean level of reliability and the state mean household income. Not surprisingly, states which are not doing well concerning grid connections, are also doing badly reliability-wise. Both figures show a clear decrease in variance at the top of the distribution.

Table (4) reports descriptive statistics by state. As we would expect we can observe that the northern states (closer to the Himalaya) report the highest mean elevation and the bigger range, for instance Himachal Pradesh and Uttarakhand. Not surprisingly these states are also characterized by the highest variation in land elevation. Figure 6 shows the district-level variation of land elevation. When computing this variable we have to drop all the coastal district, because data on elevation are not sufficiently precise. In our case this corresponds to dropping 8 districts out of the 157 sampled.

Table (5) exhibits some descriptive statistics of the measures used in order to construct the instrument, i.e. the normalized transmission cables' density. The two different

[4] Approximately three quarters of the households reports data on reliability of electrification. The full sample is used in the analysis wherever possible.

[5] Figure 4 and Figure 5 present data for 2005, while Figure B.8 and Figure B.9 in the appendix present data for 1994. The story told is the same.

phases of evolution of the transmission network used here present an evolution of more than 7,000 extra kilometers (corresponding to an expansion of 22.8% of the network). In two of the states taken into account (Uttarakhand and West Bengal) the total length of the transmission cables decreased between 1994 and 2005. This reductions are due either to the outdated state of the infrastructure or, as we mentioned before, to infrastructure thefts. In states such as Gujarat, Maharashtra, Punjab, Rajasthan and Uttar Pradesh, the total length of transmission cables increased significantly. Apart from Gujarat, these states are also characterized by a significant increase in mean household income. Overall the transmission cables' density increased by 22.8%, yet we encounter a great variation among states (the variation is even greater when we look at districts) going from a decrease of 3.3% in West Bengal, to an increase of 96.7% in Gujarat.

A further proof that India is not doing particularly well in terms of universal electrification comes from comparing its national transmission cables' density to the one of China (another BRIC country) and of the US. Not surprisingly, densities for these two countries are higher than the one found for India. The fact that China shows a density somehow in between the one of the US and the one of India only underlines the importance of electricity to development.

5 Empirical Approach and Results

We deal with the endogenous probability of electrification and reliability by using an instrumental variable approach, following Angrist (1990), Angrist and Imbens (1994) and Angrist (1998). In India, the variation of electricity distribution and generation infrastructure across districts is large. Rural electrification was not officially part of the Indian electrification policy until the Electricity Act of 2003. Therefore, up to 2003, the main purpose of building transmission lines was to deliver power to industrial and urban areas, for example coming from a big hydro power plant situated in the mountains. When the second round of the survey was conducted between the end of 2004 and the beginning of 2005, the Electricity Act 2003 was still very young. For this reason we can assume that during the period covered by our data there were no significant government policy in place for rural electrification. As a result, rural households were electrified as a byproduct rather than direct targeting, and we can assume that rural electrification was not taken into account in the design of the transmission network.

Our approach is based on the use of two different instruments, one aimed specifically at electrification, and one at power reliability. Following Dinkelman (2012), we instrument connection to the grid using the district-level variation in land elevation. We argue that the land variation affects the probability of connection to the grid in a non-linear way. Therefore, we use a probit model in the first stage.

To the best of our knowledge, this is the first study dealing with power reliability, thus we use a newly constructed instrument in order to deal with its endogeneity. We instrument power reliability using the normalized transmission cables' density. Closeness to the transmission network virtually means closeness to the majority of power plants in the country and therefore a higher probability of receiving a reliable power supply. This newly constructed instrument can also be used to instrument connection to the grid, as we will see it is weaker than the variation in land elevation, yet provides very similar results. This instrument affects the probability of having a reliable power supply in a linear way.

That said, villages that are near an industrial area or villages that are located within states with significant industrial activity are more likely to be electrified. These villages may be better off in terms of general income levels as a result of the economic activity in urban areas. We deal with this by introducing village and year fixed effects in our regressions to account for variation across villages in terms of proximity to cities, industrial regions, and other characteristics such as land quality, that may affect the income levels in the village, and may change over time. All of our results are therefore identified within villages.

It is possible that, within villages, the investment necessary for connection to the grid was better justified for households with significant amounts of land, or for households involved in some home-based economic activity. Households that can invest in electrical appliances may find it worthwhile to connect to the grid. Even for households connecting to the grid illegally, the initial connection may require a minimum amount of fixed cost for cables, etc., that may be infeasible for poorer households. We therefore present our results with a full set of household controls for factors that relate to the general well-being of the household, including assets, occupation and household composition.

Following standard identification of average treatment effects, our specification takes the following form,

$$
\begin{aligned}
Y_{it} &= \alpha + \delta_t + \delta_v + \beta \hat{T}_{it} + X\gamma + \varepsilon_{it} && (1) \\
T_{it} &= \varphi + \delta_t + \delta_v + \eta Z_{it} + X\zeta + u_{it} && (2)
\end{aligned}
$$

where subscripts i, t and v denote household, time and village, respectively. Thus, δ_t and δ_v represent time and village fixed effects. T denotes the treatment variable, which can either be electrification – taking value 0 if the household is not electrified and 1 otherwise – or reliability. Y is income, the dependent variable and X is a vector of controls. Z is our instrument, the normalized transmission cables' density, and ε and u are error terms. The coefficient of interest is β. The first stage, equation (2) is modelled in a linear way when using the normalized transmission cables' density as instrument, and as a probit when using the district-level variation in land elevation.

Table (6) presents first stage regressions – results for equation (2) – both for connection to the grid and the reliability index, using the newly constructed instrument, the normalized transmission cables' density.[6] As seen above, all specifications presented contain time and village fixed effects. The error terms are clustered at the village level. The coefficients of interests here are those on the *Instrument*, the normalized transmission cables' density.

Let us first focus on columns (1) to (5), where the dependent variable is the connection to the grid. The coefficient of interest is extremely stable across the different specifications, equal to 0.019, and statistically significant at the 1% level. Therefore, as expected, living in a district characterized by a higher transmission cable density with respect to the national average increases households' probability of being connected to the grid. This is true even when controlling for village and household characteristics. Let us now focus on columns (6) to (10), where the dependent variable is the reliability index. Also here, the coefficient of interest is extremely stable across specifications. Its magnitude is constant, at 0.038, and it is statistically significant at the 1% level, also in this case the effect holds even when controlling for village and household characteristics. An household living in a district with a higher transmission cable density is more likely to enjoy a more reliable power supply. Reliability data are characterized by a relatively high number of missing values. In Table (6) we can notice the loss of around 5,000 observations.

We are now going to analyze several aspects of households connection. The first exercise concerns whether or not an household is connected to the grid. This analysis is the one usually performed in the literature, simply focusing on whether the household is electrified. Second, we run the same specification on a reliability index. We also run the latter specification using a village-level reliability index, which allows us to reduce the loss of observations.

In the last section of the paper we split income between wage and salary income and income coming from small domestic businesses or petty trades. This division generates a fairly high number of zeros. We deal with the zeros using a tobit specification censored at 0. This specification is very standard and implies the existence of a latent variable Y_{it}^*, so that the income we observe, Y_{it}, is

$$Y_{it} = \begin{cases} Y_{it}^* & \text{if } Y_{it}^* > 0 \\ 0 & \text{if } Y_{it}^* \leq 0 \end{cases} \tag{3}$$

[6] The reliability index takes value 0 when the household is not connected to the grid, 0.5 when it is connected yet it receives an unreliable power supply and 1 when the household is connected and enjoys a reliable power supply.

5.1 Income

For the sake of clarity in the interpretation of our results, we remind here that when using the term income we are referring to total household income excluding agricultural income, but including income from wages and salaries paid in the agricultural sector. Income is measured in per-adult equivalent terms. Meaning that it is computed by dividing the household income by $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). This expression gives us the number of adult equivalent members of the household.

5.1.1 Connection

Instrument I Let us first analyze the impact of electrification using as instrument the district-level variation in land elevation. Table (7) reports results for Ordinary Least Squares (OLS) and Instrumental Variables (IV) estimations of the effect of electrification on rural households' income. All estimations contain time and village fixed effects. Standard errors are robust and clustered at the village level. Columns (1) and (2) report the baseline estimates. In the following columns we add a number of household level controls. In columns (3) and (4) we add household composition controls, in columns (5) and (6) we include household composition and household assets' controls. Columns (7) and (8) incorporate household assets' and occupations controls, excluding household composition controls. Finally, columns (9) and (10) include all household-level controls. This last specification is the more interesting, because it controls for village and time fixed effects and a full array of household-level effects. Across all specifications, the coefficient of interest is the one on *Electricity*.

The coefficient of interest is stable, positive and statistically significant at the 1% level across specifications. Focusing on the baseline estimation, the income of people who received a connection to the grid went up on average by an extra 8.5% per year with respect of income of people who did not receive it. The effect predicted by the OLS estimation is much smaller, estimating an extra income of 1.6% per year for recently connected households. After incorporating all the household level controls, the IV estimator is still positive and statistically significant at the 1% level, while is magnitude is slightly smaller, implying an extra income growth of 8.3% per year. The OLS estimator instead still predicts an average extra income growth of 1.6%.

Instrument II We also analyze the impact of electrification using an alternative instrument, the normalized transmission cables' density. Table (8) also shows OLS and IV estimations for the impact of electrification on rural households' income. All estimations contain village and time fixed effects. Standard errors are robust and clustered at the village level. The table is organized as Table (7) and the coefficient of interest is the one on *Electricity*.

In this case, like above, the coefficient of interest is stable in magnitude across specification and statistically significant at least at the 5% level. The magnitude observed using this instrument is slightly bigger than the one found above. The baseline IV estimation predicts an average extra increase in income of 9.9% per year with respect to people not receiving a connection. The OLS prediction is slightly different from the one obtained above because, in order to use the former instrument we had to drop 8 district from the sample. In this case OLS predicts an average extra income of 1.5% per year. After incorporating all controls, the magnitude of these values decreases faintly. The IV estimator envisions an extra income increase of 9.8%, while the OLS estimator still predicts an extra increase by 1.5%.

The extra income increase in case of connection to the grid predicted by the two different instruments is extremely similar, roughly 9% per year. The results suggest that OLS significantly underestimates the impact of electrification, implying that the households who received electricity between 1994 and 2005 are living in under-performing areas with slower growth and economic improvement rates. This phenomenon is observed also in Dinkelman (2012).

Analyzing the results of these estimation we should not forget that here an household is classified as electrified even when it is receiving only two hours of power per day. Therefore, there is a risk of underestimation of the real effect of being electrified, which could be significantly higher once we take into account who actually received a reliable supply of power and who did not.

5.1.2 Reliability

As mentioned above, the normalized transmission cables' density is the more meaningful instrument for the reliability index. We run all regressions using OLS and IV specifications. The IV specifications are run using the two instruments separately and together. The normalized transmission cables' density is consistently the strongest instrument among the three possibilities. The reliability variable can take value 0 if the household is not connected to the grid, 1 if the power it receives is not regular (for the 1994 wave of the survey) or cover less than 18 hours a day (for the 2005 wave) and 2 if the power supply is regular or above 18 hours a day, respectively. The reliability index simply takes these values and normalizes them to be included between 0 and 1, for an easier interpretation.

Household-level reliability index Table 9 shows the impact of the power reliability index on income. We report results for OLS and IV estimations. In all specifications standard errors are robust and clustered at the village level and all estimations contain village and year fixed effects. Columns (1) to (4) outline results including only household-composition controls, while columns (5) to (8) include all household-level controls. Columns (1) and (5) report OLS estimation results. The IV estimation reported in columns (2) to (4) and (6) to (8) are organized as follows. First, we instrument using the normalized transmission cables' density; second we instrument using both, the normalized transmission cables' density and the district-level variation in land elevation; and finally we instrument using only the district-level variation in land elevation. While the coefficients obtained using the first instrument and the combination of both are relatively stable and statistically significant at least at the 10% level, the coefficient obtained by instrumenting with the district-level variation in land elevation are very different in magnitude and not statistically significant. This lack of consistency in the coefficient together with the extremely low value of the first stage F statistic confirms our claim that this is not a good instrument for reliability.

