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Solar home systems for rural India: Survey evidence on awareness and willingness to pay from Uttar Pradesh ☆

Johannes Urpelainen *, Semee Yoon

Columbia University, USA

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ABSTRACT

While solar home systems hold considerable promise for improving access to electricity in developing countries in tropical regions, scholars and practitioners argue that the lack of awareness, interest, and ability to pay for the technology undermines the growth of the market. We describe and explain patterns of awareness and interest in solar home systems (SHS) in a survey of 760 respondents in rural Uttar Pradesh, India. We conducted the surveys in collaboration with a local solar enterprise, Boond, and chose villages that are prime locations for the installation of solar home systems. We found that high household income and education levels, as well as young age, predict awareness of SHS products. In addition to wealthy and educated households, willingness to pay is higher in households that have electricity. The findings can help policymakers identify and target households with low levels of awareness and solar entrepreneurs identify suitable customers for their products.

Introduction

More than a billion people in the world remain without access to even basic household electricity (IEA, 2013), and energy access has become an important topic for both academics and practitioners (Cook, 2011; Javadi et al., 2013). The year 2012 was declared as the year of Sustainable Energy for All by the United Nations and the years 2014–2024 the decade for the same. New technologies, such as solar power, play an increasingly prominent role in rural electrification efforts. Indeed, thanks to the rapid decrease in the cost of solar panels, the possibility of electrifying rural communities in a decentralized fashion with solar home systems (SHS) has become a promising alternative to conventional rural electrification through grid extension (Wamukonya, 2007; Chaurey and Kandpal, 2010; Kamalapur and Udaykumar, 2011). Both government programs and private companies can install SHS in rural communities previously without access to electricity grid or limited electricity supply.

In technology adoption, informational barriers play a critical role (Foster and Rosenzweig, 1995; Bandiera and Rasul, 2006; Mainali and Silveira, 2011). In the case of solar power, one impediment to the development of a healthy SHS market is the lack of awareness among rural populations (Rebane and Barham, 2011). Indeed, the survey data we have collected shows that segments of the rural population in the Indian state of Uttar Pradesh remain unaware of SHS. According to Wong (2012), solar projects in India and Bangladesh have failed in the past because the local population has not participated in them. Since SHS are a relatively new technology and remain relatively rare in most developing countries, including India, many rural households are not aware of this option. Even if they know about SHS, they may not know where to purchase solar products or whom to ask for adequate maintenance services (Friebe et al., 2013). The demand for SHS may not be sufficient to encourage supply by private entrepreneurs. Low awareness reduces demand for SHS, and the low demand discourages entrepreneurs from entering the market.

This article offers a new contribution to the study of SHS markets by investigating patterns of awareness, access, and public perceptions of SHS in the Unnao district of Uttar Pradesh, located in the northern part of India. To describe and identify variation in awareness and access to solar products, we conducted a survey in January–February 2014 in the 76 largest villages of the central subdistrict around the district capital, Unnao. This area is of great interest for understanding SHS because it has low levels of electrification and, even where electricity is available, households typically have access for only 4–8 hours a day. Unnao is also close to the capital of Uttar Pradesh, Lucknow, making it a potentially attractive market for solar technology entrepreneurs. We fielded a 20-minute survey with detailed questions on household characteristics, awareness and access to SHS, willingness to pay, and policy preferences.

Overall awareness levels are relatively high, as 64% of the respondents report knowing what a SHS is. Moreover, after we explain the

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* Corresponding author at: 420 West 118th Street, 712 International Affairs Building, New York, NY 10027, USA. Tel.: +1 734 757 0161.

E-mail address: ju2178@columbia.edu (J. Urpelainen).

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concept of SHS to the respondents, 89% say that they have seen such a system before. Wealthy and highly educated households with young household heads are more aware of SHS than their counterparts. Of particular importance is the strong association between education and awareness. In their study on SHS awareness, for example, Rebane and Barham (2011) did not consider the role of education. Our study identifies education as an important factor in predicting willingness to pay for an SHS, highlighting the added value of our study. Our results on age and income, on the other hand, are fully consistent with those reported by Rebane and Barham (2011).

