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Keywords

Community electricity, sexual violence, mobility, fertility, health care, women's autonomy

JEL Classification

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Community Electrification and Women's Autonomy

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April 12, 2023

Abstract

This study examines the effects of community-level electrification on women's social autonomy in India using panel household survey data, administrative data and satellite data spanning over two decades. Using flexible difference-in-difference estimators, we find higher community-level electricity hours reduce incidence of sexual violence against women, and improve women's mobility, fertility choices and access to health care. Results are robust when using night-time luminosity as an alternative indicator of community electrification, most recent data on reliability of electricity and alternative longitudinal estimation techniques. Heterogeneity analysis shows that the effects are stronger in rural areas compared to urban areas. We identify four main channels through which electricity impacts women's autonomy: paid employment, education, exposure to mass media and safety.

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1 Introduction

A large literature in developing countries finds that household access to electricity economically empowers women with better employment opportunities, improves women's educational attainment and reported health [Dinkelman, 2011; Sedai et al., 2022]. However, so far, a robust and objective analysis of the impact of reliable electricity on women's social autonomy, in terms of physical safety, mobility and fertility, marital decision making, and access to health care has been missing. In addition to providing economic efficiency and empowerment, and improved technology [Burlig and Preonas, 2016; Thomas et al., 2020; Lewis and Severnini, 2020], a well lit community with reliable electrification could also provide physical security to women in communities with high sexual violence, extend the time for socialization with other people, access health care services, and also create positive spill-over effects for women through awareness and communication. Accounting for the social autonomy gains from reliable electrification could help target gendered energy policies for sustainable development.

This study adds to the scholarship about the social benefits of community electrification and night-time luminosity by examining their impact on women's social autonomy in India. Restrictive norms on women's mobility and high incidence of sexual assault on women makes India an apt context for our study. From an empirical standpoint, we conduct a comprehensive longitudinal analysis using community level electrification and night-time luminosity as treatments, and five spatio-temporal individual, household and administrative datasets spanned over two decades. We present robust point estimates of impact using flexible difference in difference estimators, with subsequent robustness checks using fixed effects, two stage least squares estimators and falsification tests.

In recent years, India has shown an impressive progress in the extensive margin of electrification, especially in rural areas [Jain et al., 2018; Agrawal et al., 2021; Kennedy et al., 2020]. Recent data from Indian Residential Energy Survey (2020) says that 96.7 percent households in India are connected to grid [Agrawal et al., 2021]. There are improvements in the intensive margin as well, but the reliability aspect of electrification still needs a lot of attention. The hourly supply quality data from the Electricity Supply Monitoring Initiative (ESMI)[1] shows that in June 2019, 63 percent of ESMI locations experienced more than 15 hours of power outage and 39 percent locations experienced more than 30 interruptions,

[1]ESMI is an initiative by Prayas Energy Group, that monitors the quality of hourly electricity supply in India since 2015, covering 55 districts across India as of June 2019.

each greater than 15 minutes [Phadke et al., 2019]. There also exists a huge disparity in reliable electricity, not only between rural and urban areas but also between different states. ESMI June 2019 data shows that only 5 percent rural areas (within ESMI locations) receive entire six hours of evening supply (5-11 pm), whereas the same for mega cities is 45 percent. On the other hand, data from 'Access to Clean Cooking Energy and Electricity-Survey of States' (ACCESS) shows that in six energy poor states in India, average hours of electricity have increased marginally from 12.3 hours in 2015 to 14.9 hours in 2018 and the average hours of night-time electricity remained almost stagnant (3.3 hours in 2015 and 3.7 hours in 2018). India is increasingly witnessing a number of power outages every year, mostly during the peak summer months. In April 2022, India faced the worst electricity outage in decades amidst extreme heatwaves[2], which was attributed to the decreasing coal reserves in several states, fast-paced increase in electricity demand and inefficiency of distribution companies (DISCOMs).[3]

This study contributes to the existing scholarship in the following ways: (i) this is the first study to examine the impact of electrification, both community electrification and night-time luminosity, on women's safety, explicated through the incidence of rapes, a critical concern which significantly curtails women's mobility, and thereby their socio-economic decisions, especially in India;[4] (ii) we use community electrification level which account for larger effects of household electrification by taking into account the externality or the spillover effects generated in the locality by that household [Khandker et al., 2014]; (iii) we use the most recent energy survey, Indian Residential Energy Survey (IRES) 2020 in addition to the existing data, to show that our results are relevant in recent times, as opposed to existing studies who use decades old data sets;[5] (iv) this study is the first to use the DID-M estimator proposed by De Chaisemartin and d'Haultfoeuille [2020] to estimate the impact of reliable electrification, which takes care of the problems of negative weights and treatment heterogeneity present in the traditional two-way fixed effect model used by most of the previous studies. It is also an improvement over the spatial leave-one-out

[2]Link for the article on heat waves and power demand: Reuters.

[3]Link for the article on lack of reliable electrification in India: Indian Express article.

[4]In this paper, we combine the data from National Crime Records Bureau (NCRB) with other datasets to empirically establish that community electrification and night-time luminosity reduces the incidence of rapes.

[5]Available studies look at the impact of electrification in India using different datasets. Indian Human Development Survey (IHDS) is the most commonly used dataset [Chakravorty et al., 2014; Rathi and Vermaak, 2018; Samad and Zhang, 2019; Sedai et al., 2021, 2022]. Studies have also used Socioeconomic and Caste Census (SECC) data combined with satellite data [Burlig and Preonas, 2016], Rural Economic and Demographic Survey (REDS) [Van de Walle et al., 2017] and even primary data [Thomas et al., 2020; Kennedy et al., 2020; Winther et al., 2020].

instrumental variable used extensively in previous studies, whose validity is questioned in the presence of cross-unit spillovers and interdependence [Betz et al., 2018].

Existing studies have not focused on the role of electrification on social awareness through exposure to mass media and societal gatherings, which have a large direct and spill over effect on women's social autonomy. Following the literature on rigid gender norms in India [Jayachandran, 2021], we posit that higher community level electrification and night-time luminosity could increase information sharing among women through increased socialization and exposure to mass media, which could subsequently affect women's social autonomy, measured in terms of objective outcomes, namely, the incidence of rapes, knowledge of husband before marriage, contraceptive use and age at marriage. In addition, we argue that health care facilities could function better and for longer duration in areas with access to reliable electrification, which has been under examined so far. In this context, women who face time and familial constraints in access to health care could be served more effectively with reliable community level electrification. This channel could have significant effects on women's health seeking behavior.

To examine the impact of reliable community electricity on women's social autonomy outcomes, we use the two-period panel data from Indian Human Development Survey (IHDS 2005 and 2012) [Desai and Vanneman, 2018] and administrative data on crime against women from National Crime Records Bureau (NCRB) to estimate the DID-M estimator proposed by De Chaisemartin and d'Haultfoeuille [2020]. We find that the results are consistent even with the use of other estimation techniques like two-way fixed effect (TWFE) and generic 'leave-one-out' spatial instrumental variable (IV) approach. We use night-time luminosity data from Socioeconomic High-resolution Rural-Urban Geographic Dataset on India (SHRUG) [Asher et al., 2021] as an alternative indicator of community-electricity and show that our results remain intact. We also combine two recent most datasets — Indian Residential Energy Survey, 2020 and National Family Health Survey 5 (2019-2021), to show that our results are relevant contemporaneously.

Results show that with 10 hours of increase in average electricity hours in a community, freedom of movement of women increases by 0.44 SD, value of opinion of women in the household increases by 0.04 SD, contraceptive use increases by 4 percent, likelihood of receiving treatment increases by 1 percent, mean age of marriage in the community increases by 0.07 years, the likelihood of knowing husband increases by 5 percent and lastly, number of rapes decreases by 0.43 percent. Findings indicate higher social autonomy for women in areas where average electricity in the community is higher. We also find that the effects are mostly stronger in rural areas. We analyze four possible channels through which community electrification could affect women's social autonomy, namely, paid employment, years of education, exposure to mass media (television) and, harassment perception in the community. We find significant impacts as per expectations on all the channel variables which provides credence to the social autonomy outcomes observed.

2 Related literature

Given the increasing relevance of improving the reliability of electricity in India, there is a shift of focus from extensive margin[6] to intensive margin of electricity among researchers and policymakers. Lipscomb et al. [2013]; Khandker et al. [2014]; Rathi and Vermaak [2018] looked at the impact of household's access to electricity, whereas relatively recent studies by Kennedy et al. [2020]; Sedai et al. [2021] focus more on the impact of reliability of electricity. From policy perspective, Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), launched in 2005, focused on providing access to electricity in villages, whereas Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY), launched in 2015, focused more on continuous electricity supply to the electrified households [Jain et al., 2018].

Reliability of electricity in a community can benefit women in several ways. The most important and direct impact is through better lighting in the community in the evening or night-time. More reliable electricity means better-operating streetlights, which increases safety of women, especially at public places. This makes it easier for women to stay out of their houses after dark, for working late or attending night schools or even for attending meetings in the community [Clancy et al., 2003]. Reliable community electrification can also increase economic activity in the locality, creating more paid employment opportunities for women. Homegrown small-scale enterprises like beauty parlour, xerox shop, home-cooked food delivery service etc can also be opened by women/a group of women, which will make them financially independent and help them gain more social autonomy.

Another important channel of increased autonomy of women is education. If the community has reliable electricity in the evening, it might facilitate opening of evening or night schools and libraries for women and girls who can't attend day schools because of household respon-

[6] Extensive margin refers to access to electricity, whether or not is a household connected to grid/off-grid sources of electricity. Intensive margin refers to reliability, how many hours of power supply does the household get per day.

sibilities. Better lighting condition at home or in the neighbourhood might allow students to study at night and their mothers might also be able to monitor their study and help them with homework in the evening [Daka and Ballet, 2011]. Studies by Kanagawa and Nakata [2008]; Khandker et al. [2009] show how access to electricity improves educational outcomes, especially for women and girls.