The coefficients of interest, those of columns (2), (3), (6) and (7) are stable and statistically significant at least at the 10% level. The magnitude of these coefficients, is much more important than the one we observed for electrification. The coefficient of column (6), implies that the income of an household whose reliability index goes from 0 to 1 should increase by an extra 12.6% per year. Therefore, the impact of receiving a reliable power supply is roughly 40% higher than the effect of electrification computed above. If instead, the household only receives an unreliable supply of power, its income is expected to grow by an extra 8% per year. Hence this effect was overestimated by roughly 11%. Here as well, OLS underestimates the effect with respect to IV.

Village-level reliability index Data on reliability are characterized by a relatively high number of missing values. In order to minimize their importance and as a sensitivity test, we resort to a village-level reliability index. This index is computed using the non-missing reliability values of the households living in the village. Table (10), presents the OLS and IV estimations of the effect of the village-level reliability index on income. All estimations contain village and time fixed effects and standard errors are robust and clustered at the village level. The table is organized exactly as Table 9. The coefficients of interest are those on the *Village-level reliability index*, which can take any value between 0 and 1. 0 means that no household within the village is connected to the grid, and 1 means that all households are connected and enjoy a reliable power supply.

The coefficients of interest – again those of columns (2), (3), (6) and (7) – are stable, positive and statistically significant at the 10% level across specifications. The magnitude of the coefficients is slightly inferior here. Focusing on the coefficients of columns (6), if the village-level reliability index goes from 0 to 1, meaning that the whole village moves from not being connected to the grid to being connected with a reliable power supply, on average households will experience an extra income growth of 10.4% per year. Therefore, the coefficient for the effect of full electrification is roughly 15% higher than the one predicted by the electrification estimations. If a village moves from a no-electricity status to an uniformly unreliable electricity supply, on average per capita income will increase by an extra 6.4%. This result is roughly 28% lower than what was predicted by the electrification results.

Sensitivity We check for the sensitivity of the reliability results by changing the definition of reliable and unreliable power supply. We keep the definition constant for the 1994 wave of the survey, a regular supply of electricity corresponds to a reliable supply, and vice-versa. Instead, we change the definition for the 2005 wave bringing the threshold for reliable power down to an average of 16 hours of power a day and up to an average of 20 hours of power a day. We do this for the results on the household-level reliability index and on the village-level reliability index.

Table (A.2) and Table (A.3) of the appendix report results for the household-level reliability index. The first one for a 16 hours threshold, and the second for a 20 hours threshold. Moving the threshold down does not affect neither the magnitude nor the statistical significance of the coefficients of interest. While, as expected, bringing the threshold up significantly increases the magnitude of the coefficients, but does not affect their statistical significance. Column (6) of Table (A.3) tells us that an household moving from a status of no connection to a reliable connection earns an extra income per year of 14.4%, over 60% more than what was predicted by the electrification estimations.

Table (A.4) and Table (A.5) of the appendix report results for the village-level reliability index. The first one for a 16 hours threshold and the second for a 20 hours threshold. As expected, the village-level reliability index behaves in exactly the same fashion as the household-level reliability index.

5.2 Channels

After ascertaining that a grid connection, but especially an increased power reliability, have a positive effect on income we would like to know through which channels they operate. Therefore, we proceed by splitting income into two sub-categories. We focus on income coming from wages and salaries versus income coming from family businesses, petty trades or other home based activities. Both kind of occupations are likely to be positively affected by a change in the electrification status. On the one hand, the presence of electricity (or of a more reliable supply of electricity) renders the production process more productive, think for instance of the introduction of electric pumps for irrigation.

As a consequence wages, labor demand or both may increase.[7] On the other hand, the presence of electricity may stimulate the entrepreneurial spirit of many households, driving them to buy small machines in order to start "domestic" businesses.

Table (11) reports the results for the estimations of the effect of connection to the grid and an increase in power reliability on the two sub-categories of income. Columns (1) to (4) show coefficients related to electrification, while columns (5) to (8) focus on the effect of reliability. Columns (1), (2), (5) and (6) focus on wage and salary income and columns (3), (4), (7) and (8) on business income. Data on the two separate income sources are characterized by a relatively high presence of zeros, therefore we resort to tobit estimations. For this reason, the coefficients of interests – those on *Electricity* and those on the *Village-level reliability index* – have a different interpretation. They tell us the change in income for households having a non-zero income, weighted by the probability of having a non-zero income; or, looking at it from a different perspective, they tell us the change in the probability of having a non-zero income, weighted by the expected income if positive. We instrument electrification and reliability using both instruments combined. We first intrument using the normalized transmission cables' density (IV 1) and then using the former in combination with the district-level variation in land elevation. The results are robust to both specifications.

Let us start with the results on the effect of electrification. Perhaps surprisingly, we only observe a positive effect on wage and salary income, statistically significant at the 1% level, and not on business income, which actually shows a negative coefficient statistically significant at the 10% level in one case, and not statistically significant in the other. Standard errors in these estimations are robust but not clustered at the village level. If they would be clustered they would be bigger. Therefore, coefficients statistically significant at the 10% level should be interpreted carefully. It seems that electrification does not push people toward more entrepreneurial activities. The effect is concentrated on per capita wage and salary income. As mentioned above, this effect can be explained by an increase in labor supply resulting from the fact that some people (probably especially women) are freed from domestic chores by the availability of electricity. An alternative explanation is that labor supply does not change but wages and salaries increase, due to the productivity increase driven by the availability of electricity. These two effects could also be taking place at the same time. The negative effect on business income which seems barely statistically significant, could be explained in several ways. One possibility would be a movement of people getting out of their small businesses and, given the higher wages, getting a wage or salaried job. If this movement is sufficiently important, it could even hide an increase in business income for those staying in it. Some people

[7] It would be extremely interesting to observe the effects of electrification on labor demand, unfortunately the data available do not allow for this exercise.

may actually pick up wage or salary paying jobs and decrease the time they dedicate to the home based activities, observing therefore a decrease in the income it generates. The absence of an effect on business income could also be due to a perfect offsetting between the increase in income for those keeping their activity and the reduction of labor supply directed at these activities.

Let us now move to the results on the effect of reliability, i.e. columns (5) to (8) of Table (11). The results are very similar to those obtained for electrification. The difference being that their magnitude is slightly bigger, mimicking the effect which we observed for total income. Also, the negative effect on business income seems to become more robust.

6 Conclusion

In this paper we have analyzed the effect of rural electrification on household income in India. This study differs from previous literature in three main aspects. First, we do not only focus on the extensive margin of electrification, i.e. only verifying if an household is connected to the grid or nor, but we also focus on the intensive margin of electrification, i.e. knowing how reliable is the supply of power received by the household. We argue that this extra information is crucial in order to precisely assess the effect of rural electrification. An household could be connected to the grid, yet not receive any power at all. A case like this, which is highly plausible in a developing country, is likely to heavily bias all estimation. Second, we use a newly developed instrument in order to solve the endogeneity issue related to grid connection and especially to the reliability issue. We instrument electrification and reliability using a normalized measure of the district-level transmission cables density and the district-level variation of land elevation. The intuition behind the first instrument is that if an household lives in a district characterized by a higher transmission cables' density it will be more likely that it will be connected to the grid and that it will receive a reliable power supply. While the intuition for the latter instrument is that the higher is the variation in land elevation, the more costly it is to electrify a region. Finally, our study is based on a nationally representative sample, while the majority of previous studies focused on specific electrification projects, being therefore weaker with respect to an eventual selection bias.

Our results suggest that the reliability of electric supply is more important than being connected to the grid. Moving to a reliable power supply, either starting off with no connection to the grid or with an unreliable power supply is welfare improving. In this case, an household gains an average 12.6% of extra income per year with respect to other household who did not experience this improvement. If a household moves from not being connected to the grid to an unreliable connection, its income only increases by a smaller amount, around 8% per year. In order to correctly assess the gains of electrification we must therefore know which kind of connection is provided to households.

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7 Tables

Table 1: Household Electrification Rate by State (%)

	1994	2005
Andhra Pradesh	54.1	85.6
Assam	33.3	100.0
Bihar	10.1	21.4
Chhattisgarh	36.3	68.7
Gujarat	71.9	86.4
Haryana	83.2	90.4
Himachal Pradesh	91.7	97.2
Jharkhand	20.4	63.9
Kerala	76.6	89.7
Maharashtra	66.7	78.0
Madhya Pradesh	61.9	71.7
Orissa	17.7	33.9
Punjab	77.6	94.9
Rajasthan	47.9	53.3
Tamil Nadu	66.6	88.4
Uttar Pradesh	19.6	39.4
Uttarakhand	32.3	66.2
West Bengal	12.7	36.3
India	53.1	68.9

Notes: The table reports the percentage of households that reported to have grid connection in 1994 and 2005.

Table 2: Summary statistics

Variable	*Year*	*Mean*	*Std. Dev.*	*Obs.*
Size	*1994*	6.577	3.322	9791
	2005	5.546	2.759	9791
Child	*1994*	0.341	0.21	9791
	2005	0.3	0.222	9791
Teen	*1994*	0.146	0.166	9791
	2005	0.136	0.173	9791
Adult	*1994*	0.513	0.187	9791
	2005	0.564	0.216	9791
Hindu	*1994*	0.854	0.353	9791
	2005	0.848	0.359	9791
Home	*1994*	0.968	0.175	9791
	2005	0.98	0.139	9791
Livestock	*1994*	0.704	0.456	9791
	2005	0.845	0.361	9791
Occupation Head	*1994*	1.262	0.614	9782
	2005	0.908	0.866	9719

Notes: The table reports descriptive statistics of the household controls used in the estimations. The following variables are dummies: *Hindu*, *Home* and *Livestock*. *Child*, *Teen* and *Adult* represent percentages and finally *Occupation Head* can take four different values according to the 4 occupation groups described in Table (A.1).

Table 3: Households Electrification and Reliability

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

Notes: The table reports the absolute numbers of households moving from one state to the other between 1994 and 2005 and the variation in the household total income, not including income from agriculture. Asterisks report statistics for a test of two means between 1994 income and 2005 income. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Reliable electricity supply is defined as at least 18 hours electricity per day in 2005, while households are directly asked whether or not electricity supply is reliable in 1994.

Table 4: Summary Statistic – Land Elevation

	Range	*Mean*	*Mean St. Dev.*
Andhra Pradesh	1,253	381.7	105.6
Assam	1,872	124.4	76.0
Bihar	722	75.5	25.2
Chhattisgarh	1,227	425.1	116.8
Gujarat	1,065	149.7	71.6
Haryana	1,254	253.3	24.8
Himachal Pradesh	6,224	2,093.3	683.8
Jharkhand	1,202	318.2	94.8
Kerala	2,492	513,6	351.3
Maharashtra	1,349	454.4	89.7
Madhya Pradesh	1,119	413.4	78.5
Orissa	1,483	305.2	139.0
Punjab	694	241.5	22.5
Rajasthan	1,562	305.2	65.0
Tamil Nadu	2,535	352.8	213.3
Uttar Pradesh	761	146.7	14.7
Uttarakhand	7,232	1,853.6	819.2
West Bengal	3,497	119.7	80.5

Notes: The measured reported in the table are expressed in feet. These measures do not include coast districts. Elevation for those districts cannot be accurately measured.