Regarding willingness to pay, education, household income, and kerosene expenditures have positive effects, exactly as one would expect based on earlier studies (McEachern and Hanson, 2008; Rebane and Barham, 2011; Lay et al., 2013). Perhaps most interestingly, we find that electrified households are, even controlling for the aforementioned factors, more willing to pay for SHS. This could reflect their earlier decisions to purchase electric appliances that are difficult to use on grid electricity due to the low quality of the supply in Uttar Pradesh. While perhaps surprising, the finding is consistent with the fact that early adopters of solar panels in Tanzania tend to have grid electricity (Smith and Urpelainen, 2014). One possible explanation is that grid electricity in the state of Uttar Pradesh provides only intermittent and unreliable supply, with high transmission and distribution losses and frequent load shedding Urpelainen (2014). Future research could further scrutinize this hypothesis using data that yield more variation in the quality of household electricity supply.

These findings have notable implications for the academic study of SHS and distributed energy generation more generally. Our findings complement a growing body of literature on solar technology adoption (McEachern and Hanson, 2008; Rebane and Barham, 2011; Lay et al., 2013). Most interesting is the fact that, while grid electricity does not enhance awareness of SHS products, it does increase willingness to pay. The strong effect of education is notable as well. For policymakers, the findings are also significant. There is still a great scope for improving awareness through education and information campaigns, and progress in rural electrification seems to contribute to, as opposed to subtract from, the development of a robust SHS market in rural Uttar Pradesh — at least as long as the quality of the power supply remains a problem.

Solar home systems for rural electrification: challenges and opportunities

A SHS consists of a solar panel and the ancillary equipment – typically batteries, charge controllers, wiring, and electric appliances – needed to generate electricity for household uses, such as lighting and mobile charging. The SHS charges a battery during the day, and households typically use the electricity at night. System size may vary from 10 to 500 W, depending on the household's willingness and ability to pay. Even a 40-watt system is enough to significantly improve the quality of household lighting, while also offering a convenient solution to the problem of mobile phone charging. As Chaurey and Kandpal (2010) note, the SHS is a preferred alternative to a village microgrid in small habitations, sparsely populated areas, and geographies that prevent wiring. More generally, Harish and Raghavan (2011) argue that countries such as India should put more emphasis on decentralized energy generation and direct their national policies toward improving affordability, finances, and product standardization.

Even though the SHS does not replace grid electricity, there is reason to believe that they have notable benefits for rural households. Although economists have yet to conduct randomized controlled trials of the benefits of SHS to rural households, several observational studies find suggestive evidence for positive benefits (Samad et al., 2013). According to these studies, SHS can increase children's study time, reduce kerosene consumption, and provide health benefits. Observational studies of rural electrification from sub-Saharan Africa and South Asia report broadly similar findings (Dinkelman, 2011; Khandker et al., 2013). In India, Van de Walle et al. (2013) report long-term benefits from rural electrification through improved earnings and female education. However, it is important to remember that electrification is but one aspect of the broader energy access problem. As Bhattacharyya (2012) notes, electrification is not an adequate solution to the pervasive problem of sustainable cooking and heating energy in developing countries.

The world market for SHS has grown rapidly in the past years. While the total number of SHS in the world is difficult to estimate, they are now available in virtually every country, though there is significant variation between different areas within any given country. In Bangladesh, there are now more than two million SHS in rural areas, largely thanks to a collaboration between the World Bank, the national government, and the local non-government organizations (Samad et al., 2013: 3). In the country, the nonprofit company Grameen Shakti has promoted energy access through off-grid solutions since 1996 with excellent results and useful implications for common lessons to other energy development aid projects (Sovacool and Drupady, 2011). Kenya is another example of a robust and vibrant SHS market, and the neighboring country of Tanzania is also catching up with increasing mature markets (Ondraczek, 2013).