Reliable electricity supply will also improve the health infrastructure in the locality; hospitals will be more likely to invest in modern medical tools and they will be able to operate at night in the time of emergencies. At the household level, women will have access to safer substitutes of biomass fuel or kerosene (e.g. electric stoves), which will reduce their exposure to indoor air pollution while cooking [Duflo et al., 2008]. The health benefits will indirectly translate to women and girls being more regular at work and school/college, as well as more efficient.

The last and one of the most important drivers of women's empowerment and autonomy is increase in awareness among women due to electrification. If electricity is reliable in a community, more number of households will purchase televisions, radios, mobile phones, internet etc. Through exposure to mass medias, women will learn about alternative gender norms [Winther et al., 2017], their knowledge horizon will be broadened [Kitchens and Fishback, 2015], and they will be more connected to the outside world [Clancy et al., 2003]. A study by Jensen and Oster [2009] has shown that access to cable TV increased autonomy of women and reduced acceptability of domestic violence in rural India, pointing to the significance of awareness in enhancing women empowerment.

So far, we have discussed how the so-called 'empowerment enablers' [Winther et al., 2017] like employment, education, awareness etc get affected by community-level reliable electrification. However, in this paper, our focus is on the more direct indicators of women's autonomy in different spheres of life. The idea of empowerment is to enable an individual to make strategic choices about her own life[7], in a context where she was denied such ability previously [Kabeer, 1999]. Keeping this broad concept in the background, women empowerment can be considered as a route towards gender equality [Winther et al., 2017]. When it comes to women's empowerment, there are three interrelated dimensions of measuring it: resources, agency and achievements [Kabeer, 1999]. These three dimensions are not mutually exclusive; they often overlap with one another. In our present study, we use seven different

[7]Strategic life choices are described as first-order choices in Kabeer [1999] which involve major decisions about the woman's life. Second-order choices (involving the well-being of the woman) are also important, even though they don't form a part of the definition of empowerment.

indicators of women empowerment that are closely related to their autonomy: Freedom of movement, value of opinion in the household, contraceptive use, receiving treatment in short-term morbidity, age of marriage, knowing husband before marriage and violence against women. Freedom of movement can be interpreted as both agency and achievement; agency because it represents women's choice about going out alone and achievement in the sense that it signifies women's emancipation. Value of opinion of women in the household is a measure of women's ability to convey her choice in the decision-making process of the household and hence it exemplifies agency. Use of contraceptive involves both resources and agency. On one hand, it implies the access to contraceptives and on another hand, the ability to make reproductive choices about whether or how many children to have. Receiving treatment in short term morbidities also represents resources (healthcare facilities) and agency (the choice of getting treatment). Age of marriage and knowing husband before marriage both exemplifies agency in the sense that with an increase in either of them, the choice of women about their marriage increases. Lastly, violence against women implies negative agency because higher violence is indicative of higher male dominance and lower female agency [Kabeer, 1999].

In India, social and cultural norms play an important role in women empowerment, especially in women's autonomy [Jayachandran, 2021]. All the outcome variables chosen in our study are inextricably linked to one or more social norms such as not allowing girls to step out of their homes unattended by any male member of the household, marrying off girls too early without even letting them choose their husbands, not including women in important household decisions, or even decisions about her own well-being (like fertility and other health-related decision). Hence, in the process of finding out the impact of community electrification on women empowerment outcomes, our study underscores the norm-breaking ability of reliable electrification, which can be useful from policy perspectives.

The rest of the paper is organized as follows. Section 2 describes the datasets we use in detail, section 3 provides an outline of the empirical strategies used, section 4 presents the results as well as the robustness checks and section 5 concludes.

3 Data

The data used for empirical analysis consists of household and administrative surveys covering the time period from 2004 to 2020. For our main analysis, we use the Indian Human Development Survey (IHDS) panel 2005-2012 [Desai and Vanneman, 2018] and crime against women data from National Crime Records Bureau (NCRB) [8]. To substantiate the main results through an alternate treatment variable, we use nightlight data from Socioeconomic High-resolution Rural-Urban Geographic Dataset on India (SHRUG) [Asher et al., 2021] as an indicator of community-level electrification. Lastly, to examine more recent evidence and provide robustness to our main results, we merge the data from Indian Residential Energy Survey (IRES) (2020) [Agrawal et al., 2021] with National Family Health Survey 5 (2019-21) (International Institute for Population Sciences and ICF, 2021). Next, we describe each dataset in detail.

3.1 Indian Human Development Survey (IHDS)

IHDS is the largest panel survey in India, a collaborative project of the National Council of Applied Economic Research (NCAER) and the University of Maryland. It is a multi-topic survey covering a wide range of human development indicators across all the states and union territories of India (Excluding Andaman & Nicobar Islands and Lakshadweep). The first round of IHDS, conducted during 2004-05, interviewed a total of 41,554 rural and urban households. In 2011-12, the second round of IHDS interviewed 42,152 households with a re-interview rate of 83%.

One distinguishing feature of IHDS is that it contains detailed information on energy use at the household level as well as information on several empowerment outcomes of the female members of the household. To bring these two pieces of information into a single dataset, we merge the household data with the eligible women[9] data and individual data. Within the variables related to energy use, we focus on the hours of electricity available in the household and average it over the primary sampling units (PSUs), which is then used as a measure of community-level electricity, our main treatment variable. Table 1 shows that despite a significant improvement in electricity access over the two survey periods (from 76.3% to 87%), the hours of electricity (intensive margin) did not change noticeably, and the community average electricity hours actually decreased. This finding matches with [Sedai et al., 2021], who found an increase in electricity access from 77% to 88% and a stagnation in the reliability of electricity. This is also reflected in figure 1, where we show district-level average electricity hours during IHDS 1 (panel a) and IHDS 2 (panel b). The

[8] Accessible from https://ncrb.gov.in/en/crime-in-india

[9] Eligible women refers to women aged between 15 and 49

darker shaded districts represent higher average electricity hours in the district.

Insert Figure 1 about here

Insert Table 1 about here

From eligible women and individual datasets, we draw our outcome/dependent variables related to women autonomy. The first five outcomes (see table 1) are drawn from eligible women's file; 'treatment in short-term morbidity' is drawn from the individual file. The variables named 'freedom of movement' and 'value of opinion' are created using the principal component analysis[10]. Our sample is restricted to ever-married or eligible women, which indicates women aged between 15 to 49 (reproductive age) who had been married at least once in their lifetimes, although their current marital status could be different. Our sample consists of 31,293 ever-married women in each survey wave, which leads to a strongly balanced panel of 62,586 women.

Table 2 summarizes the outcome variables for each of the survey periods. To compare the means of these variables over two survey periods, we conduct a t-test for each of them. We find that the means of 'mean age of marriage' and 'knowing husband before marriage' has not changed significantly, but for 'freedom of movement', 'value of opinion', 'contraceptive use' and 'treatment in short term morbidity' mean values have increased significantly from IHDS 1 to 2, indicative of trend effects in these variables.

Insert Table 2 about here

3.2 National Crime Records Bureau (NCRB)

NCRB is an agency under the Ministry of Home Affairs, Government of India, responsible for collecting data on different types of crime as per the definition of Indian Penal Code

[10] Principle component analysis (PCA) aims to find a set of components (linear combination of original variables) with maximum variance. Following the Kaiser criterion, we retain only those components for which the eigenvalue is greater than or equal to 1 [Costello and Osborne, 2005]. Using PCA, the 'freedom of movement' index is created using three dummy variables: health centre, friend's house, and grocery shop, where each of these dummies takes value 1 if the woman is allowed to go to that particular place at her own will, without the permission of any household member. Similarly, 'value of opinion' index is formed using three dummy variables: work, politics and expenditure, where each of these dummies takes value 1 if the woman participates in household discussion about that particular topic.

(IPC) and Special and Local Laws (SLL)[11]. It has been digitising and publishing 'Crime in India' data every year, starting from 1967. For our analysis, we extract district-wise crime against women data from NCRB for the years 2004, 2005, 2011 and 2012. Average numbers of crime against women for 2004 and 2005 are merged with IHDS 1, and the same for 2011 and 2012 are merged with IHDS 2. We focus on the most severe form of crime against women, which is rape. Summary statistics of the number of rapes are shown in table 2. In crime against women data, there might be over-dependence on the average of certain districts where the averages are too high or too low. To avoid this problem, the rape variable is winsorized at 1% and 99%. By winsorizing, we are also able to exclude zero number of rapes from the data, which ensures the absence of any non-linear switch in the estimated coefficients.

3.3 Night-time luminosity data

Night-time luminosity, drawn from the Socioeconomic High-resolution Rural-Urban Geographic Dataset on India (SHRUG) [Asher et al., 2021], is used as an alternative indicator of community-level electrification. Asher et al. [2021] find that night lights are a log-linear proxy for a set of development outcomes in India, including electrification. The data is extracted from the Defense Meteorological Satellite Program-Operational Line Scan (DMSP-OLS) programme of the National Oceanic and Atmospheric Administration (NOAA)[12]. Of the different measures of nightlights in SHRUG, we use the 'total night light' variable (a sum of pixels of the luminosity values [0-63] across the geographic unit) as it is consistent across different satellite measures and time periods[13]. For our analysis, the average of total lights in 2004 and 2005 is merged with IHDS 1 and the same for 2011 and 2012 is merged with IHDS 2. Figure 2 shows the nightlight map of India during IHDS 1 in panel (a) and during IHDS 2 in panel (b). The brighter dots in these maps signify higher night-time luminosity in those areas. From panel (a) and panel (b), it is evident that night-time luminosity has increased significantly over two survey periods of IHDS.