Table 5: Instrument – Summary statistics

	1994			*2005*				
	Total length	*Length/km*^{2}	*Real mean income*	*Total length*	*Length/km*^{2}	*Real mean income*	*Total surface*	*# of district surveyed*
Andhra Pradesh	2,057.2	0.0074	24,192.8	2,281.9	0.0082	27,215.3	276,472.5	11
Assam	465.5	0.0055	33,245.5	465.3	0.0055	10,921.8	84,841.0	1
Bihar	1,635.1	0.0169	25,179.1	1,644.6	0.0170	24,842.4	96,875.8	8
Chhattisgarh	368.6	0.0027	18,060.5	383.6	0.0028	16,857.7	137,771.5	7
Gujarat	1,118.5	0.0060	23,179.1	2,186.9	0.0118	22,626.3	185,460.2	10
Haryana	736.9	0.0167	36,755.6	978.3	0.0222	52,558.4	44,017.4	11
Himachal Pradesh	281.7	0.0051	33,296.9	292.6	0.0053	51,985.8	54,997.7	8
Jharkhand	1,320.0	0.0160	39,286.0	1,326.7	0.0161	45,039.8	82,330.5	4
Kerala	1,368.0	0.0362	30,393.1	1,566.0	0.0414	54,139.0	37,824.5	4
Maharashtra	2,337.9	0.0076	25,364.8	3,100.4	0.0101	28.537.8	307,545.2	16
Madhya Pradesh	2,359.0	0.0076	17,754.8	2,965.8	0.0096	18.673.2	308,997.3	18
Orissa	3,568.6	0.0224	19,556.5	3,621.0	0.0227	19,977.2	159,348.7	11
Punjab	1,018.0	0.0202	38,883.9	1,673.0	0.0332	55,157.2	50,330.2	8
Rajasthan	1,076.2	0.0032	30,476.7	2,132.1	0.0062	34,403.1	341,790.7	12
Tamil Nadu	3,041.5	0.0233	30,620.9	3,422.0	0.0262	28,513.2	130,586.9	8
Uttar Pradesh	5,326.9	0.0220	28,370.0	6,798.5	0.0280	35,848.6	242,618.2	9
Uttarakhand	323.2	0.0060	22,342.3	323.1	0.0060	29,570.4	53,833.8	3
West Bengal	807.4	0.0091	26,830.0	785.6	0.0088	28,439.0	88,992.4	8
India	32,432.0	0.0101	28,710.6	39,779.3	0.0124	22,564.0	3,195,023.0	157
China (2000)[1]	157,031	0.0163					9,640,821	
US (2002)[2]	253,971	0.0258					9,826,675	

Notes: Real mean income is calculated using the households comprised in the sample. For example only 3 households are interviewed in Assam, explaining the big variance of mean income. [1]Yang (2006). [2]Brown and Sedano (2004)

Table 6: First stage regressions on electrification and reliability

	Dependent variable:									
	Electrification					Reliability				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Instrument	0.019***	0.018***	0.018***	0.019***	0.019***	0.038***	0.038***	0.037***	0.038***	0.038***
	(0.007)	(0.006)	(0.006)	(0.007)	(0.006)	(0.010)	(0.010)	(0.009)	(0.010)	(0.009)
Size		0.021***	0.020***		0.019***		0.010***	0.009***		0.009***
		(0.001)	(0.001)		(0.002)		(0.001)	(0.001)		(0.001)
Child		−1.371***	−1.348***		−1.286***		−0.628**	−0.613**		−0.622**
		(0.420)	(0.415)		(0.456)		(0.299)	(0.297)		(0.298)
Teen		−1.227***	−1.210***		−1.152**		−0.529*	−0.519*		−0.526*
		(0.419)	(0.415)		(0.455)		(0.299)	(0.297)		(0.298)
Adult		−1.202***	−1.182***		−1.142**		−0.501*	−0.489*		−0.495*
		(0.421)	(0.416)		(0.457)		(0.298)	(0.297)		(0.297)
Hindu		0.024	0.022		0.024		−0.001	−0.001		−0.002
		(0.018)	(0.018)		(0.018)		(0.016)	(0.016)		(0.016)
Home			0.019	0.039	0.023			−0.007	0.005	−0.004
			(0.028)	(0.027)	(0.027)			(0.019)	(0.020)	(0.020)
Livestock			0.040***	0.068***	0.046***			0.040***	0.052***	0.042***
			(0.010)	(0.010)	(0.010)			(0.010)	(0.010)	(0.010)
Agriculture				−0.112***	−0.093***				−0.025***	−0.013
				(0.010)	(0.010)				(0.009)	(0.009)
Low skill				−0.058***	−0.031***				−0.005	0.011
				(0.010)	(0.010)				(0.008)	(0.009)
High skill				0.101***	0.116***				0.036	0.045**
				(0.029)	(0.029)				(0.022)	(0.023)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
District F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	19,582	19,582	19,582	19,501	19,501	14,374	14,374	14,374	14,322	14,322

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. *Reliability* refers to a reliability index worth 0 when the household is not connected to the grid, 0.5 when it is connected with an unreliable supply of power and 1 when it is connected with a reliable power supply. *Instrument* is the district deviation from the national density of transmission cables per squared kilometer. *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed.

Table 7: Effect of electrification on income – instrumented with the district level variation in land elevation

	Dependent variable: Log income per adult equivalent									
	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Electricity	0.192***	1.457***	0.219***	1.491***	0.225***	1.493***	0.176***	1.400***	0.189***	1.411***
	(0.024)	(0.065)	(0.024)	(0.060)	(0.024)	(0.060)	(0.023)	(0.061)	(0.023)	(0.057)
Size			−0.034***	−0.035***	−0.031***	−0.032***			−0.023***	−0.024***
			(0.004)	(0.004)	(0.004)	(0.004)			(0.004)	(0.004)
Child			−1.547	−1.641	−1.622	−1.711			−2.095	−2.120*
			(1.586)	(1.445)	(1.580)	(1.435)			(1.419)	(1.261)
Teen			−1.262	−1.339	−1.318	−1.393			−1.736	−1.755
			(1.586)	(1.445)	(1.579)	(1.435)			(1.419)	(1.262)
Adult			−1.004	−1.091	−1.071	−1.154			−1.429	−1.461
			(1.590)	(1.448)	(1.584)	(1.438)			(1.422)	(1.264)
Hindu			0.021	0.020	0.028	0.026			0.030	0.030
			(0.036)	(0.035)	(0.036)	(0.035)			(0.033)	(0.032)
Home					−0.038	−0.038	0.024	0.020	0.018	0.016
					(0.048)	(0.047)	(0.049)	(0.048)	(0.047)	(0.047)
Livestock					−0.147***	−0.140***	−0.134***	−0.131***	−0.096***	−0.092***
					(0.020)	(0.019)	(0.019)	(0.019)	(0.019)	(0.018)
Agriculture							−0.136***	−0.158***	−0.111***	−0.134***
							(0.026)	(0.025)	(0.025)	(0.024)
Low Skill							0.394***	0.369***	0.424***	0.395***
							(0.025)	(0.024)	(0.024)	(0.023)
High Skill							1.241***	1.212***	1.227***	1.192***
							(0.075)	(0.071)	(0.072)	(0.068)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	17,282	17,282	17,282	17,282	17,282	17,282	17,207	17,207	17,207	17,207
Wald chi2 first stage		282.34		321.72		322.27		293.38		317.55
Wald p-value		0.000		0.000		0.000		0.000		0.000

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income excluding income coming from agricultural activities and is computed in per adult equivalent, by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. Electrification is instrumented using the district-level variation (standard deviation) in land elevation. The first stage is modelled in a non-linear way using a probit estimation. *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed.

Table 8: Effect of electrification on income – instrumented with the normalized transmission cables' density

	Dependent variable: Log income per adult equivalent									
	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Electricity	0.180***	1.806**	0.205***	1.775**	0.212***	1.887**	0.165***	1.889**	0.177***	1.793**
	(0.023)	(0.792)	(0.023)	(0.853)	(0.023)	(0.867)	(0.022)	(0.795)	(0.022)	(0.827)
Size			−0.035***	−0.068***	−0.031***	−0.065***			−0.023***	−0.054***
			(0.004)	(0.018)	(0.004)	(0.018)			(0.004)	(0.017)
Child			−1.561	0.597	−1.638	0.626			−2.131	−0.045
			(1.577)	(2.372)	(1.572)	(2.393)			(1.412)	(2.211)
Teen			−1.293	0.638	−1.350	0.681			−1.789	0.079
			(1.577)	(2.312)	(1.572)	(2.335)			(1.412)	(2.158)
Adult			−1.053	0.838	−1.121	0.864			−1.499	0.352
			(1.581)	(2.309)	(1.576)	(2.331)			(1.415)	(2.159)
Hindu			0.013	−0.024	0.019	−0.018			0.020	−0.018
			(0.033)	(0.044)	(0.033)	(0.045)			(0.029)	(0.043)
Home					−0.052	−0.084	0.001	−0.065	−0.002	−0.039
					(0.044)	(0.063)	(0.044)	(0.070)	(0.043)	(0.063)
Livestock					−0.154***	−0.222***	−0.139***	−0.258***	−0.104***	−0.178***
					(0.019)	(0.041)	(0.019)	(0.058)	(0.018)	(0.043)
Agriculture							−0.115***	0.077	−0.089***	0.060
							(0.024)	(0.092)	(0.024)	(0.080)
Low Skill							0.413***	0.513***	0.442***	0.491***
							(0.023)	(0.052)	(0.023)	(0.035)
High Skill							1.259***	1.085***	1.246***	1.060***
							(0.072)	(0.112)	(0.069)	(0.120)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	19,582	19,582	19,582	19,582	19,582	19,582	19,501	19,501	19,501	19,501
F-stat first stage		8.16		7.83		7.71		8.77		8.51
K-P F-stat (weak ident)		8.6		8.34		8.21		9.28		9.28

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income excluding income coming from agricultural activities and is computed in per adult equivalent, by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. Electrification is instrumented using the district deviation from the national density of transmission cables per squared kilometer. *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed.

Table 9: Effect of household-level reliability index on income

	Dependent variable: Log income per adult equivalent							
	OLS	**IV1**	**IV2**	**IV3**	**OLS**	**IV1**	**IV2**	**IV3**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Reliability index	0.180***	2.773*	2.621**	1.219	0.159***	2.671*	2.357*	−0.631
	(0.037)	(1.500)	(1.322)	(1.581)	(0.035)	(1.459)	(1.237)	(2.372)
Size	−0.032***	−0.053***	−0.052***	−0.040***	−0.019***	−0.038***	−0.036***	−0.013
	(0.004)	(0.014)	(0.012)	(0.014)	(0.004)	(0.013)	(0.011)	(0.018)
Child	−1.692	−0.211	−0.298	−1.098	−2.206*	−0.815	−0.989	−2.643
	(1.482)	(1.429)	(1.374)	(1.558)	(1.320)	(1.280)	(1.214)	(1.956)
Teen	−1.411	−0.171	−0.244	−0.914	−1.845	−0.676	−0.822	−2.212
	(1.482)	(1.348)	(1.308)	(1.479)	(1.320)	(1.199)	(1.153)	(1.823)
Adult	−1.082	0.108	0.038	−0.605	−1.468	−0.348	−0.488	−1.820
	(1.488)	(1.338)	(1.302)	(1.470)	(1.325)	(1.188)	(1.146)	(1.801)
Hindu	0.050	0.025	0.026	0.040	0.044	0.024	0.027	0.050
	(0.048)	(0.054)	(0.053)	(0.049)	(0.042)	(0.048)	(0.046)	(0.050)
Home					0.049	−0.010	−0.002	0.067
					(0.058)	(0.076)	(0.071)	(0.085)
Livestock					−0.115***	−0.212***	−0.200***	−0.084
					(0.023)	(0.063)	(0.055)	(0.093)
Agriculture					−0.123***	−0.072	−0.078*	−0.139**
					(0.029)	(0.048)	(0.044)	(0.058)
Low Skill					0.440***	0.430***	0.432***	0.443***
					(0.028)	(0.033)	(0.032)	(0.030)
High Skill					1.258***	1.139***	1.154***	1.296***
					(0.074)	(0.117)	(0.107)	(0.135)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	12,632	12,632	12,632	12,632	12,585	12,585	12,585	12,585
F-stat first stage		4.67	3.06	1.46		4.88	3.12	1.38
K-P F-stat (weak ident)		5.07	3.47	1.84		5.28	3.54	1.75

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income excluding income coming from agricultural activities and is computed in per adult equivalent, by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. The *Reliability index* is instrumented using the district deviation from the normalized transmission cables' density (IV1); with the normalized transmission cables' density and the district-level variation in land elevation (IV2) and finally only with the district-level variation in land elevation (IV3). *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed. The *Reliability index* takes value 0 for no electricity, 1 for reliable electricity and 0.5 for unreliable electricity. The threshold for reliability in 2005 is fixed at an average of 18 hours of power per day.