In India, where we fielded our survey, the SHS market has also begun to grow. According to the 2011 Census of India (Government of India, 2011), there are now more than one million households in India that use solar power as their main source of lighting. With an average household size of almost five, this means that about five million people in India rely on solar for their lighting needs. According to the literature, the potential for expansion is also large (Kamalapur and Udaykumar, 2011). The solar market has grown fast in the past years and the government has made off-grid electrification a core component of the National Solar Mission. Kapoor et al. (2014) review the solar policy of India, noting that the interest in solar markets is growing as both the central government and various state governments are increasingly investing in solar energy, both on-grid and off-grid.

Despite encouraging growth, many obstacles remain to further the growth of solar markets. One key problem is finance (Palit and Chaurey, 2011; Wong, 2012; Friebe et al., 2013; Palit, 2013; Kapoor et al., 2014). Rural households rarely have the disposable income to purchase the systems as an alternative source of electricity. Instead, they have to rely on leasing arrangements or bank loans. This means that the reach and effectiveness of the local banking system can be a serious impediment to SHS market growth. Unless banks are able to develop financial instruments that allow them to profit from small loans to rural households in difficult conditions, the lack of disposable income may prevent otherwise willing households from adopting SHS. According to Palit and Chaurey (2011: 266), the development of an "innovative micro-lending model" is essential for improving the sales of SHS in India, due to the problem of end user finance. In a more recent article, Palit (2013) also emphasizes process standardization, infrastructure development, and local technical capacity as keys to successful SHS projects for governments, business, and communities.

Our emphasis here is on behavioral issues, such as the lack of awareness and access to products among potential customers. In a survey in Nicaragua conducted by Rebane and Barham (2011), only half of the respondents, who did not possess SHS, considered themselves familiar with the technology, and only 37% lived in a neighborhood where some SHS had been already installed. Lay et al. (2013) also found that in Kenya, education levels are an important predictor of SHS use among potential customers. According to Mainali and Silveira (2011), awareness about the benefits of SHS and related products has increased significantly in Nepal with greater demand in rural areas, but finance remains an issue. Wong (2012) notes that low levels of customer participation in solar projects and programs have been an impediment to success in both India and Bangladesh. Kapoor et al. (2014) agree, noting that low levels of participation and a lack of awareness and interest among rural populations present challenges. In what follows, we provide further evidence on these issues from a survey that specifically focuses on the SHS market and interviews a large number of possible customers.

Research design and descriptive statistics

The survey was conducted in the central subdistrict, or *tehsil*, of the Unnao district in the state of Uttar Pradesh, India. We selected the 76 largest villages from the 2011 Census of India in the subdistrict based on the criterion that the number of households (477) should be above the median in the area. Such villages are prime targets for SHS marketing. The availability of electricity is sufficiently poor to create demand for SHS markets, yet these villages are large enough that providing them with solar products can, under the appropriate policy framework, be a lucrative business. In each village, we went to the center and chose a random sample of ten households among those visible. This random sampling procedure is ideal, because SHS are typically marketed in central locations with high population densities.

The survey was conducted in the local language, Hindi, by experienced enumerators from the survey company MORSEL India. The survey team was trained by one of the authors and a local project manager for two days, with training both in the office and in the local pilot villages. One of the authors also supervised some of the first village visits by the enumerator team. Every village visit was supervised by a project manager who did not himself conduct any interviews. The data were cleaned and processed in the MORSEL India head office in Lucknow and then sent to the authors for analysis. There were very few missing values and the quality of the data was excellent. The survey lasted only about 20 minutes and we interviewed adult household heads, most of which were male (94%). The survey began with an introduction by the enumerator and the request of consent for the interview. The survey began with a module on basic personal and socio-economic characteristics, such as household income, education, religion, and caste group. The survey also contained modules on lighting and electricity, solar products, views about politics, views about solar technology, and social relations in the village. Throughout the survey, the respondents were encouraged to ask questions and request clarification as necessary. For questions about solar technologies, an image of a SHS was shown.