Insert Figure 2 about here

[11] https://ncrb.gov.in/en/crime-india

[12] It compiles photos from U.S. Air Force satellites that photograph the earth every day between 8:30 p.m. and 10:00 p.m., starting from the year 1994 to 2013.

[13] To get a consistent estimation across years, the total light variable is then calibrated following the method described in Elvidge et al. [2014]

3.4 Indian Residential Energy Survey (IRES)

IRES is the recent most energy survey of India, conducted in 2019-20 [Agrawal et al., 2021]. It is a collaborative project of the Council on Energy, Environment and Water (CEEW) and the Initiative for Sustainable Energy Policy (ISEP), covering nearly 15000 households across the 21 most populous states of India. IRES contains a rich set of information on access, reliability, and consumer satisfaction with electricity supply across India. To keep the treatment consistent, we draw the data on community-level average electricity hours from IRES. Figure 3 shows the state of district-level average electricity in 2020 following IRES.

The main purpose of using IRES is to check if our results from IHDS are still valid for the recent data. But IRES doesn't contain any information on women empowerment outcomes. Therefore, for our analysis, we merge IRES with National Family Health Survey 5 (NHFS 5), which contains information on women empowerment and is contemporary of the IRES.

Insert Figure 3 about here

3.5 National Family Health Survey 5 (NFHS 5)

NFHS is a pan-India survey conducted in five rounds till date with the International Institute for Population Sciences (IIPS) acting as the nodal agency. The latest (fifth) round of NHFS started in 2019 and was completed in 2021. Since IRES and NHFS 5 wave 1 were conducted during the same time, we merge these two together for the empirical analysis. NFHS does not contain the exact same women empowerment outcome variables as IHDS; hence, we use similar but slightly different outcomes from NFHS that are related to women empowerment. The outcome variables 'mean age of marriage' and 'contraceptive use' are the same as IHDS; but 'freedom of movement' and 'treatment' is by construction different from their IHDS counterparts. Table 3 provides the summary statistics of the outcome variables from NFHS-5. To check the robustness of crime against the main results in 2020, we merge the data on the number of rapes in 2020 from NCRB with the merged data of IRES-NFHS 5 and winsorize the rape data at 1 percent and 99 percent. The last row of table 3 summarizes the rape variable.

Insert Table 3 about here

4 Empirical Strategy

4.1 Difference-in-difference model

To estimate the impact of community-level electricity on women's autonomy outcomes, we use the DID-M estimator proposed by De Chaisemartin and d'Haultfoeuille [2020], which is unique in terms of its flexibility. We follow a sharp DID design where all units in a particular group and period get the same treatment[14]. In our study, the treatment variable is the average hours of electricity in a community and it is distributed continuously over time. DID-M estimator, for continuous treatment, is based on the assumption that with a movement from period 1 to period 2 (in a two-period model, as is the case in our study), treatment of some units changes and for the other units, it remains the same [de Chaisemartin et al., 2022][15]. The units for which treatment changes are called 'movers' or 'switchers' and the units with unchanged treatment are called 'stayers' or 'non-switchers'. However, as pointed out by de Chaisemartin et al. [2022], in case of continuous treatment, there might not be sufficient number of non-switchers in the data. In IHDS panel data, we found that only in 6.5% communities, average electricity hours remained unchanged in between 2004 and 2012. For the other communities, it has either increased (hereafter described as 'switchers in' group) or decreased (hereafter described as 'switchers out' group). To ensure having enough number of non-switchers for the analysis, we round off the average community electricity hours to their nearest integers and include some quasi-stayers[16] in the group of stayers.

DID-M estimator can be described as the weighted average of the following two DID models:

1. DID model that compares the outcome difference of non-switcher groups with the outcome difference of "switchers in" groups.
2. DID model that compares the outcome difference of non-switcher groups with the outcome difference of "switchers out" groups.

Hence, the DID-M estimator can be presented as,

[14] We use the STATA command did_multiplegt introduced by De Chaisemartin and d'Haultfoeuille [2020]

[15] They assume that there will be sufficient number of 'non-switchers', i.e., the groups for which treatment remain the same (stable) for both the periods. This assumption is called 'Stable group' assumption. For details, see the online appendix of De Chaisemartin and d'Haultfoeuille [2020]

[16] Quasi-stayers are those units for which the treatment values change little across time, not substantially. We use the 'threshold$_s$$table_treatment'optioninthedid_multiplegtcommandtoincludethequasi-stayers$.

$$DID - M = (Y_{s,2012} - Y_{s,2005}) - (Y_{ns,2012} - Y_{ns,2005}) \quad (1)$$

Where s stands for switchers (either 'switchers in' or 'switchers out') and ns stands for non-switchers. The outcome variables (Y) include the freedom of movement of women, value of opinion of women in the household, contraceptive use, receiving treatment in short term morbidities, mean age of marriage of women in the community, knowing husband before marriage, and violence against women[17].

The parameter of interest in the DID-M model is the average slope of the potential outcome function of the switchers in between two time periods and is known as average of movers' potential outcome slope [de Chaisemartin et al., 2022] or movers' average partial effect [Graham and Powell, 2012]. It can be interpreted as the average effect of one unit increase in the treatment on the outcome variable. Under common trends[18] and stable groups assumption, DID-M estimates this parameter, and this estimator is asymptotically normal (Online appendix, De Chaisemartin and d'Haultfoeuille [2020]).

Most of the previous studies on impact of reliable electricity have used the traditional two-way fixed effect (TWFE) model. But we claim that DID-M is a better estimator and switch from TWFE model to DID-M model because of the following reasons:

Firstly, in case of TWFE, the presence of negative weights is a common phenomenon, because TWFE estimator is a weighted sum of the treatment effects,

$$\hat{\beta}_{TWFE} = \sum_{(g,t)\,\in\, set\, of\, treated\, units} \theta_{g,t}\; ATE_{g,t} \quad (2)$$

where $\theta_{g,t}$ and $ATE_{g,t}$ are the weight and average treatment effect of group g and period t respectively. The weights can be negative here even though they sum up to 1. The negative weights make the TWFE estimator biased when ATEs are not homogeneous across groups and time periods [De Chaisemartin and d'Haultfoeuille, 2020]. In our model setup, the presence of treatment heterogeneity is highly probable because our treatment variable, average electricity hours in the community, does not specify whether the available electricity

[17] For details of the outcome variables, refer to table 2

[18] Since our data is available only for two periods, we can't test common trends assumption. If data for more than two years were available, we could have tested this assumption using placebo effects [De Chaisemartin and d'Haultfoeuille, 2020]

hours are daytime electricity or night-time electricity. For example, if community 1 gets 8 hours of electricity at night and community 2 gets 8 hours of electricity in the daytime; both are assigned the same value of treatment, even though night-time electricity is supposed to have a stronger impact on women's safety and autonomy compared to daytime electricity. In our data, nearly 50% of the weights are negative for each outcome variable[19], which implies that the TWFE coefficients are not robust to treatment heterogeneity.

Secondly, in our data, treatment is reversible. Average community-level electricity hours might increase or decrease in IHDS 2 as compared to IHDS 1, i.e., units can switch to or out of treatment at any point of time[20]. In the presence of this treatment switching, TWFE estimator gives biased estimators as it becomes difficult to disentangle treatment effects from individual fixed effects. But DID-M estimator compares the outcome difference of the switchers and non-switchers over time and gives an unbiased estimator of the treatment effect.

4.2 Two-way fixed effect (TWFE) and Instrumental variable (IV) model

As a robustness check to the above-mentioned DID-M estimator and to examine the extent of bias in the traditional TWFE estimator as compared to the DID-M estimator, we use the following model:

$$Y_{ipt} = \beta E_{pt} + X'_{ipt}\gamma + \alpha_i + \delta_t + \epsilon_{ipt} \tag{3}$$

Y_{ipt} is the outcome variable of ith individual belonging to p-th community (Primary Sampling Unit i.e., village or town) for time t. E_{pt} is the average electricity hours in community p at time t, which serves as our main treatment variable. X_{ipt} is vector of time-variant observable household/individual characteristics, including age, marital status, highest level of

[19]We employ the STATA command 'twowayfeweights' to calculate the weights of TWFE regression as described in De Chaisemartin and d'Haultfoeuille [2020]. For example, for the outcome variable contraceptive use, TWFE estimates a weighted sum of 11126 ATTs (Average Treatment on the Treated) under the 'parallel trends' assumption, where 5565 ATTs receive a positive weight, and 5561 receive a negative weight. The sum of the positive weights is equal to 2.4029069, while the sum of the negative weights is equal to -1.402907.

[20]For graphical analysis of the increase and decrease in electricity hours between 2005 and 2012, see Sedai et al. [2021]

male and female education in the household, log of household income, household networks etc. α_i is time-invariant cross-section specific unobserved heterogeneity (individual fixed effect) and δ_t is survey wave intercept (time fixed effect).

The TWFE model in equation 2 looks at the impact of one additional unit increase in average electricity hours in the community. But in reality, electricity hour increases rarely by just one additional unit; rather it takes a jump. To incorporate this fact in our analysis, we divide the electricity hours into three equal quantiles: the first tercile (0-10 hours) represents low reliability of electricity, the second tercile (10-19) represents medium reliability and the third tercile (19-24 hours) represents high reliability of electricity. Then we carry out a piecewise linear regression model with the first tercile being treated as the base category to see how the outcome variables are being impacted when community-level electricity moves from one category to the other.