Table 10: Effect of village-level reliability index on income

	Dependent variable: Log income per adult equivalent							
	OLS	IV1	IV2	IV3	OLS	IV1	IV2	IV3
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Village-level reliability index	0.230***	1.876*	1.876*	−60.625	0.230***	1.965*	1.965*	−1.444
	(0.087)	(1.056)	(1.055)	(74.970)	(0.086)	(1.051)	(1.051)	(70.738)
Size	−0.031***	−0.032***	−0.032***	0.021	−0.020***	−0.021***	−0.021***	−0.019
	(0.004)	(0.004)	(0.004)	(0.068)	(0.004)	(0.004)	(0.004)	(0.043)
Child	−1.824	−1.651	−1.651	−8.216	−2.319*	−2.142*	−2.142*	−2.489
	(1.493)	(1.285)	(1.285)	(12.238)	(1.336)	(1.110)	(1.110)	(7.367)
Teen	−1.507	−1.331	−1.331	−7.999	−1.932	−1.749	−1.749	−2.108
	(1.493)	(1.286)	(1.286)	(12.257)	(1.336)	(1.111)	(1.111)	(7.613)
Adult	−1.251	−1.104	−1.104	−6.696	−1.633	−1.484	−1.484	−1.777
	(1.497)	(1.288)	(1.288)	(11.580)	(1.339)	(1.112)	(1.112)	(6.268)
Hindu	0.028	0.030	0.030	−0.047	0.035	0.038	0.038	0.031
	(0.037)	(0.036)	(0.036)	(0.270)	(0.033)	(0.032)	(0.032)	(0.136)
Home					0.035	0.044	0.044	0.027
					(0.048)	(0.057)	(0.057)	(0.360)
Livestock					−0.096***	−0.122***	−0.122***	−0.071
					(0.019)	(0.025)	(0.025)	(1.061)
Agriculture					−0.127***	−0.130***	−0.130***	−0.124
					(0.026)	(0.028)	(0.028)	(0.122)
Low Skill					0.420***	0.413***	0.413***	0.427
					(0.025)	(0.025)	(0.025)	(0.288)
High Skill					1.248***	1.235***	1.235***	1.261**
					(0.073)	(0.074)	(0.074)	(0.537)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	17,290	17,290	17,290	17,290	17,215	17,215	17,215	17,215
F-stat first stage		7.01	5.26	3.68		7.03	3.85	1.18
K-P F-stat (weak ident)		7.65	5.51	3.58		7.67	4.12	1.00

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income excluding income coming from agricultural activities and is computed in per adult equivalent, by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. The *Reliability index* is instrumented using the district deviation from the normalized transmission cables' density (IV1); with the normalized transmission cables' density and the district-level variation in land elevation (IV2) and finally only with the district-level variation in land elevation (IV3). *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed. The *Village-level reliability index* takes value 0 for no electricity, 1 for reliable electricity and 0.5 for unreliable electricity. The threshold for reliability in 2005 is fixed at an average of 18 hours of power per day.

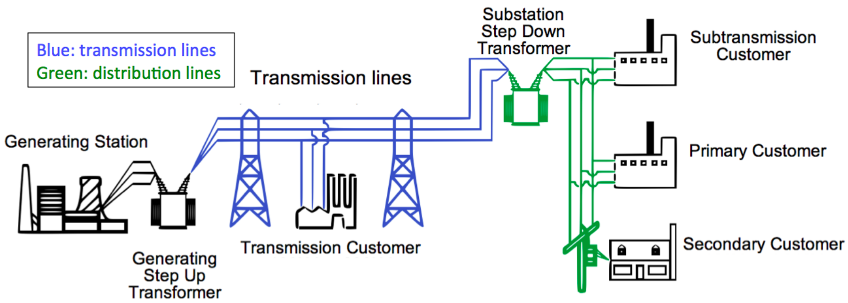
Table 11: Effect of connection and power reliability on wage and salary income and business income

	Dependent variable: Log income per adult equivalent							
	Effect of electrification				Effect of reliability			
	Wage and salary income		Business income		Wage and salary income		Business income	
	IV1	**IV2**	**IV1**	**IV2**	**IV1**	**IV2**	**IV1**	**IV2**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Electricity	8.447***	7.843***	−7.788*	−6.700				
	(3.102)	(2.961)	(4.283)	(4.103)				
Village-level reliability index					9.309***	9.304***	−8.560**	−8.546**
					(2.669)	(2.668)	(4.271)	(4.271)
Size	−0.075	−0.063	0.242***	0.220***	0.087***	0.087***	0.091***	0.091***
	(0.063)	(0.061)	(0.088)	(0.084)	(0.012)	(0.012)	(0.019)	(0.019)
Child	7.674	6.883	−7.173	−5.751	−2.352	−2.353	2.137	2.138
	(9.766)	(9.487)	(11.907)	(11.522)	(7.198)	(7.198)	(9.287)	(9.286)
Teen	7.656	6.946	−5.913	−4.635	−1.211	−1.211	2.322	2.323
	(9.604)	(9.335)	(11.654)	(11.281)	(7.200)	(7.200)	(9.290)	(9.290)
Adult	7.528	6.829	−4.670	−3.413	−1.370	−1.370	3.592	3.592
	(9.582)	(9.314)	(11.619)	(11.248)	(7.198)	(7.198)	(9.286)	(9.285)
Hindu	0.065	0.079	−0.418	−0.444*	0.282**	0.282**	−0.610***	−0.610***
	(0.195)	(0.189)	(0.262)	(0.255)	(0.141)	(0.141)	(0.218)	(0.218)
Home	−0.422	−0.406	0.719*	0.691*	−0.131	−0.131	0.474	0.474
	(0.291)	(0.282)	(0.414)	(0.404)	(0.218)	(0.218)	(0.365)	(0.365)
Livestock	−1.150***	−1.121***	0.720***	0.670***	−0.900***	−0.900***	0.485***	0.485***
	(0.183)	(0.176)	(0.254)	(0.245)	(0.097)	(0.097)	(0.158)	(0.158)
Agriculture	5.446***	5.392***	−6.546***	−6.448***	4.680***	4.680***	−5.844***	−5.844***
	(0.304)	(0.291)	(0.417)	(0.401)	(0.097)	(0.097)	(0.147)	(0.147)
Low Skill	5.864***	5.846***	−3.931***	−3.897***	5.569***	5.569***	−3.665***	−3.665***
	(0.158)	(0.152)	(0.210)	(0.203)	(0.100)	(0.100)	(0.148)	(0.148)
High Skill	5.124***	5.196***	−1.112	−1.241*	6.058***	6.058***	−1.979***	−1.979***
	(0.536)	(0.516)	(0.719)	(0.694)	(0.301)	(0.301)	(0.453)	(0.453)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	17,261	17,261	17,261	17,261	17,261	17,261	17,261	17,261
Wald chi2 first stage	16.27	14.77	5.36	4.27	13.94	13.92	4.72	4.71
Wald p-value	0.000	0.000	0.021	0.038	0.000	0.000	0.029	0.030

Notes: All estimations are tobit IV specifications, performed using the two steps methodology. All specifications contain a constant. Standard errors in parentheses are robust. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income coming respectively from wage and salary activities or business activities and is computed in per adult equivalent by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. Electrification and the reliability index are instrumented using the normalized transmission cables' density (IV1) a combination of the normalized transmission cables' density and the district-level variation in land elevation (IV2). *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed. The *Village-level reliability index* takes value 0 for no electricity, 1 for reliable electricity and 0.5 for unreliable electricity.

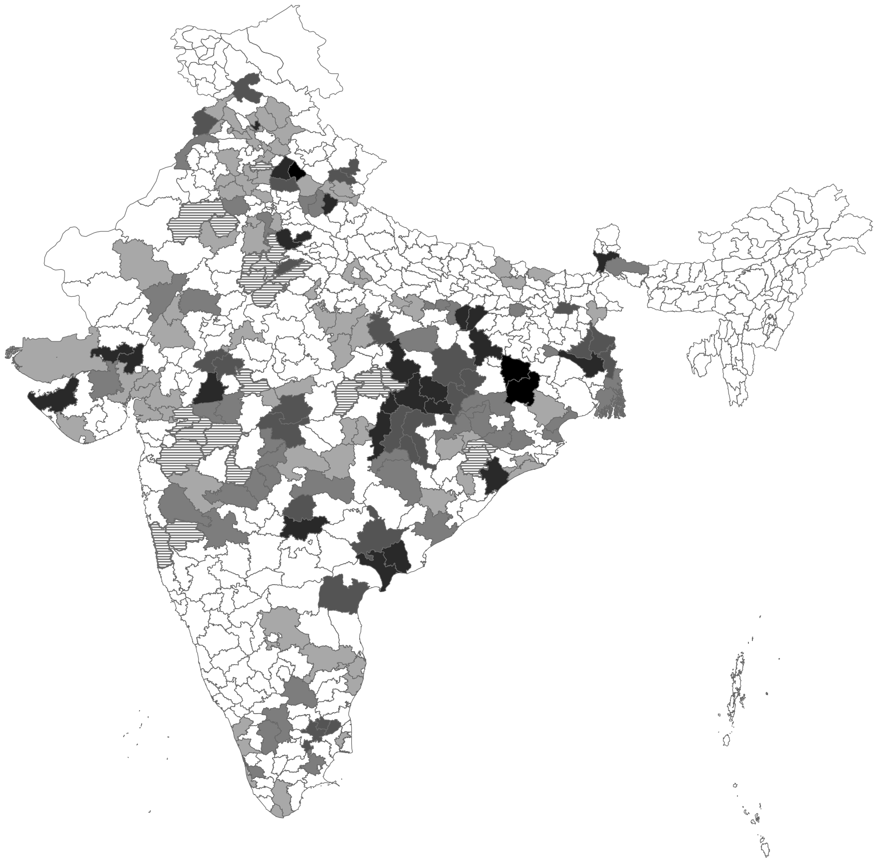
8 Figures

Figure 1: Description of the Power Grid



Source: United States Department of Energy.

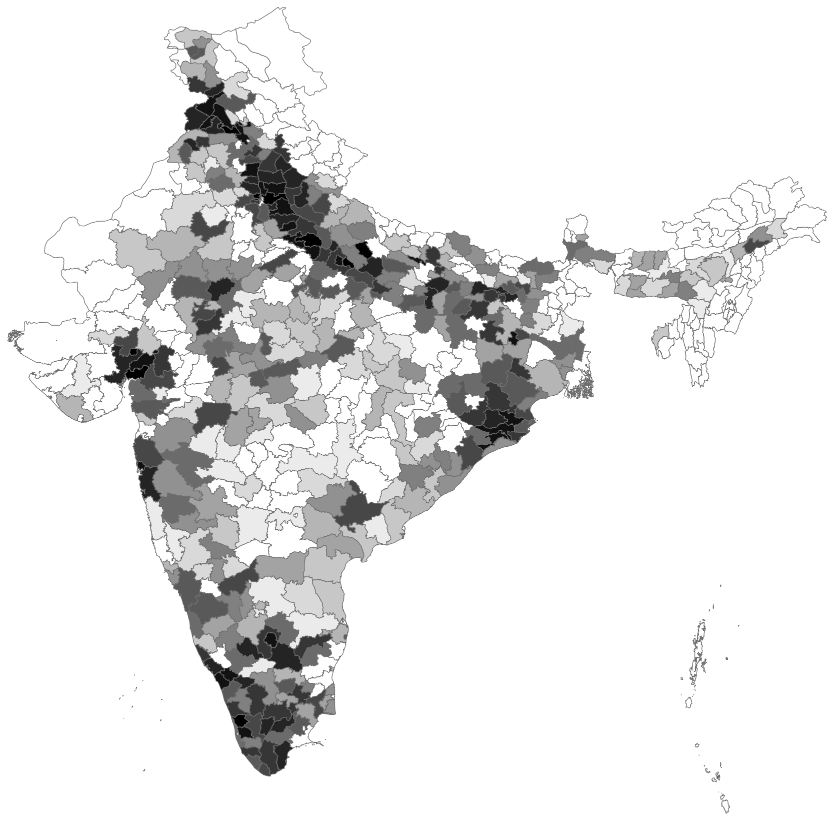
Figure 2: Difference in percentage points between households' electrification rate in the district surveyed in 1994 and in 2005



Source: ESRI ArcGIS World package and geocommons.

Note: Districts left white are not part of the surveyed sample. District shaded in horizontal lines experienced a reduction in households' electrification rate.