The Unnao area is appropriate for this kind of surveys. It is a relatively poor area of India with large swaths of unelectrified terrain. According to the 2011 Census of India (Government of India, 2011), only 59% of the 1689 villages in the district had any kind of electricity access. This low electrification rate, combined with the chronic supply problems prevalent in Uttar Pradesh, underscores the need for solar power as an alternative. This is exactly the kind of rural area of India where social enterprises focusing on solar power can have a real impact on livelihoods. The district is also large, with a population of more than 2.7 million.

In addition to reporting descriptive statistics, we conduct both linear and logistic regression analyses, depending on the outcome variable under consideration. Let i index households. For binary dependent variables Y_i, such as awareness of solar power, we estimate logistic regressions of the following type:

$$\text{Logit}(Y_i) = \alpha + \beta\mathbf{X} + \epsilon_i, \tag{1}$$

where β is a vector of coefficients and $\mathbf{X}$ is a vector of explanatory variables. The models also contain village random or fixed effects, depending on the specification. Households are clustered under villages, but we omit the multilevel notation to avoid clutter. For linear dependent variables Z_i, such as willingness to pay, we estimate linear regressions:

$$Z_i = \alpha + \beta\mathbf{X} + \epsilon_i. \tag{2}$$

In many specifications, we also logarithmize the dependent variable to meet the normality assumption required for ordinary least squares. Again, village random or fixed effects are included as necessary. We conduct the regression analysis with and without outlier observations to ensure the robustness of our results.

Dependent variables

The first set of dependent variables that we consider pertains to the respondent's awareness of solar power. First, we asked if the respondent knew what a “solar home system” is. We then showed him or her a picture of a system and explained how it works. After this introduction, we posed two additional questions:

- Has the respondent seen SHS before?
- Does the respondent know someone with SHS?

For descriptive analysis, we also inquired about whether the respondent knows where the nearest “energy center” for purchasing SHS is, whether the respondent believes the system requires little maintenance, and whether the respondent believes the technology provided would fix the system quickly upon request.

The next set of dependent variables captures the respondent's willingness to pay and estimation of the market price of SHS. The respondent was requested to give his or her estimate of the market price for the SHS and also tell how much he or she would pay for it. The specific question wording for willingness to pay, which is our key dependent variable, was as follows:

> “How much would you be willing to pay for a 40-watt SHS that provides enough power to charge a mobile phone and run 3–4 lights?”

Note that this methodology provides the details of a specific technology so that the respondent's answer captures a realistic decision about a specific purchase of a 40-watt system.

From these variables, we also constructed a “payment gap” variable, recorded as the difference between estimated price and willingness to pay. Positive values indicate that the respondent is not willing to pay the full market price for the product. Finally, we also requested that the respondent considers the possibility of leasing the SHS on a monthly basis. Again, we requested the respondent to tell us how many rupees per month he or she would pay for the system.

Explanatory variables for regression analysis

To understand the relationship between household characteristics and the outcome variables of this study, the following set of explanatory variables is used.

Household electrification

The respondent was asked whether he or she has a grid electricity connection. Among a population that does not have access to grid electrification, households that are using off-grid electricity are more likely to be curious about a potential new supply of electricity. This reasoning follows results found in Bangladesh, where the ownership of rechargeable batteries, the most common source of electricity, had a significant impact on the adoption of SHS (Komatsu et al., 2011). Conversely, Smith and Urpelainen (2014) report that in 2007, households with grid electricity were more likely to own solar panels than their unelectrified counterparts.

Monthly kerosene spending in rupees

In the case of rural households in India, kerosene is mostly used for lighting and, to a much lesser extent, cooking and/or water heating (Rao, 2012). According to the 2011 Census from the Indian government, about 350 million people in rural areas use kerosene as their primary source of lighting. Expenditure on kerosene reveals how much each household invests to secure lighting. Moreover, the direction of the relationship between kerosene spending and willingness to pay for SHS can shed light on whether or not solar energy is a substitute or complement to kerosene use. For farmers in Bangladesh and Sri Lanka, SHS was a substitute for kerosene (Komatsu et al., 2011; Wijayatunga and Attalage, 2005).