However, the TWFE model suffers from the problem of endogeneity because the community-level electrification in India is not random [Khandker et al., 2014]. Electrification decision in a particular area can be driven by the cost-effectiveness of grid expansion caused by unmeasured economic advantage in that area [Rathi and Vermaak, 2018] or from unmeasured political motivations [Sedai et al., 2021], leading to endogeneity due to omitted variable bias.

The other two sources of endogeneity, measurement error and reverse causality, will not cause any problem in this context. Any bias at the household level caused by reverse causality will be eliminated because we are using the community-level average of household electricity hours as our main independent variable [Dang and La, 2019]. The attenuation bias caused by measurement error will also be eliminated because positive and negative measurement errors of household electricity hours will be neutralised while averaging at the community level.

As an additional model of robustness to test the direction of effects, we use the generic 'leave one out' instrumental variable (IV) and carry out two-stage least square (2SLS) estimation technique. Our instrumental variable[21] is the average electricity hour in the

[21] A good IV is supposed to satisfy three conditions: (i) the IV must be uncorrelated with the random error term (orthogonality condition), (ii) it has to be correlated with the endogenous regressor and (iii) it has to affect the dependent variable indirectly, only through the endogenous regressor (exclusion restriction). The orthogonality condition is satisfied because the error term here contains all the unobserved variables that could affect women autonomy in the households in community p and our IV is not correlated to those variables. The second and third conditions are also satisfied because electricity hours in other communities do not have any direct impact on p-th community's women autonomy outcomes, but it affects

household's district, excluding the PSU where the household lives. Similar IVs have been used previously in multiple studies to address the problem of endogeneity in electricity hours [Dang and La, 2019; Sedai et al., 2021]. This instrument has been criticized in for its inability to address the non-local spill-over effects; hence it only acts as a robustness measure in our study, and we do not claim that the coefficients from this model are causal.

5 Results

5.1 Electricity and empowerment: DID-M estimator

We present our results from DID-M model[22] in table 4. The graphs of the estimates in table 4 are furnished in figure 4 in the appendix. For each outcome variable in table 4, we report number of observations and number of switchers[23] along with the sharpened q values[24] following the method by Anderson [2008], which adjust the p values for multiple hypothesis testing.

An increase in average community-level electricity by 10 additional hours increases the freedom of movement index of women by 0.44 standard deviation. Even though in part 3 of Indian constitution, article 19(1)(d) permits every Indian citizen to move freely within the Indian territory, the freedom of movement of Indian women are highly limited. The data from IHDS-II says that 78.08% Indian women need permissions from their husbands/elder members of the household to visit health centre alone, whereas the same for visiting friend's house and grocery shop are 69.65% and 57.06% respectively. This is the result of the

pth community's electricity hours via demonstration effect. A community is more likely to get higher electricity hours if the neighbouring communities in the same district start deriving positive benefits of reliable electricity in several developmental aspects. This can be considered as the positive demonstration effect of community electrification.

[22]In all the models, we control for household size. In addition, for mean age of marriage and knowing husband before marriage, we control for education level of women. For freedom of movement, we control for perception about the frequency of harassment of young girls in the locality. For contraceptive use, we control for number of children. For value of opinion and receiving treatment, we control for marital status of the women.

[23]In all the outcome variable, the number of switchers (units for which electricity hour changes in between 2004 and 2012) are nearly half of the number of observations, which indicates towards a 50-50 balance between control and treatment group. To arrive to such case, we use the option 'threshold_stable_treatment' with the 'did_multiplegt' command in STATA.

[24]Since we're using a large number of outcome variables (7 in total) to represent women empowerment, some of them can turn out to be significant even when no such effect exists (false discoveries/type I errors). Sharpened q values account and adjust for this concern Anderson [2008].

centuries-old social norms which restrict women from stepping out of their houses unchaperoned. Hence, an increase in freedom of movement not only empowers women to exercise their constitutional rights but also helps them to break the related social norms in the process.

We found positive impact on another index related to women's autonomy, value of opinion of women in the household's decision-making process, which increases by 0.04 standard deviation with 10 hours increase in electricity hours. Value of opinion represents women's agency in the sense that an increase in this index would imply women taking part in household discussions regarding work, expenditure and even politics. Not only does it indicate an increasing importance of women's opinion in spheres other than household activities, but also an increase in women having outward mindsets.

Women's agency is also reflected in their reproductive freedom, which is proxied by contraceptive use in our study and it increases by 4 percentage point (pp) with 10 hours increase in community-level electricity. Use of contraceptives can help women exercise their basic human right to decide whether and when to have children, the number of children and birth intervals [WHO, 2007]. However, in India, the data from IHDS-II suggests that there are 38.24% women aged between 15 and 49 who have a greater number of children than their desired number of children, which reveals the gloomy picture of reproductive freedom of women in India and emphasizes the importance of improving the situation as presented in our results. Apart from reproductive freedom, women's autonomy related to their health-related decision-making is also an important factor of empowerment. We proxy this health-related autonomy by the likelihood of receiving treatment in case of short-term morbidities of women, which increases by 1 pp with electricity[25].

Studies by Samad and Zhang [2019]; Sedai et al. [2021, 2022] have also found similar impacts of electrification on women's empowerment outcomes related to mobility, autonomy (reproductive as well as financial) and health of women. Using IHDS-II data, Samad and Zhang [2019] look at the impact of having electricity grid connection on women empowerment in rural areas, whereas Sedai et al. [2022] show the effects of power outrage on similar outcomes. Sedai et al. [2021] use the panel data of IHDS-I and II to study the impact of an increase in household electricity hours on women empowerment, focusing on labour market outcomes of women. However, these studies significantly differ from our results because

[25]The number of observations in case of receiving treatment (in column 4) is noticeably higher than that in column 1, 2, 3, 5 and 6 because this variable is drawn from the individual data while others (excluding rape) are drawn from eligible women questionnaire.

(a) we look at the impact of community-level electrification instead of household-level, which takes into account the possible spillovers of an electrified household on its neighbouring households, (b) we use the latest DID-M methodology which is an improvement over the two-way fixed effect and IV methods used in those previous studies, (c) we provide robustness to our results using different methodologies, different indicators of community electrification and different datasets spanning over almost two decades and (d) the outcome variables we look at reflect women's social autonomy, which has not been looked at in the previous studies.

An increase in the average community level electricity by 10 hours increases the mean age of marriage in that area by 0.07 years. At first look, this number might seem insignificant, but here we must note that the outcome is not individual age of marriage, but the mean age of marriage in a community. One year increase in individual age of marriage will translate into less than one year increase in mean age of marriage and that increase is equal to the reciprocal of community population. Keeping in mind this and the fact that community population is generally a fairly large number, the increase in mean age of marriage by 0.07 year can be considered as a significant impact, especially in countries like India, where the highest number of child brides live [UNICEF, 2019]. Alongside the increase in mean age of marriage, the likelihood of knowing husband before marriage increases by 5 pp with one hour increase in the average electricity hours. Both of these impacts ensure better marital outcomes of women [Field and Ambrus, 2008; Sekhri and Debnath, 2014; Chari et al., 2017; Roychowdhury and Dhamija, 2021]. It also breaks several social norms related to marriage in India including the parents having the agency to decide the groom for their daughters, the practice of arranged marriage and marrying off daughters too early.

Lastly, we found a negative impact of community electricity hours on violence against women[26]. With a 10-hour increase in electricity, the average number of rapes in the district[27] reduces by 0.43. Since violence against women is considered as negative agency of women [Kabeer, 1999], this result can be indicative of an improvement in women empowerment and autonomy. Lower violence against women in an area also reinforces other women empowerment outcomes like female employment [Chakraborty et al., 2018] and age of marriage [Sarkar, 2021].

Insert Table 4 about here

[26] Violence against women (rape) data is from NCRB, which is merged with IHDS household data. All other results in table 4 are from individual and eligible women data.

[27] Number of crimes against women data is only available at district level in NCRB.

Insert Figure 4 about here

5.2 Robustness check 1: Falsification tests

To check the validity of the above methodology, we carry out three falsification tests using three different outcome variables that should not be impacted by electricity at all. The first outcome variable is the month of birth dummy, which takes value 1 if the woman is born between January to June of any given year and 0 otherwise. Second, the month of marriage dummy is generated in the same way except that here the month of birth is replaced by month of marriage. The third falsification outcome is the joint family dummy which takes value 1 if the woman lives in a joint family and 0 otherwise. Table 5 shows the DID-M estimators of these three falsification outcomes. As expected, the coefficients of all three outcomes are insignificant[28]. These falsification tests eliminate the possibility of the presence of any spurious correlation in our results.

Insert Table 5 about here

5.3 Robustness check 2: TWFE and piecewise analysis

As our second robustness check, we present the traditional two-way fixed effect estimates in panel (a) of table 6. The signs of all the coefficients here are the same as in table 4, indicating the consistency of our results in a different methodological setup. However, the magnitudes of the coefficients in panel (a) of table 6 are different from those in table 4, which arises because DID-M estimator doesn't allow the assignment of negative weights and permits the presence of treatment heterogeneity, unlike the TWFE estimator.

In panel (b) of table 6, we present the estimates for the piecewise regression model with fixed effects. We have divided the electricity hours into three equal quantiles here, where the first tercile is 0-10 hour (low reliability of electricity), the second tercile is 10-19 hours (medium reliability) and the third tercile is 19-24 hours (high reliability). Moving from base category (first tercile) to second and third tercile increases freedom of movement by

[28] The number of observations in month of birth dummy is the lowest because this data is missing for those women who don't have a birth certificate or don't know the exact month of their birth. The month of marriage dummy also has lesser number of observations compared to joint family dummy, which is because of the missing data on month of marriage for unmarried women.