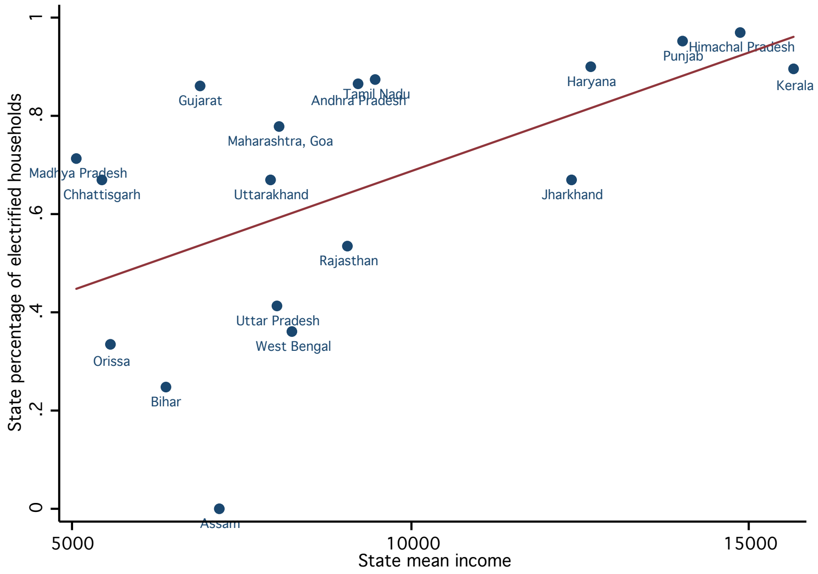
Figure 3: Districts' density of transmission cables per km^2, 2005



Source: ESRI ArcGIS World package and geocommons.

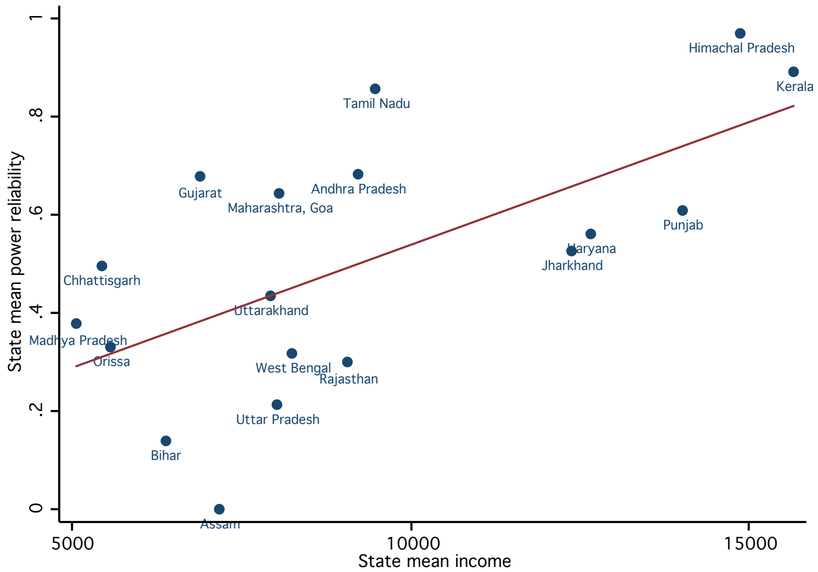
Note: The cables' density is normalized as a deviation from the national mean. The three lighter shades of gray represent negative normalized densities. The lighter shades correspond to more negative values, the darker shades to higher and positive values.

Figure 4: State household electrification vs state mean income, 2005



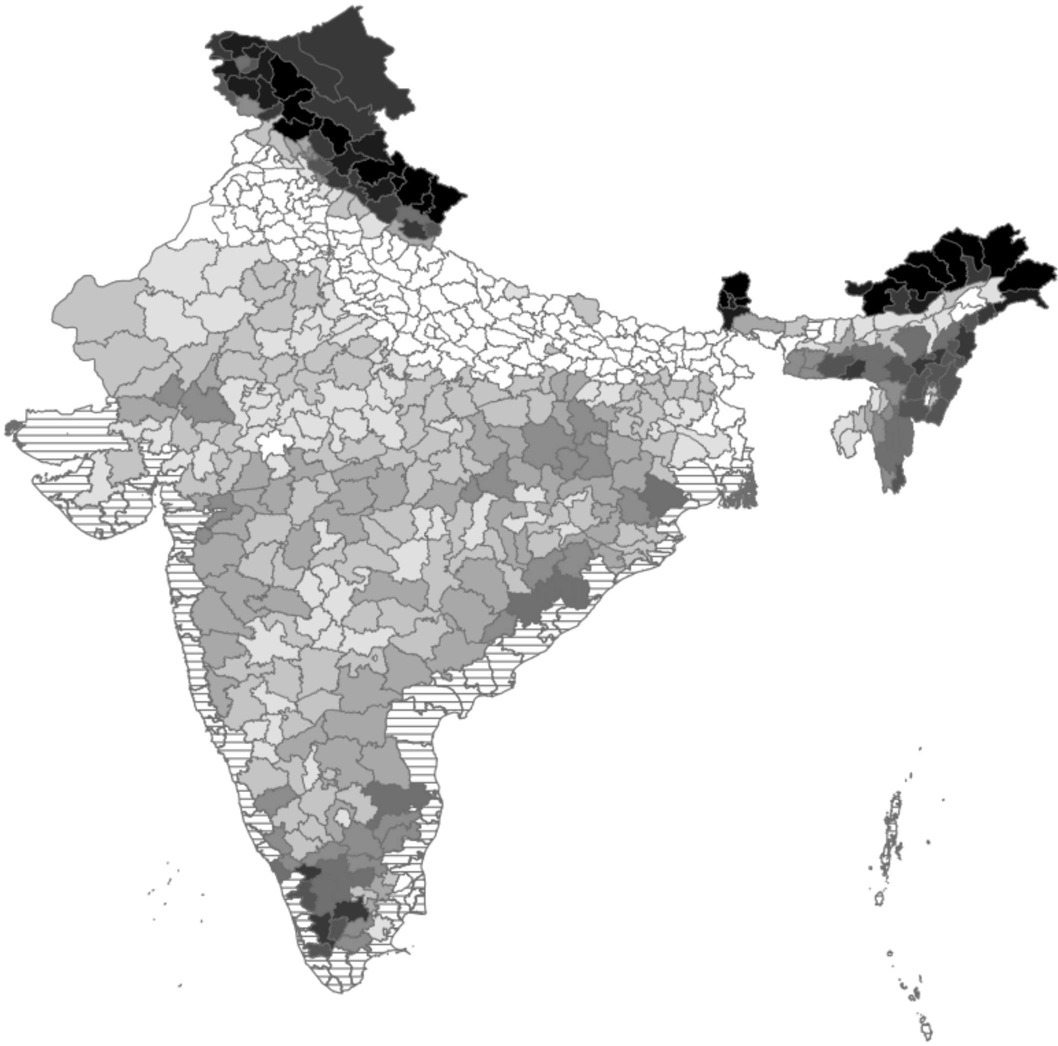
Note: The scatterplot also includes a linear fit to the data.

Figure 5: State household mean power reliability vs state mean income, 2005



Note: The scatterplot also includes a linear fit to the data.

Figure 6: District-level variation in land elevation



Source: Global Land Cover Facility (USGS, 2004).

Note: Darker shades indicate a higher degree of variability in district-level land elevation. The measure is not computed for coastal districts (striped districts). Elevation for those districts cannot be accurately measured.

A Appendix Tables

Table A.1: Occupational Categorization

#	New Group	1994 Group	2005 Group
1	agriculture	cultivation, allied agricultural activities, agricultural wage labor, cattle tending	farm manager, cultivator, other farmers, ag labor, plantation lab, other farm
2	low skill	artisan/independent work, petty shop/other small business, organized business/trade, domestic servant, salaried employment/pension, non-agricultural wage labor,	money lenders, house keepers, maids, sweepers, launderers, elected officials, govt officials, clerical supe, village officials, clerical nec, typist, book-keepers, computing op, transp/commun supe, transp conductors, mail distributor, telephone op, shopkeepers, manuf agents, technical sales, sales, shop, FIRE sales, salesa, nec, hotel/restaurant, cooks/waiters, police, service nec, barbers, tanners, tailors, electrical, plumbers/welders, jewellery, shoe makers, carpenters, stone cutters, construction, forestry, hunters, fishermen, miners, metal workers, wood/paper, chemical, textile, foods, tobacco, machine tool op, assemblers, cinema op, potters, rubber/plastic, paper, printing, painters, production nec, boilermen, loaders, drivers, labour nec
3	high skill	qualified profession/not classified	physical sci tech, engineers, eng tech, air/ship officer, life sciantists, life science tech, physicians, nursing, other scientific, statisticians, economists, accountants, social scientists, lawyers, teachers, journalists, mgr whsl/retail, mgr finance, mgr manf, mgr transp/commun, mgr service, managerial nec
4	other	own household work, student, family work, child (<15), living on income from rent, int, div,âĂę, unemployed, any other, not willing to work, not specified	n/a

Table A.2: Effect of household-level reliability index on income – 16

	Dependent variable: Log income per adult equivalent							
	OLS	**IV1**	**IV2**	**IV3**	**OLS**	**IV1**	**IV2**	**IV3**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Reliability index	0.176***	2.636*	2.635*	1.704	0.151***	2.538*	2.535*	1.377
	(0.036)	(1.384)	(1.381)	(12.873)	(0.035)	(1.351)	(1.346)	(7.574)
Size	−0.032***	−0.053***	−0.053***	−0.045	−0.020***	−0.039***	−0.038***	−0.030
	(0.004)	(0.013)	(0.013)	(0.108)	(0.004)	(0.012)	(0.012)	(0.059)
Child	−1.699	−0.413	−0.414	−0.900	−2.206*	−0.994	−0.995	−1.583
	(1.479)	(1.317)	(1.316)	(6.830)	(1.318)	(1.172)	(1.170)	(3.983)
Teen	−1.418	−0.372	−0.373	−0.769	−1.845	−0.857	−0.859	−1.338
	(1.479)	(1.245)	(1.245)	(5.595)	(1.318)	(1.099)	(1.098)	(3.301)
Adult	−1.087	−0.072	−0.073	−0.457	−1.471	−0.512	−0.514	−0.979
	(1.486)	(1.243)	(1.243)	(5.442)	(1.323)	(1.096)	(1.095)	(3.223)
Hindu	0.055	0.022	0.022	0.035	0.047	0.019	0.019	0.033
	(0.047)	(0.055)	(0.055)	(0.181)	(0.042)	(0.049)	(0.049)	(0.102)
Home					0.058	0.021	0.021	0.039
					(0.058)	(0.070)	(0.070)	(0.136)
Livestock					−0.109***	−0.197***	−0.197***	−0.155
					(0.022)	(0.057)	(0.057)	(0.280)
Agriculture					−0.129***	−0.078*	−0.078*	−0.103
					(0.029)	(0.047)	(0.047)	(0.166)
Low Skill					0.436***	0.427***	0.427***	0.431***
					(0.028)	(0.033)	(0.033)	(0.041)
High Skill					1.253***	1.115***	1.115***	1.182***
					(0.074)	(0.119)	(0.119)	(0.451)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	12,632	12,632	12,632	12,632	12,585	12,585	12,585	12,585
F-stat first stage		5.28	2.68	0.07		5.53	2.82	0.12
K-P F-stat (weak ident)		5.75	2.92	0.08		6.01	3.07	0.14

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income excluding income coming from agricultural activities and is computed in per adult equivalent, by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. The *Reliability index* is instrumented using the district deviation from the normalized transmission cables' density (IV1); with the normalized transmission cables' density and the district-level variation in land elevation (IV2) and finally only with the district-level variation in land elevation (IV3). *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed. The *Reliability index* takes value 0 for no electricity, 1 for reliable electricity and 0.5 for unreliable electricity. The threshold for reliability in 2005 is fixed at an average of 16 hours of power per day.