Monthly household expenditures in rupees

The decision to adopt SHS will require allocating a greater proportion of household expenditure on energy use. Thus households with higher monthly expenditure will be more likely to adopt, as in the case of farmers in Nicaragua (Rebane and Barham, 2011) and in Sri Lanka (McEachern and Hanson, 2008).

Education level

The literature on technology adoption suggests that the education level of the respondent has a positive impact on whether one adopts the newly presented technology. However, recent studies on SHS adoption have not considered the education level of the household (Komatsu et al., 2011; Rebane and Barham, 2011), except for the Lay et al. (2013) study from Kenya, which finds a weak positive effect of higher education. We include an education variable with values ranging from 1 (no formal education) to 6 (graduate degree) in the regression analysis and report the exact distribution of education levels in the summary statistics.

Female household head

Research on intrahousehold allocation of resources in India reveals that there is a gender bias. Since women spend more time indoors, with a lot of need for lighting, but often do not have control over household budget allocation, female household heads should be more likely to adopt SHS than male household heads. Therefore, we include an indicator for a female household head.

Household size

The demand for lighting will generally be greater for bigger households. If kerosene lamps are the source of lights, more lamps and fuel are needed to provide lighting for each household member. The benefit of solar lighting is that additional lamps do not have to be purchased and less kerosene is consumed (Komatsu et al., 2011). Thus, we include the number of household members as a covariate.

Birth year

The decision to invest in a new technology will depend on how receptive the household head is. Whether or not age makes a difference in technology adoption remains unclear, as different studies report different results. In the case of clean energy stoves, older household heads were more likely to adopt the electric cook stove in Bangladesh (Gebreegziabher et al., 2010). For household heads in Ethiopia, the older respondents were more risk averse and thus less likely to invest in new technologies (Yesuf and Bluffstone, 2009).

Caste

Although the caste system is officially abolished, previous research indicates that forward caste households are more likely to adopt electricity and switch to cleaner fuel than backward caste households (Gundimeda and Köhlin, 2008). We will see if the same relationship holds among households in our sample. We include indicators for scheduled caste, schedule tribe, and other backward caste status, with forward caste as the omitted baseline category.

Table 1
Summary statistics for household characteristics. For values in rupees (kerosene spending, monthly expenditure), the exchange rate to USD is 62.555.

	Mean	SD	Min	Max	Count
Electricity	0.44	0.50	0	1	760
Monthly kerosene spending	99.5	68.4	0	500	760
Monthly household expenditure	5882.8	4138.2	1000	40,000	760
Female	0.063	0.24	0	1	760
Household size	6.53	3.04	1	25	760
Birth year	1970.1	14.0	1934	1996	760
Forward caste	0.43	0.50	0	1	760
Scheduled caste	0.15	0.36	0	1	760
Scheduled tribe	0.021	0.14	0	1	760
Other backward caste	0.39	0.49	0	1	760
No formal education	0.16	0.37	0	1	760
Primary school	0.19	0.39	0	1	760
Secondary school	0.26	0.44	0	1	760
High school	0.15	0.36	0	1	760
Intermediate	0.11	0.31	0	1	760
Graduate	0.13	0.34	0	1	760

The descriptive statistics for the household variables used in the study are shown in Table 1. Only 44% of the sample had electricity at home, and the mean monthly kerosene expenditures were about a hundred rupees (~USD 1.60).[1] The average household size was large, with approximately 6.5 people within each household. The respondent's age ranged from 18 to 80 years, and almost all household heads were male. The description of the dependent variables will be given below in greater detail.

Results

We begin with a description of the overall awareness and interest in solar home systems in the study area. We then conduct the regression analysis.

Description of awareness and interest

Table 2 summarizes awareness of solar home systems in the study villages. About 64% of the respondents know what a solar home system is. Once we explain to the respondent what the concept means, about 89% of the respondents report having seen a solar home system. This means that every fourth respondent had seen a SHS without knowing what it is. About three quarters of the respondents know at least one person who owns a SHS, but a much lower percentage of respondents (37%) know where the nearest energy center is.