0.204 SD and 0.495 SD respectively. From the magnitude of the coefficients, it can be inferred that the impact on freedom of movement is stronger for higher terciles. Same is true for all other outcomes except value of opinion and contraceptive use. Value of opinion increases (by 0.143 SD) only for the switch from base tercile to second tercile, not for the switch to third tercile. For contraceptive use, the impact is the same for switch to second tercile and third tercile (6.1 pp).

We also carry out falsification tests for TWFE and piecewise analysis using the same outcomes as in table 5. The results are furnished in table A1 in the appendix.

Insert Table 6 about here

5.4 Robustness check 3: Instrumental variable approach

In table 7 we report the estimates from the 2SLS procedure using the instrumental variable (IV) described in section 4 and here also the sign of the coefficients are consistent with the previous results. The IV estimates correct the bias caused by endogeneity in the TWFE model, making the magnitude of the coefficients in table 7 slightly higher than that in panel (a) of table 6. To check the strength of the IV, we use the Sanderson-Windmeijer multivariate F test of excluded instruments. If the F-statistic (reported in table 7) is higher than 10, we can infer that the IV is strong at 5% level of confidence. [Staiger and James, 1997].

Again we carry out falsification tests using the same three outcomes as in table 5. The coefficients are all insignificant as expected and they are furnished in table A1.

Insert Table 7 about here

5.5 Robustness check 4: Nightlights as an alternative indicator of community electrification

For our next robustness check, we use night-time luminosity as an alternative indicator of community level electrification. From the Socioeconomic High-resolution Rural-Urban Geographic Dataset on India (SHRUG) [Asher et al., 2021], we draw the data for total calibrated nightlight and use the log of this total light as our main independent variable. Nightlight has previously been used widely as a measure of electrification in the studies like Min and Gaba [2014]; Min et al. [2013]; Burlig and Preonas [2016] etc.

When we consider nightlight as our treatment variable, DID and TWFE becomes equivalent because nightlight is completely exogenous to our model. Hence, we report TWFE estimators of the impact of log of total calibrated light in table 8. With an increase in total calibrated nightlight by one percentage point, freedom of movement increases by 0.233 SD, value of opinion increases by 0.160 SD, contraceptive use increases by 8.5 pp, likelihood of getting treatment in short term morbidity increases by 4 pp, age of marriage increases by 0.197, the likelihood of knowing husband before marriage increases by 10.6 pp and lastly, number of rapes decreases by 4.085.

Insert Table 8 about here

Comparing table 4 with table 8, it is evident that the magnitude of the coefficients in table 8 are much bigger in magnitude compared to the same in table 8. This is because 10 units increase in community-average of electricity hours (in table 4) is not equivalent or comparable to one pp increase in total calibrated nightlight (in table 8). In the context of rural electrification in Vietnam, Min and Gaba [2014] found that one unit increase in the nightlight brightness translates into 240-270 additional electrified homes and 60-70 additional streetlights. In Indian context, no such comparison study is available, but since the study by Min and Gaba [2014] and our present study use the same source of nightlight data (DMSP-OLS), we argue that similar comparison is applicable to our study as well.

5.6 Robustness check 5: Relevance of the results in recent backdrop of reliable electrification in India

So far, we have checked the robustness of our results using different indicators of electricity and different methodologies. But all of those checks use the data from same range of time periods, from 2004 to 2012, and consequently they don't take into account the fact that electrification in India has shown significant progress after 2012 mainly owing to different government schemes like Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY; launched in 2015), Ujwal DISCOM Assurance Yojana (UDAY; launched in 2015) and Pradhan Mantri Sahaj Bijli Har Ghar Yojana (popularly known as Saubhagya scheme; launched in 2017).

According to the 'Access to Clean Cooking Energy and Electricity—Survey of States' (ACCESS) conducted in six energy-poor states of India[29], rural electrification went up from 44% in 2015 to 80% in 2018 [Jain et al., 2018]. The most recent energy survey, India Residential Energy Survey (IRES) 2020, found evidence of further progress, with 97% of Indian households having grid/off-grid electricity connection [Agrawal et al., 2021]. Apart from this progress in extensive margin, there is a significant improvement in intensive margin as well. According to the report of the IRES survey, average hours of grid power supply in an Indian household is 20.6 hours and for urban areas the average is slightly higher (22 hours) than in rural areas (20 hours) [Agrawal et al., 2021].

In our last robustness check, we show how our results still remain relevant amongst the changing scenario of electrification in India. For this purpose, we draw the data on electricity hours from the most recent energy survey, IRES 2020, and merge it with the data on women empowerment outcomes from National Family Health Survey 5 (NFHS-5) (2019-21) and NCRB as described in section 3. Since it is a cross section data, we first run the basic OLS model using average electricity hours at district as the main independent variable. Then we run the cross section 2SLS model using the instrumental variable 'average electricity hours in the state excluding the district where the household lives'[30].

We present the results in table 9. Our focus here is not on the magnitude of the coefficients, but on the signs and the directions of change. We see that with an increase in electricity hours in district, women's autonomy indicators show significant improvement with an increase in mean age of marriage in the community, freedom of movement, likelihood of contraceptive use and receiving treatment without difficulty and decrease in the violence against women (number of rapes). The results establish the validity of our results in recent backdrop.

Insert Table 9 about here

[29] Bihar, Jharkhand, Odisha, Madhya Pradesh, Uttar Pradesh and West Bengal

[30] This IV is similar to the one we used in section 5.4 , which is 'average electricity hours in the district excluding the PSU where the household lives'. We couldn't use the same IV here because NFHS and IRES doesn't have the same PSU id and hence the merging could only be done at district level.

5.7 Heterogeneity analysis: Rural vs Urban

In this section, we carry out a heterogeneity analysis to check the results separately for rural and urban areas. This analysis is particularly important because of the difference of social structure and social norms in those areas, which could be a driving factor for women's autonomy outcomes. We present the DID-M estimators separately for rural and urban areas in table 10.

Insert Table 10 about here

For freedom of movement index, the impact is higher in rural areas (0.53 S.D) compared to urban areas (0.35 S.D). This can be explained due to the well-known existence of stronger social norms in rural India, which restricts the free movement of women without any company. The impact on value of opinion index is also more prominent in rural areas, where it increases by 0.1 S.D, but in urban areas, we do not see any significant impact. Same is the case for contraceptive use and receiving treatment; both of them increase significantly in rural areas but not in urban areas. Mean age of marriage in rural areas increases by 0.15 years with an increase in electricity; however, in urban areas, we observe change in the opposite direction. This negative impact on mean age of marriage can be explained if we consider the higher scope of interacting with the opposite gender in urban areas[31] and hence finding a suitable partner more easily and quickly. This explanation can be backed up by looking at the rural-urban decomposition of the impact on the likelihood for a woman to know her husband before marriage. The results show that the increase in this likelihood is much stronger in urban areas (12 pp) compared to rural areas (4 pp). For violence against women, we find a decrease in the number of rapes in rural areas as expected, which can be attributed to an increase in the functionality and the number of streetlights making the area safer for women. But in urban areas we again observe opposite result, an increase in violence against women. In urban areas, more electricity implies workplaces and entertainment places staying open till late night and women returning home late, which increases the probability of them falling prey to violence. In rural areas, this channel of impact is not relevant because majority of rural population depends on jobs that require only daytime activity and also because of unavailability of entertainment places there.

[31] To support this hypothesis, in the model we include the outing dummy (=1 if she goes out to cinema/mela/restaurant and 0 otherwise) as a control which makes the result insignificant for urban area but it still remains significant in rural areas. Since the outing dummy can be thought of as an indicator of exposure to opposite gender, this result explains the reason of the opposite sign in mean age of marriage in urban areas.

Overall, from this analysis we can say that in general the impact of electricity on women empowerment is stronger in rural areas compared to urban areas.

5.8 Mechanism

Reliable community electricity affects women autonomy outcomes via four main channels: employment, education, awareness/exposure to mass media and safety[32]. When reliability of electricity increases in a community, economic activities increase there, creating more employment opportunities for women. If the community is well lit at night, better safety of women is ensured in that locality, which will allow women to stay out for a longer period at night, for working late or attending night schools. More reliable electricity will incentivize more households to buy TV or other mass media devices, which will create awareness not only among household members but also among the neighbourhood women.

In this subsection, we try to provide empirical evidence on how these four channels mediate the impact of electricity on our outcome variables [33]. To show the causal channel we follow the approach described in Baron and Kenny [1986]. According to this approach, causal mediation can be established in three steps: 1. To show that the independent variable affects the outcome variables, 2. To show that the independent variable affects the channel variables/mediators and 3. To show that the channel variables significantly affect the outcome variables while controlling for the independent variable [34].

In our study, step 1 is satisfied because in table 4, we show how electricity significantly impacts our outcome variables. Evidence towards step 2 is furnished in table 11, where we show how electricity impacts the four channel variables. Step 3 is shown in table 12. Significant coefficients of electricity in all panels of table 12 indicate partial mediation in all the cases. For freedom of movement, employment and safety channel play the significant role, for value of opinion exposure to mass media and safety channel do the same. Contra-

[32]Employment is a dichotomous measure of paid employment for women, education is measured by years of education of women, exposure to mass media is proxied by whether or not the woman watches TV (0/1) and lastly, safety in the locality is proxied by harassment perception which takes value 1 if girls are harassed frequently in the locality and 0 otherwise.