Table A.3: Effect of household-level reliability index on income – 20

	Dependent variable: Log income per adult equivalent							
	OLS	IV1	IV2	IV3	OLS	IV1	IV2	IV3
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Reliability index	0.233***	3.478*	3.379*	−2.320	0.201***	3.399*	3.350*	1.381
	(0.038)	(2.055)	(1.981)	(3.625)	(0.036)	(2.051)	(1.988)	(5.497)
Size	−0.032***	−0.059***	−0.058***	−0.011	−0.020***	−0.045**	−0.045***	−0.029
	(0.004)	(0.018)	(0.018)	(0.031)	(0.004)	(0.017)	(0.017)	(0.044)
Child	−1.688	−0.187	−0.233	−2.869	−2.201*	−0.721	−0.744	−1.655
	(1.439)	(1.091)	(1.068)	(2.809)	(1.287)	(1.061)	(1.036)	(2.699)
Teen	−1.410	−0.179	−0.217	−2.379	−1.839	−0.620	−0.639	−1.389
	(1.440)	(0.941)	(0.926)	(2.641)	(1.287)	(0.908)	(0.890)	(2.280)
Adult	−1.077	0.084	0.049	−1.991	−1.464	−0.320	−0.337	−1.042
	(1.446)	(0.906)	(0.894)	(2.609)	(1.292)	(0.868)	(0.852)	(2.169)
Hindu	0.056	0.027	0.028	0.079	0.049	0.025	0.026	0.040
	(0.047)	(0.059)	(0.058)	(0.075)	(0.041)	(0.055)	(0.054)	(0.058)
Home					0.054	0.033	0.034	0.047
					(0.058)	(0.076)	(0.075)	(0.068)
Livestock					−0.114***	−0.244***	−0.242***	−0.162
					(0.022)	(0.088)	(0.086)	(0.226)
Agriculture					−0.127***	−0.107***	−0.107***	−0.120***
					(0.029)	(0.040)	(0.040)	(0.044)
Low Skill					0.437***	0.386***	0.387***	0.418***
					(0.028)	(0.046)	(0.045)	(0.093)
High Skill					1.251***	0.991***	0.995***	1.155**
					(0.074)	(0.200)	(0.196)	(0.457)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	12,632	12,632	12,632	12,632	12,585	12,585	12,585	12,585
F-stat first stage		3.36	1.78	0.19		3.43	1.85	0.27
K-P F-stat (weak ident)		3.72	1.98	0.24		3.80	2.07	0.35

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income excluding income coming from agricultural activities and is computed in per adult equivalent, by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. The *Reliability index* is instrumented using the district deviation from the normalized transmission cables' density (IV1); with the normalized transmission cables' density and the district-level variation in land elevation (IV2) and finally only with the district-level variation in land elevation (IV3).. *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed. The *Reliability index* takes value 0 for no electricity, 1 for reliable electricity and 0.5 for unreliable electricity. The threshold for reliability in 2005 is fixed at an average of 20 hours of power per day.

Table A.4: Effect of village-level reliability index on income – 16

	Dependent variable: Log income per adult equivalent							
	OLS	IV1	IV2	IV3	OLS	IV1	IV2	IV3
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Village-level reliability index	0.182**	1.767*	1.768*	111.857	0.180**	1.845*	1.845*	68.833
	(0.085)	(0.987)	(0.987)	(146.739)	(0.084)	(0.981)	(0.981)	(184.884)
Size	−0.030***	−0.031***	−0.031***	−0.119	−0.020***	−0.020***	−0.020***	−0.056
	(0.004)	(0.004)	(0.004)	(0.114)	(0.004)	(0.004)	(0.004)	(0.096)
Child	−1.837	−1.709	−1.708	7.196	−2.332*	−2.205**	−2.205**	2.917
	(1.497)	(1.287)	(1.287)	(18.594)	(1.342)	(1.113)	(1.113)	(16.432)
Teen	−1.516	−1.387	−1.387	7.607	−1.943	−1.811	−1.811	3.499
	(1.497)	(1.288)	(1.287)	(18.572)	(1.342)	(1.114)	(1.114)	(16.805)
Adult	−1.262	−1.161	−1.161	5.828	−1.645	−1.547	−1.547	2.397
	(1.501)	(1.290)	(1.290)	(17.165)	(1.345)	(1.115)	(1.115)	(13.792)
Hindu	0.028	0.029	0.029	0.062	0.035	0.036	0.036	0.097
	(0.037)	(0.036)	(0.036)	(0.501)	(0.033)	(0.032)	(0.032)	(0.357)
Home					0.025	0.036	0.036	0.486
					(0.047)	(0.056)	(0.056)	(1.650)
Livestock					−0.095***	−0.121***	−0.121***	−1.181
					(0.019)	(0.024)	(0.024)	(2.954)
Agriculture					−0.125***	−0.125***	−0.125***	−0.156
					(0.026)	(0.028)	(0.028)	(0.344)
Low Skill					0.419***	0.413***	0.413***	0.165
					(0.024)	(0.025)	(0.025)	(0.711)
High Skill					1.256***	1.246***	1.246***	0.817
					(0.073)	(0.074)	(0.074)	(1.328)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	17,290	17,290	17,290	17,290	17,215	17,215	17,215	17,215
F-stat first stage		7.690	8.942	1.704		7.703	7.913	0.357
K-P F-stat (weak ident)		8.408	4.923	1.803		8.428	4.322	0.341

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income excluding income coming from agricultural activities and is computed in per adult equivalent, by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. The *Reliability index* is instrumented using the district deviation from the normalized transmission cables' density (IV1); with the normalized transmission cables' density and the district-level variation in land elevation (IV2) and finally only with the district-level variation in land elevation (IV3). *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed. The *Reliability index* takes value 0 for no electricity, 1 for reliable electricity and 0.5 for unreliable electricity. The threshold for reliability in 2005 is fixed at an average of 16 hours of power per day.

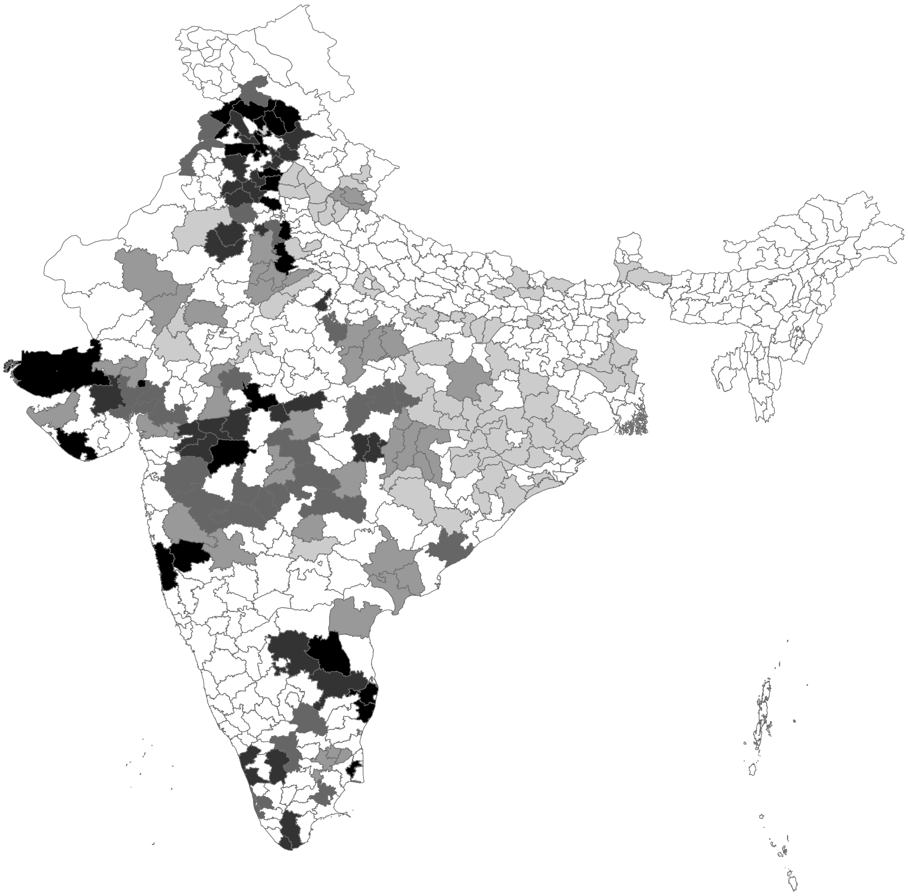
Table A.5: Effect of village-level reliability index on income – 20

	Dependent variable: Log income per adult equivalent							
	OLS	**IV1**	**IV2**	**IV3**	**OLS**	**IV1**	**IV2**	**IV3**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Village-level reliability index	0.314***	2.227*	2.227*	160.735	0.296***	2.326*	2.326*	13.136***
	(0.090)	(1.233)	(1.233)	(3,435.467)	(0.089)	(1.249)	(1.249)	(0.741)
Size	−0.030***	−0.032***	−0.032***	−0.176	−0.020***	−0.021***	−0.021***	−0.029***
	(0.004)	(0.004)	(0.004)	(3.114)	(0.004)	(0.004)	(0.004)	(0.008)
Child	−1.805	−1.511	−1.511	22.860	−2.298*	−1.982*	−1.982*	−0.299
	(1.485)	(1.269)	(1.269)	(528.355)	(1.332)	(1.102)	(1.102)	(0.402)
Teen	−1.483	−1.185	−1.185	23.514	−1.907	−1.585	−1.585	0.130
	(1.485)	(1.270)	(1.270)	(535.425)	(1.333)	(1.103)	(1.103)	(0.405)
Adult	−1.229	−0.961	−0.961	21.245	−1.610	−1.326	−1.326	0.187
	(1.489)	(1.271)	(1.271)	(481.516)	(1.336)	(1.102)	(1.102)	(0.405)
Hindu	0.028	0.033	0.033	0.405	0.034	0.040	0.040	0.071
	(0.037)	(0.036)	(0.036)	(8.183)	(0.033)	(0.033)	(0.033)	(0.055)
Home					0.024	0.051	0.051	0.193
					(0.047)	(0.061)	(0.061)	(0.197)
Livestock					−0.095***	−0.127***	−0.127***	−0.300***
					(0.018)	(0.027)	(0.027)	(0.061)
Agriculture					−0.127***	−0.136***	−0.136***	−0.180***
					(0.026)	(0.028)	(0.028)	(0.066)
Low Skill					0.416***	0.400***	0.400***	0.318***
					(0.024)	(0.026)	(0.026)	(0.052)
High Skill					1.245***	1.215***	1.215***	1.056***
					(0.073)	(0.077)	(0.077)	(0.128)
Year F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Village F.E.	yes	yes	yes	yes	yes	yes	yes	yes
Observations	17,290	17,290	17,290	17,290	17,215	17,215	17,215	17,215
F-stat first stage		7.690	8.942	1.704		7.703	7.913	0.357
K-P F-stat (weak ident)		8.408	4.923	1.803		8.428	4.322	0.341

Notes: All estimations contain a constant. Standard errors in parentheses are clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1. Income corresponds to the total household income excluding income coming from agricultural activities and is computed in per adult equivalent, by dividing it by the following expression $1 + 0.7(N_{Adults} - 1) + 0.5N_{Children}$ (OECD, 1982). We tried several different specification and they do not affect the results. The *Reliability index* is instrumented using the district deviation from the normalized transmission cables' density (IV1); with the normalized transmission cables' density and the district-level variation in land elevation (IV2) and finally only with the district-level variation in land elevation (IV3). *Hindu*, *Home* and *Livestock* are dummy variables. *Agriculture*, *Low Skill* and *High Skill* are occupations estimated with respect to a benchmark corresponding to any kind of home based activities, including students and unemployed. The *Reliability index* takes value 0 for no electricity, 1 for reliable electricity and 0.5 for unreliable electricity. The threshold for reliability in 2005 is fixed at an average of 20 hours of power per day.