[33]We look at the channels of impact on our first six outcome variables, leaving out violence against women. The reasons are (a) Violence against women data is merged with the household file of IHDS, where we do not have individual level outcomes like employment, education and exposure to mass media and (b) violence against women can itself be interpreted as the safety channel as lower violence leads to better safety in the locality.

[34]If in step 3, the coefficient of the independent variable is insignificant, then it is the case of complete mediation and if the coefficient is significant, then it is the case of partial mediation.

ceptive use is only channelled through paid employment, whereas for receiving treatment, employment and awareness channels are at play. For mean age of marriage, only education matters and for knowing husband before marriage, safety channel matters along with education.

Insert Table 11 about here

Insert Table 12 about here

6 Conclusion

In this paper, we contribute to the literature on electrification and women empowerment by using a combination of household survey data, administrative data, and satellite data to carry out a comprehensive analysis of how reliable electrification in the community can enhance the social autonomy of women in that community, via direct and spillover benefits of electrification. We use the latest DID-M methodology to arrive at the main results and show that they are robust even if we use more traditional methodologies like TWFE and spatial IV methods. We also show the robustness of the results using an alternative indicator of community electrification and three falsification tests. Using piecewise linear regression model, we show how a change from low-reliability to medium or high-reliability intensive margin can affect the autonomy outcomes more strongly. Also, using the most recent datasets we establish the relevance of our results for the current backdrop of electrification in India. Lastly, we identify the four main channels, paid employment of women, female education, safety and exposure to mass media, which partially mediate the impact of reliable electrification on direct indicators of women's autonomy.

Another contribution of our study is that the empowerment and social autonomy indicators we choose for our study are closely linked to existing social and gender norms in India. This allows us to use the results of the impact of electrification on women's empowerment and autonomy to understand the norm-breaking ability of reliable electrification, which could be useful from policymaking perspective. The reliability aspect of electrification in India still needs to improve, the distribution companies need to be made more efficient and given the depleting coal reserve in different states, more focus should be given on renewable sources of electrification. In recent union budget (for the financial year 2023-24), renewable electricity including solar, wind and nuclear power sector got almost 50 percent higher allocation compared to last year. We can therefore say that India is on the right track.

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Table 1: Extensive and Intensive margin of electricity

	IHDS 2005		IHDS 2012	
Variables	Observations	Mean (S.D)	Observations	Mean (S.D)
Electricity access (0/1)	39,731	0.763 (0.425)	39,861	0.870 (0.337)
Hours of electricity	30,337	15.898 (6.740)	34,586	15.049 (6.869)
Average electricity hours at community	29,710	15.315 (6.326)	30,900	14.675 (6.216)

Source: Authors' calculation using IHDS 1 and IHDS 2.

Table 2: Summary Statistics of outcome variables

		IHDS 1		IHDS 2		IHDS 1 - IHDS 2
Variable name	Variable description	No of obs	Mean (S.D)	No of obs	Mean (S.D)	t-stat
Freedom of movement	An index constructed by PCA using 3 binary variables: permission to visit health center alone; friend's house alone; and grocery store alone	17,225	-0.070 (0.964)	18,051	0.066 (1.029)	-12.835
Value of opinion	An index constructed by PCA using 3 binary variables: women's participation in household discussion about expenditure, work issues and politics	20,829	-0.023 (1.018)	20,538	0.023 (0.981)	-4.682
Contraceptive use (0/1)	Dummy variable; takes value 1 if the woman uses contraceptive, 0 if no	19,435	0.620 (0.485)	19,520	0.809 (0.393)	-42.110
Short Term Illness Treatment (0/1)	Dummy variable; takes value 1 if the woman receives proper treatment in short-term illnesses	31,293	0.010 (0.3)	31,293	0.178 (0.382)	-28.348
Mean age of marriage	Average of age of marriage of women in a particular community	31,252	17.506 (2.251)	31,255	17.505 (2.164)	0.055
Knowing husband	Dummy variable; takes value 1 if the the woman got to know her husband before marriage, 0 otherwise	21,168	0.325 (0.469)	21,203	0.330 (0.470)	-1.051
Number of rapes	Total number of reported rape cases in the district (winsorized at 1% and 99%) Drawn from the NCRB dataset	35812	36.40 (34.26)	36060	44.20 (36.16)	-29.704

Source: Authors' calculation using IHDS 1, IHDS 2, NCRB 2005 and NCRB 2012.

Table 3: Outcome variables from IRES-NFHS merged data

Variables	Variable description	Number of obs	Mean (S.D)
Mean age of marriage	Same as mean age of marriage in IHDS	3,401	15.50 (3.511)
Freedom of movement	An index, created using PCA with two binary variables, permission to visit health center alone and friend's house alone	5,987	0.000 (1)
Contraceptive (0/1)	Same as contraceptive variable in IHDS	63,745	.528 (0.499)
Short Term Illness Treatment (0/1)	Dummy variable; takes value 0 if the woman faced difficulty in receiving treatment in case of illness, 1 otherwise	63,747	.773 (0.419)
Number of rapes	Total number of reported rape cases in the district (winsorized at 1% and 99%) Drawn from the NCRB dataset	53,880	38.303 (37.593)

Source: Authors' calculation using IRES (2020), NFHS 5 (2019-21) and NCRB 2020

Table 4: Effect of community electrification on women's autonomy: DID-M estimator

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Freedom of movement	Value of opinion	Contraceptive use	Treatment received	Mean age of marriage	Knowing husband	Rape
10 hours electricity	0.44*** (0.02)	0.04* (0.02)	0.04*** (0.01)	0.01*** (0.01)	0.07*** (0.02)	0.05*** (0.01)	-0.43* (0.24)
Number of obs	14091	19054	16965	29599	19956	19876	29703
Switchers	6956	9166	8112	14241	9624	9569	14237
Two-stage q values	0.001	0.026	0.001	0.006	0.001	0.001	0.026

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Standard errors clustered at household level. Additional controls included. Source: Authors' calculation.

Table 5: Falsification tests for DID-M estimator

	Coefficient (S.E)	No of observations	Switchers
Month of birth dummy	0.000 (0.02)	4403	1833
Month of marriage dummy	0.01 (0.01)	10749	4811
Joint family	0.01 (0.01)	19990	9643

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Standard errors clustered at household level. Additional controls included. Source: Authors' calculation.

Table 6: Effect of community electrification on women empowerment: TWFE estimates.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Freedom of movement	Value of opinion	Contraceptive use	Treatment received	Mean age of marriage	Knowing husband	Number of rapes
Panel (a) Linear Estimates							
10 electricity hours	0.33***	0.09***	0.05***	0.03***	0.10**	0.06***	-1.40*
	(0.04)	(0.03)	(0.01)	(0.01)	(0.05)	(0.01)	(0.75)
Panel (b) Piece-wise Linear Estimates							
Baseline electricity (0-11 hours)							
Second tercile	0.204***	0.143***	0.061***	0.025***	0.119**	0.064***	-0.101
(12-19 hours)	(0.049)	(0.038)	(0.015)	(0.007)	(0.061)	(0.017)	(0.822)
Third tercile	0.495***	0.070	0.061***	0.036***	0.121*	0.093***	-2.295*
(19-24 hours)	(0.056)	(0.043)	(0.018)	(0.008)	(0.068)	(0.020)	(1.201)
Observations	31,441	37,535	35,619	56,077	38134	38,068	62,754
Number of Individuals	19,153	20,346	20,072	30,196	20527	20,520	
Number of Households							34,521

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Individual fixed effects included in col (1) to (6). Household fixed effect included in col (7). Standard errors clustered at PSU level. Additional controls included. Source: Authors' calculation.

Table 7: Effect of community electrification on women's autonomy: IV estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Freedom of movement	Value of opinion	Contraceptive use	Treatment received	Mean age of marriage	Knowing husband	Number of rapes
10 electricity hours	0.54*** (0.05)	0.09** (0.04)	0.05*** (0.02)	0.05*** (0.01)	0.12** (0.05)	0.07*** (0.02)	-2.75*** (0.95)
F test (instrument)	2383.79	2546.08	2332.51	2482.26	2542.76	2523.69	2510.51
Observations	31,043	37,047	35,172	55,356	37636	37,571	62,159
Number of Individuals	18,919	20,102	19,829	29,834	20278	20,271	-
Number of Households	-	-	-	-	-	-	34204
Two-stage q values	0.001	0.008	0.003	0.001	0.009	0.001	0.004

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Individual fixed effects included in col (1) to (6). Household fixed effect included in col (7). Standard errors clustered at PSU level. Additional controls included. Source: Authors' calculation.

Table 8: Effect of change in nightlight on women's autonomy

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Freedom of movement	Value of opinion	Contraceptive use	Treatment received	Age of marriage	Knew husband	Number of rapes
Log of total light	0.233**	0.160**	0.085***	0.040***	0.197*	0.106***	-4.085**
(calibrated)	(0.095)	(0.066)	(0.030)	(0.014)	(0.101)	(0.026)	(1.610)
Observations	31,314	37,617	35,619	56,140	38,217	38,153	63,241
Number of Individuals	18,859	19,992	19,755	29,687	20,164	20,156	
Number of Households							34,169
Two-stage q values	0.012	0.011	0.011	0.012	0.018	0.001	0.012

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Individual fixed effects included in col (1) to (6). Household fixed effect included in col (7). Standard errors clustered at PSU level. Additional controls included. Source: Authors' calculation.

Table 9: Effect of electricity on autonomy (from IRES and NFHS 5 data)

	(1) OLS	(2) IV
(a) Mean age of marriage		
10 electricity hours	1.84*	5.63***
	(1.07)	(1.74)
F test (instrument)	-	193.75
Observations	3,297	3,297
(b) Freedom of movement		
10 electricity hours	0.19***	0.53***
	(0.07)	(0.12)
F test (instrument)	-	876.13
Observations	5,831	5,831
(c) Contraceptive use		
10 electricity hours	0.07***	0.21***
	(0.01)	(0.02)
F test (instrument)	-	3282.51
Observations	61,615	61,615
(d) Receiving treatment		
10 hours electricity	0.05***	0.14***
	(0.01)	(0.02)
F test (instrument)	-	3282.76
Observations	61,617	61,617
(e) Number of rapes		
10 electricity hours	-11.11***	-37.35***
	(2.71)	(4.54)
F test (instrument)	-	2322.99
Observations	53,827	53,827

Note: Robust standard errors in parentheses (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). Individual fixed effects included in panel (a) to (d). Household fixed effect included in panel (e). Standard errors clustered at PSU level. Additional controls included. Source: Authors' calculation.

Table 10: Rural vs Urban, DID-M estimators

	(1) Rural	(2) Urban
Freedom of movement	0.53***	0.35***
	(0.04)	(0.04)
No of observations	9189	4898
Switchers	4748	2204
Value of opinion	0.10***	-0.04
	(0.03)	(0.05)
No of observations	12909	6137
Switchers	6482	2679
Contraceptive use	0.06***	0.01
	(0.01)	(0.02)
No of observations	11485	5476
Switchers	5724	2384
Treatment received	0.01*	0.01
	(0.01)	(0.01)
No of observations	19450	10144
Switchers	9838	4398
Mean age of marriage	0.15***	-0.06*
	(0.02)	(0.04)
No of observations	13473	6479
Switchers	6786	2834
Knowing husband	0.04***	0.12***
	(0.01)	(0.02)
No of observations	13416	6456
Switchers	6747	2818
Number of rapes	-3.24***	2.67***
	(0.29)	(0.32)
No of observations	20158	9540
Switchers	10048	4184

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Standard errors clustered at household level. Additional controls included. Source: Authors' calculation.

Table 11: Effect of community electrification on channel variables: DID-M estimator

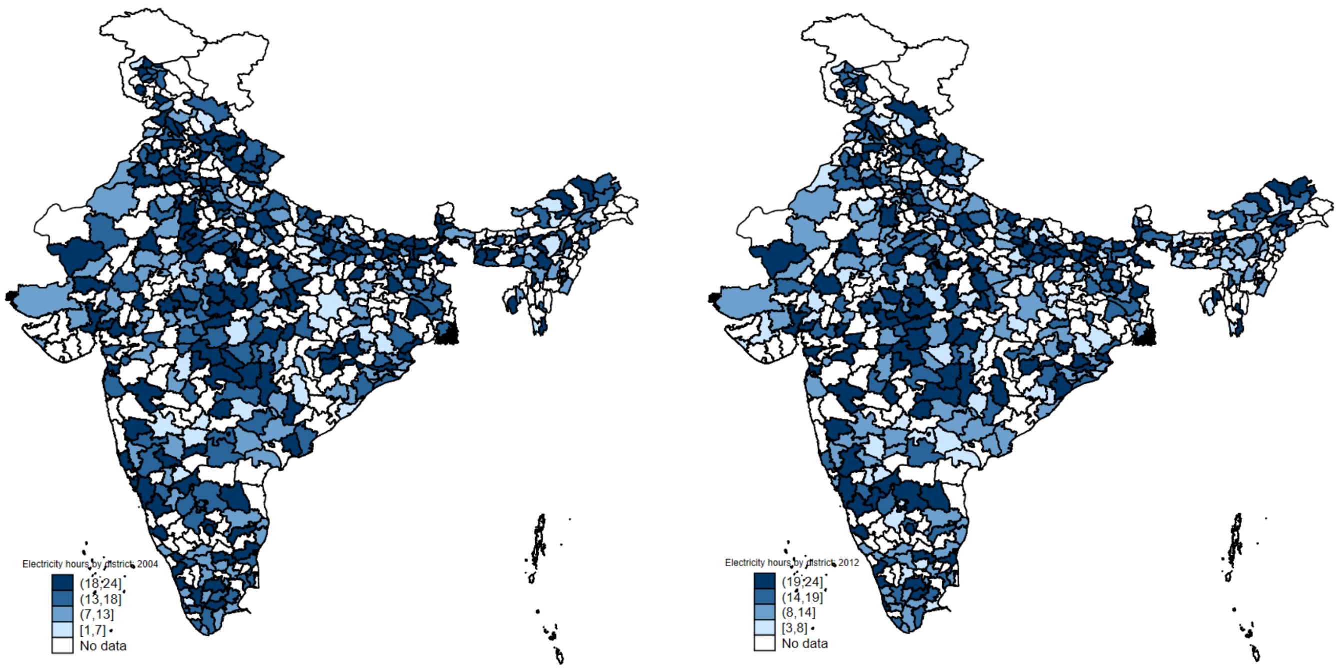
	(1)	(2)	(3)	(4)
VARIABLES	Paid employment of women (0/1)	Years of education of women	Exposure to mass media (TV) (0/1)	Harassment perception
10 hours electricity	0.02***	0.06	0.01*	-0.05***
	(0.01)	(0.05)	(0.01)	(0.01)
Number of observations	19990	29407	19478	19826
Switchers	9643	14164	9337	9573
Sharpened two-stage q values	0.004	0.079	0.038	0.001

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Standard errors clustered at household level. Additional controls included. Source: Authors' calculation.

Table 12: Channels of impact

VARIABLES	(1) Freedom of movement	(2) Value of opinion	(3) Contraceptive use	(4) Treatment received	(5) Mean age of marriage	(6) Knowing husband
Panel (a)						
Paid employment (0/1)	0.113***	0.015	0.075***	0.012**	0.000	0.005
	(0.027)	(0.024)	(0.010)	(0.006)	(0.025)	(0.010)
Average electricity hours at PSU	0.034***	0.009***	0.005***	0.003***	0.011**	0.006***
	(0.004)	(0.003)	(0.001)	(0.001)	(0.005)	(0.001)
Observations	34,106	39,939	37,706	60,610	40,996	40,917
Number of individuals	19,902	20,885	20,705	31,011	21,036	21,037
Panel (b)						
Years of education	-0.003	-0.005	-0.000	-0.001	0.010*	0.005**
	(0.006)	(0.005)	(0.002)	(0.001)	(0.005)	(0.002)
Average electricity hours at PSU	0.034***	0.009***	0.005***	0.003***	0.011**	0.006***
	(0.004)	(0.003)	(0.001)	(0.001)	(0.005)	(0.001)
Observations	34,033	39,845	37,622	60,418	40,901	40,823
Number of individuals	19,887	20,881	20,698	31,011	21,036	21,037
Panel (c)						
Exposure to mass media (0/1)	0.039	0.140***	0.011	0.013**	-0.026	0.013
	(0.029)	(0.026)	(0.010)	(0.006)	(0.026)	(0.010)
Average electricity hours at PSU	0.033***	0.008***	0.005***	0.003***	0.012**	0.005***
	(0.004)	(0.003)	(0.001)	(0.001)	(0.005)	(0.001)
Observations	33,638	39,411	37,249	59,826	40,456	40,380
Number of individuals	19,825	20,836	20,635	30,971	21,005	21,007
Panel (d)						
Harassment perception (0/1)	-0.127***	-0.063**	0.008	-0.004	-0.034	-0.034***
	(0.032)	(0.025)	(0.010)	(0.006)	(0.032)	(0.011)
Average electricity hours at PSU	0.034***	0.009***	0.005***	0.003***	0.011**	0.005***
	(0.004)	(0.003)	(0.001)	(0.001)	(0.005)	(0.001)
Observations	33,964	39,775	37,552	60,343	40,827	40,748
Number of individuals	19,873	20,878	20,683	31,005	21,031	21,032

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Standard errors clustered at PSU level. Source: Authors' calculation.

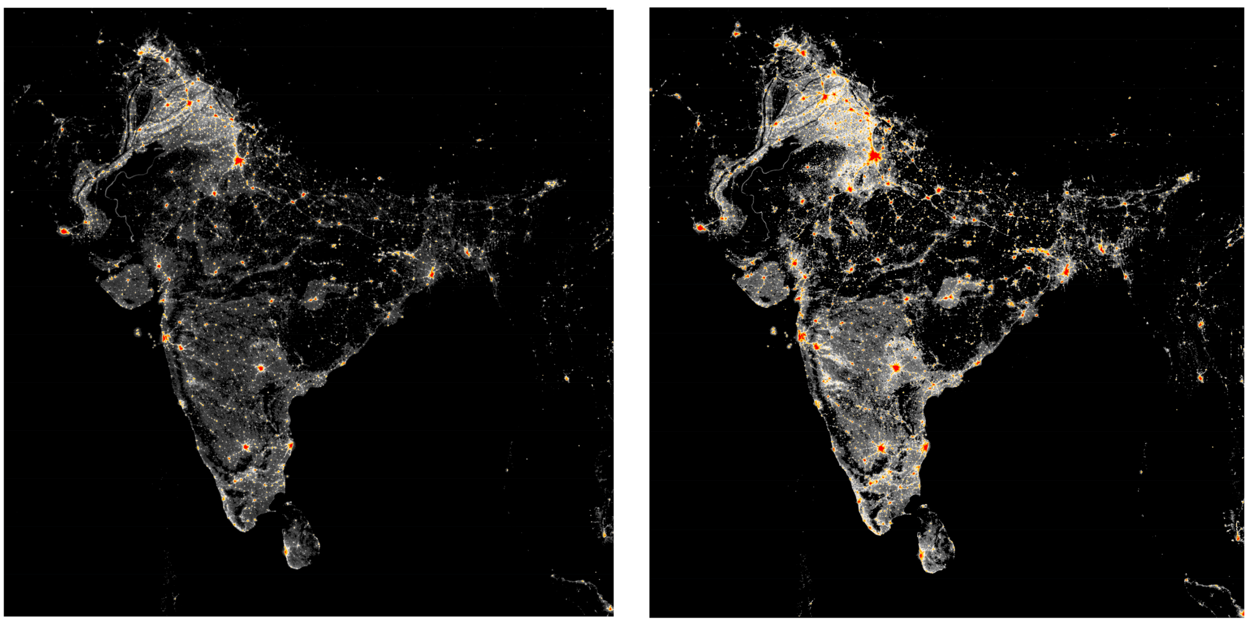


Panel A

Panel B

Figure 1: District level average electricity hours in India

Note: Panel A: 2004 (from IHDS 1), Panel B: 2012 (from IHDS 2). Source: Authors' calculation.