B Appendix Figures

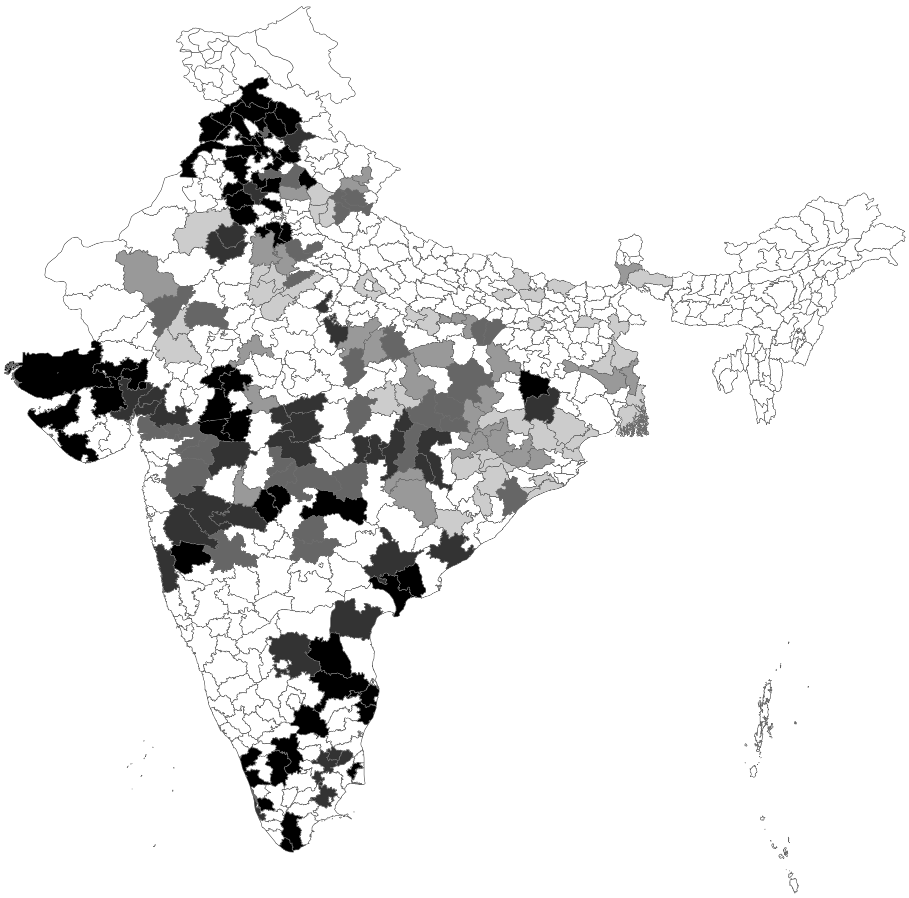
Figure B.1: Households' electrification rate in the district surveyed, 1994



Source: ESRI ArcGIS World package and geocommons.

Note: Districts left white are not part of the surveyed sample.

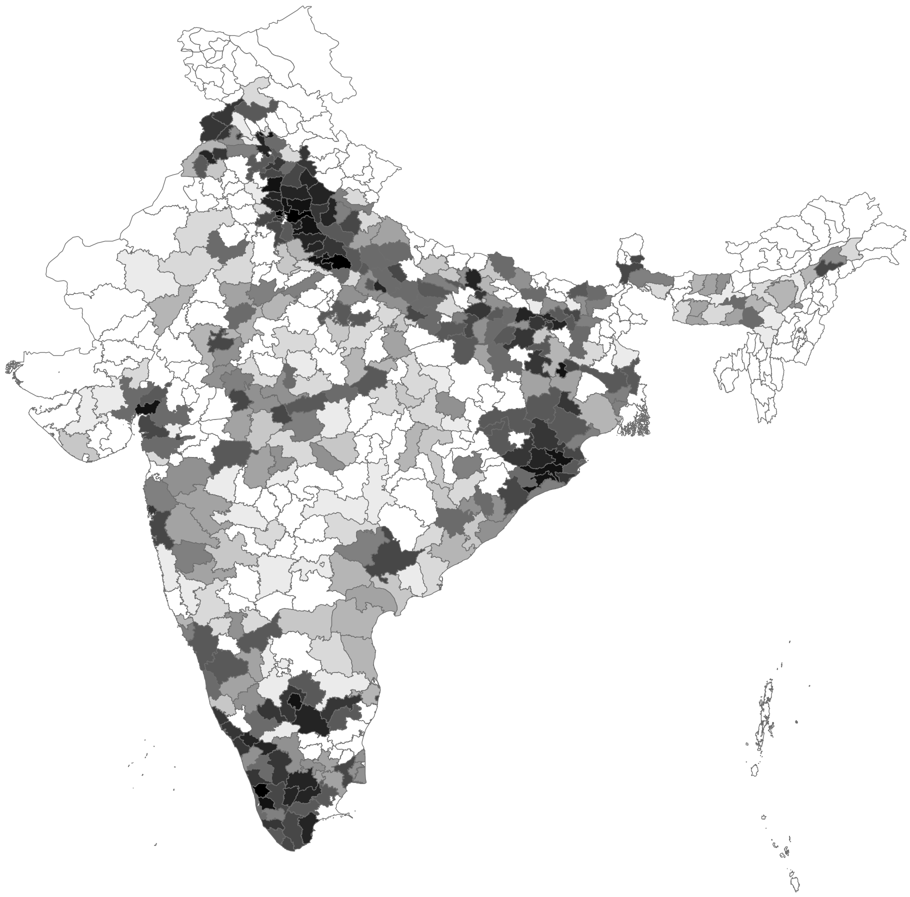
Figure B.2: Households' electrification rate in the district surveyed, 2005



Source: ESRI ArcGIS World package and geocommons.

Note: Districts left white are not part of the surveyed sample.

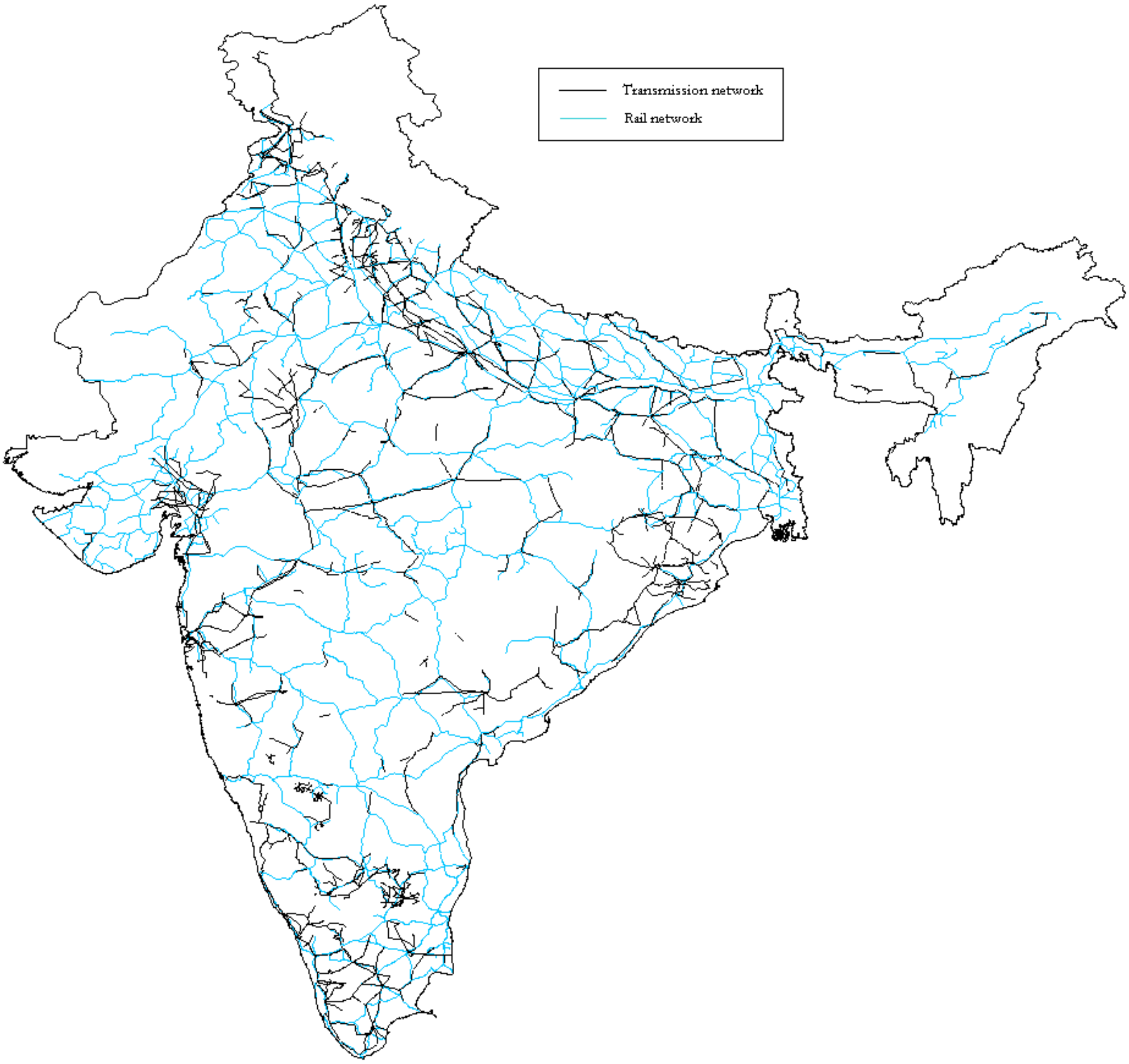
Figure B.3: Districts' density of transmission cables per km^2, 1994



Source: ESRI ArcGIS World package and geocommons.

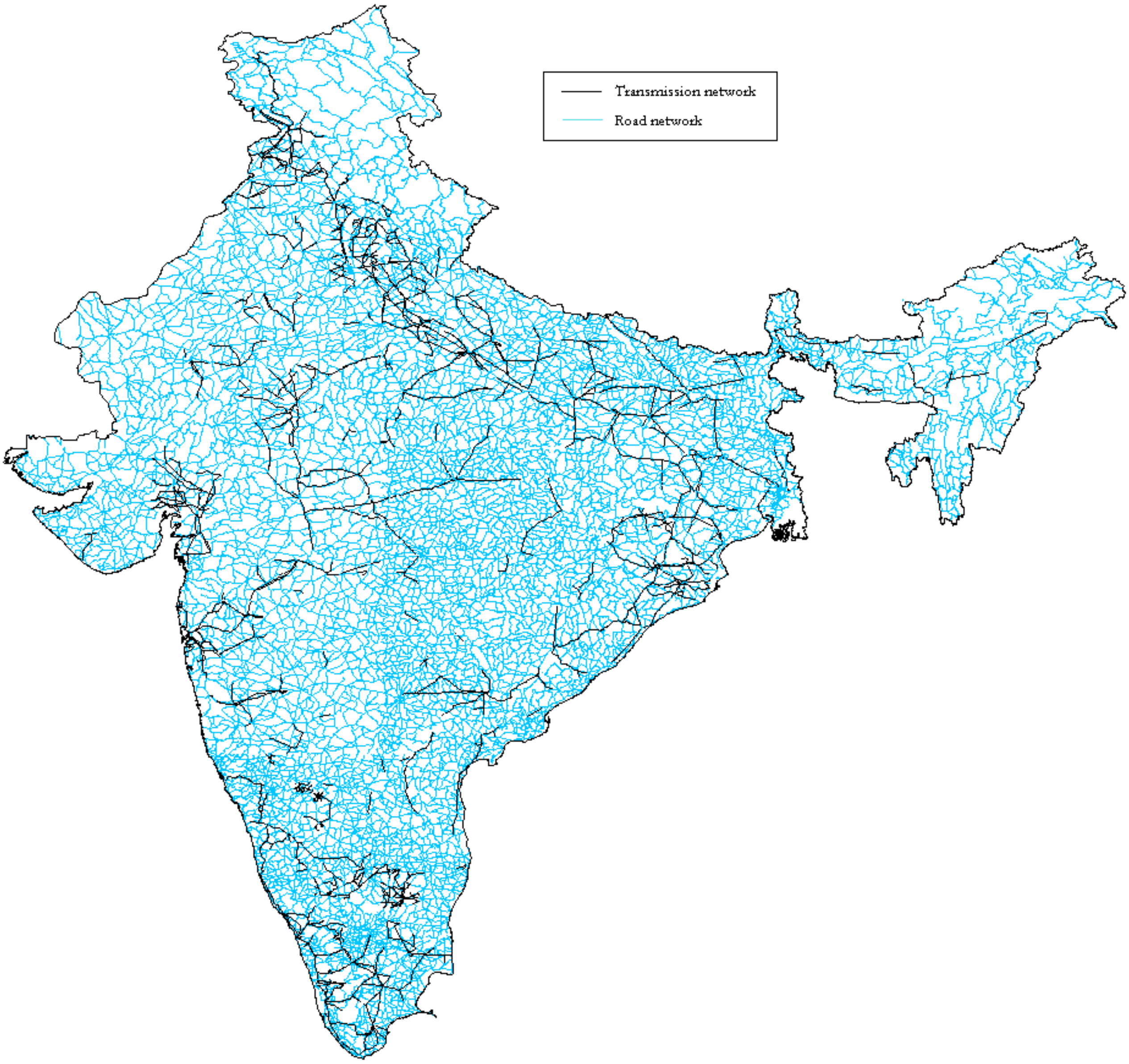
Note: The cables' density is normalized as a deviation from the national mean. The three lighter shades of gray represent negative normalized densities. The lighter shades correspond to more negative values, the darker shades to higher and positive values.

Figure B.4: Indian Transmission Network and the Rail Network



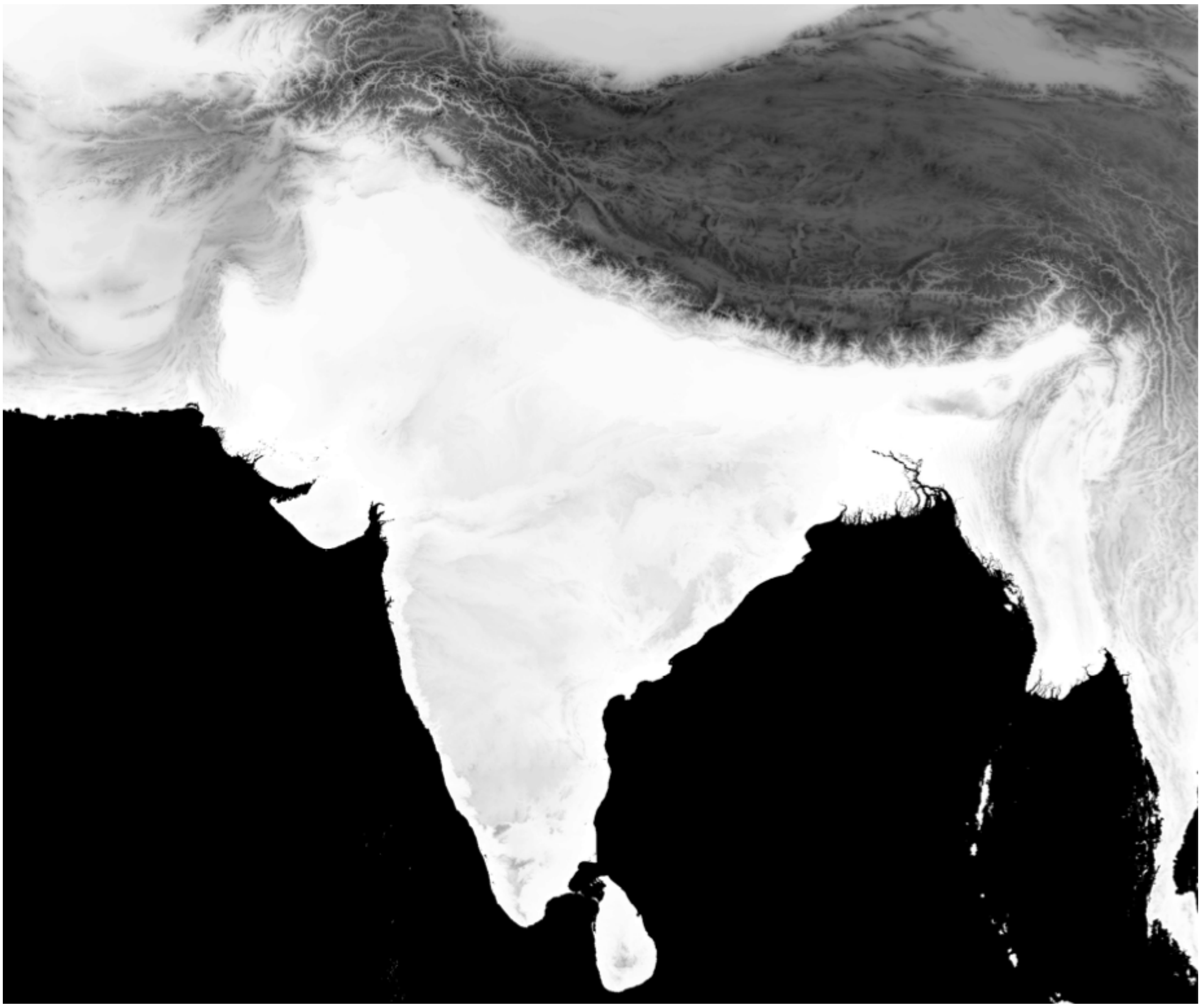
Source: ESRI ArcGIS World package and geocommons.

Figure B.5: Indian Transmission Network and the Road Network



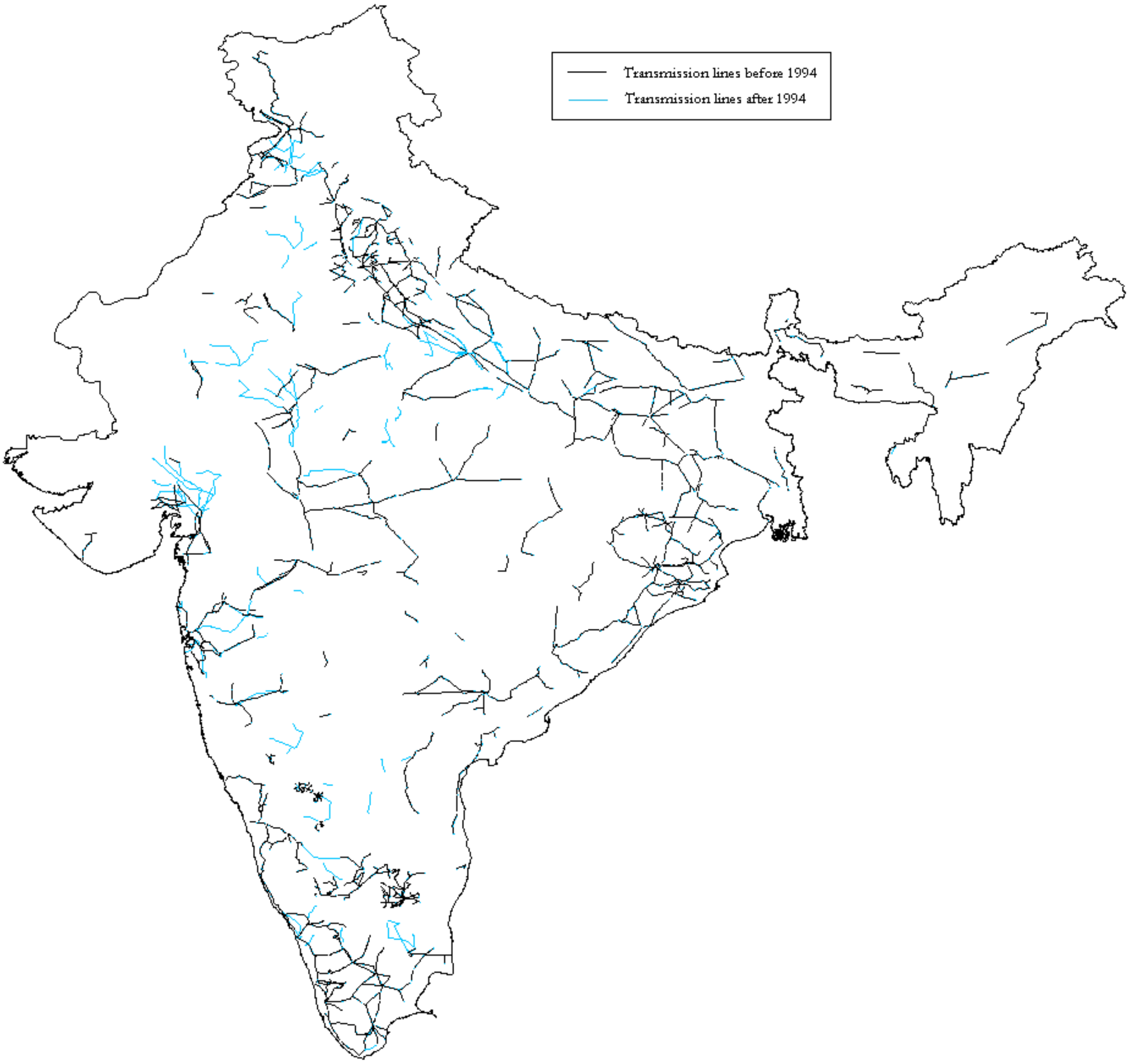
Source: ESRI ArcGIS World package and geocommons.

Figure B.6: India, Land elevation map



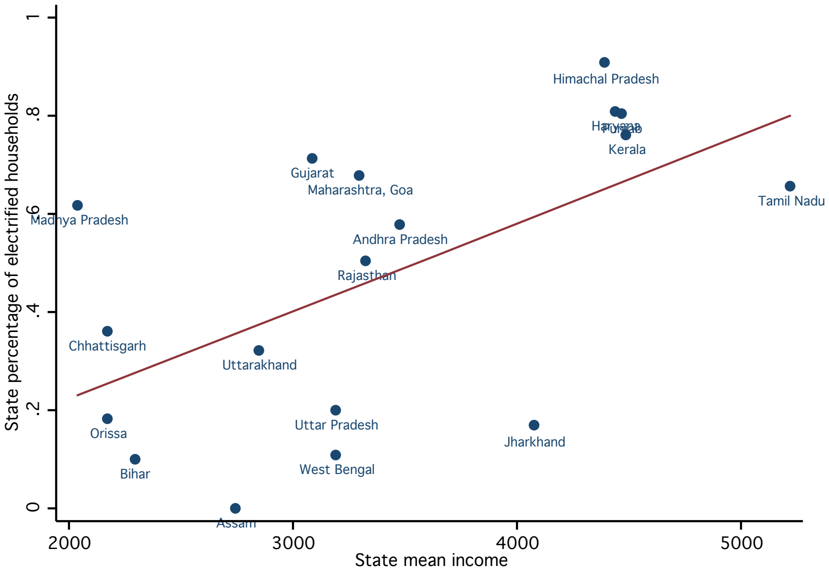
Source: Global Land Cover Facility (USGS, 2004).

Figure B.7: Two phases of expansion of the Indian Transmission Network



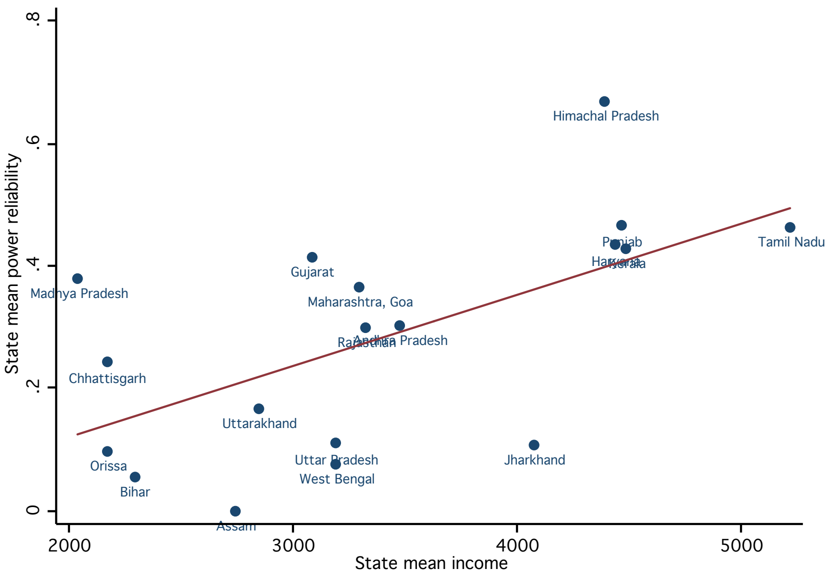
Source: ESRI ArcGIS World package and geocommons.

Figure B.8: State household electrification vs state mean income, 1994



Note: The scatterplot also includes a linear fit to the data.

Figure B.9: State household mean power reliability vs state mean income, 1994



Note: The scatterplot also includes a linear fit to the data.