Panel A: 2004

Panel B: 2012

Figure 2: District level average electricity hours in India

Note: Panel A: 2004, Panel B: 2012. Source: Authors' calculation using Google Earth Engine from DMSP-OLS data.

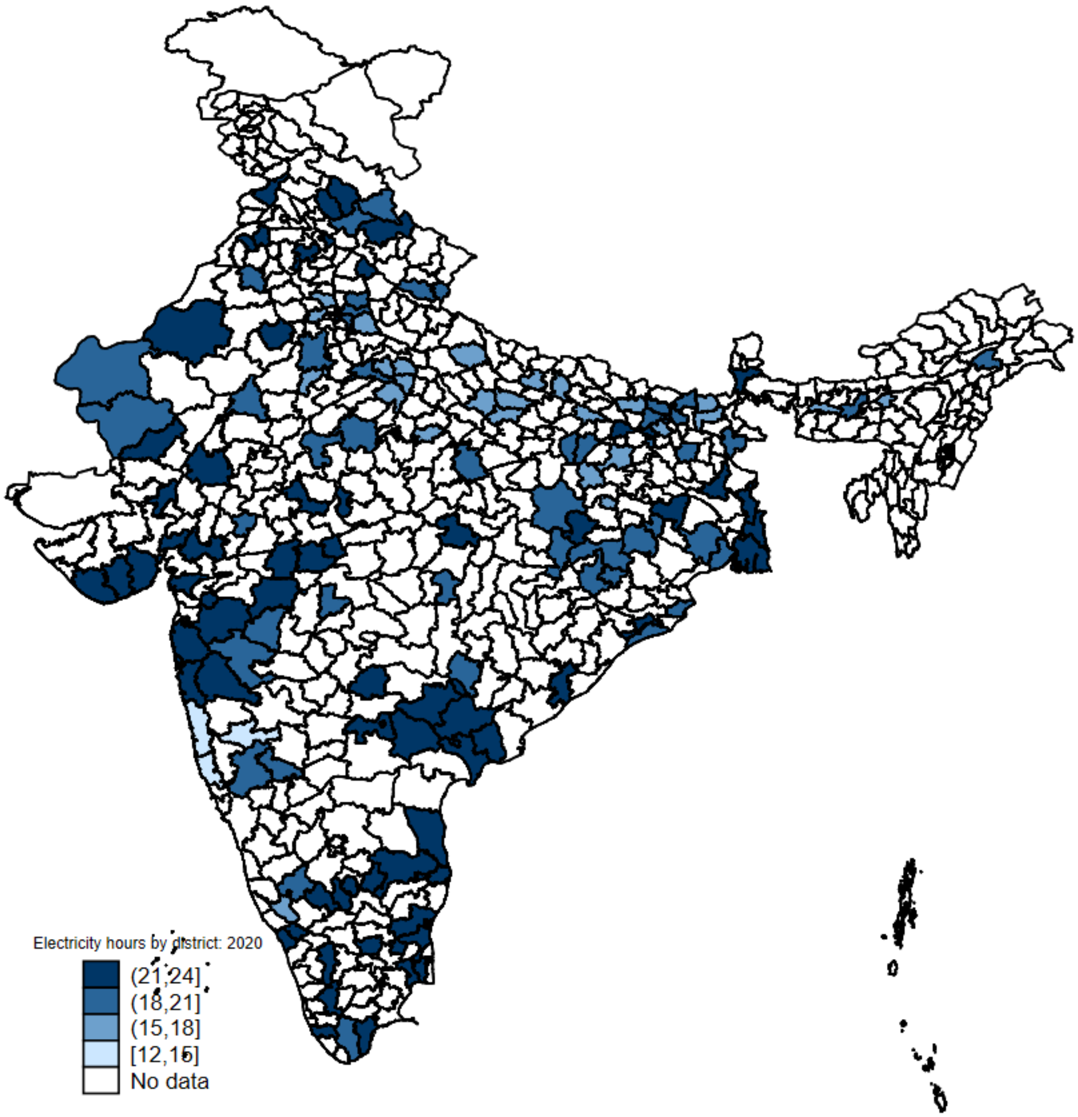
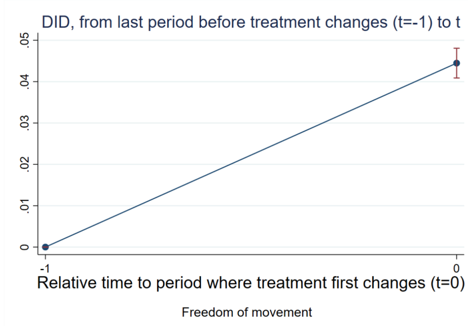
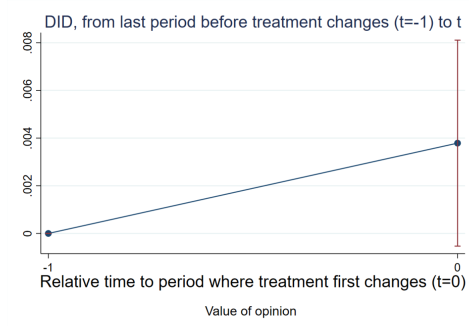


Figure 3: District level average electricity hours in India

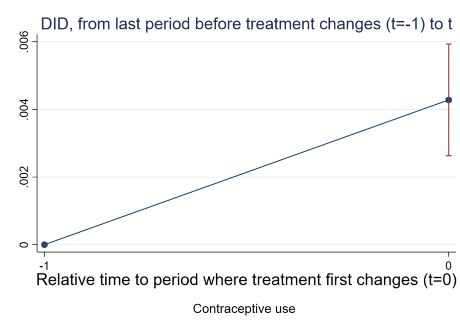
Source: Authors' calculation using IRES, 2020.



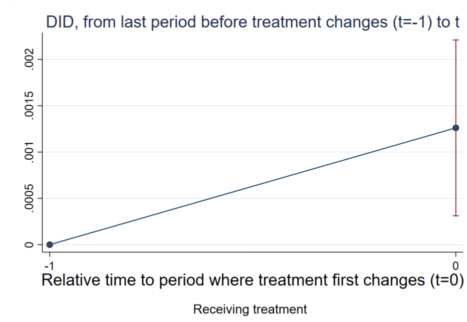
(a)



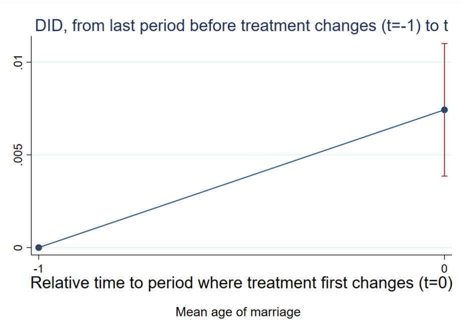
(b)



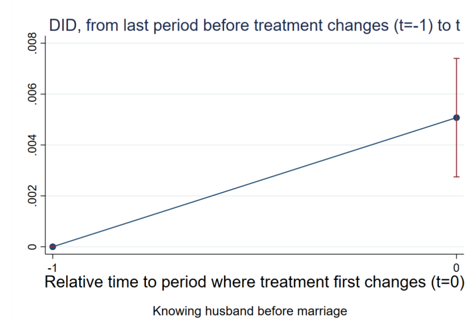
(c)



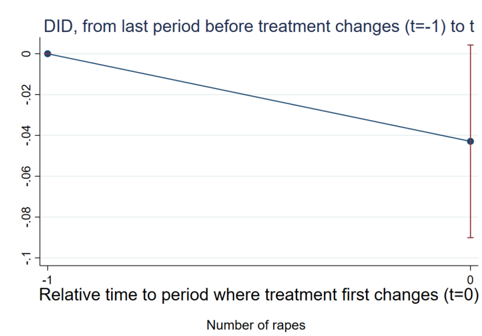
(d)



(e)



(f)



(g)

Figure 4: DID-M graphs

Online Appendix

Table A1: Falsification tests for TWFE, piecewise analysis and IV

	Birth Month Dummy			Marriage Month Dummy			Joint family dummy		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
	FE	FE	FE-IV	FE	FE	FE-IV	FE	FE	FE-IV
Baseline: first tercile (0-11 hours) electricity									
Second tercile		0.013 (0.024)			0.001 (0.010)			0.000 (0.008)	
Third tercile		0.020 (0.024)			-0.003 (0.012)			0.004 (0.009)	
10 electricity hours	0.01 (0.02)		0.03 (0.02)	0.00 (0.01)		0.01 (0.01)	0.00 (0.01)		0.00 (0.01)
Observations	14033	14033	13877	27,127	27,127	26,797	56,077	56,077	55,356
Number of individuals	10084	10084	9980	17,605	17,605	17,382	30,196	30,196	29,834

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Standard errors clustered at PSU level. Additional controls included.