After realizing that they have seen a SHS, 85% of the respondents believed, correctly, that they qualify for a solar subsidy from the government. A relatively small proportion of households think that a SHS is low maintenance, underscoring the difficulty of maintenance reported in Friebe et al. (2013). There are more components in a SHS compared to a kerosene lamp or a solar lantern. Thus, an educational program to explain how each part works will be needed to improve upon this misconception. Unlike the opinion on maintenance concerns, about 76% of respondents think that SHS would be quickly fixed by the technology provider, suggesting that the local population trusts solar entrepreneurs.

In Table 3, we provide summary statistics for willingness to pay for a SHS. We asked respondents to provide a price estimate for the solar home system shown during the survey session. The average estimate of the price was about 7526 rupees (~USD 120), while the real price of the system in the picture was about 13,000 rupees (~USD 208). Compared to the estimate, the willingness to pay for SHS was much lower. Of course, it is possible that systems of lower quality are available at the

[1] Exchange rate on January 30, 2014 was 62.555.

Table 2
Descriptive statistics for awareness of solar home systems (upper) and perceptions of the product (lower). The number gives the proportion of people who responded "yes" and there were no missing observations.

	Mean	SD
Knows SHS	0.64	0.48
Has seen SHS	0.89	0.31
Knows a person with SHS	0.75	0.43
Knows the nearest energy center	0.37	0.48
Qualify for SHS subsidy	0.85	0.35
SHS is low maintenance	0.35	0.48
SHS would be quickly fixed	0.76	0.42

lower price, which may explain the gap. The difference is represented as the payment gap, which is on average 3288 rupees (~USD 53). In addition to the price estimate and willingness to pay, respondents reported how much they are willing to pay to lease a SHS per month. Annually, households would be willing to pay about 1828 rupees (~USD 29) to use a SHS. This is well below the market price of any such system, even if the 30% capital subsidy that the government offers is considered. A loan arrangement for payments in installations would not help either, as high inflation would rapidly increase the total payment flow over time.

In Fig. 1, we show the histogram of the willingness to pay for a SHS among the respondents. Most of the households are willing to provide less than 10,000 rupees and very few are willing to pay for price greater than 10,000 rupees. Since the market price of a high-quality 40-watt SHS is about 13,000 rupees, there is a gap between the market price of SHS and the willingness to pay by households for solar energy as the source of lighting.

Fig. 2 shows the histogram of the payment gap. A large proportion of the respondents have reported estimates for the price of SHS and willingness to pay for a SHS, so that the difference between the two is smaller than 5000 rupees. In general, the majority of households report price estimate to be greater than the willingness to pay, which suggests that they see the value of using a SHS. However, there are circumstances at play that drive this payment gap.

Regression analysis

We now present results from the regression analysis. Table 4 presents odds ratios (exponentiated coefficients) of the logistic regressions on awareness and interest. Ratios above one mean a positive effect, while ratios below one indicate a negative effect. We present both random and conditional fixed effect models by village. To begin with, consider self-reported knowledge of what a SHS is. Household expenditures, education levels, and young age are strong predictors of awareness. For example, the probability of having awareness about a SHS increased by 10% for every 1000 rupees in additional monthly expenditure. The effect of each additional level of education is 50–52%, while the effect of one less year of age is only 2%. The results are remarkably consistent across the random and fixed effect regressions.

The effects are similar, though less consistent, for having seen a SHS and knowing someone with a SHS after we show a picture and explain what a SHS is. The most consistent and strong predictor is education. Each additional level increases the probability of having seen a SHS by 69% and the probability of knowing someone who has a SHS by 50–53%. Overall, these results emphasize the importance of education for awareness, consistent with earlier results and arguments (Rebane and Barham, 2011).

In Table 5, we present linear regressions on willingness to pay. Except for the first model, all models contain village fixed effects. Although the R^2 statistic initially seems low, it is important to remember that it captures within-village variation only and is typical of econometric models saturated with many fixed effects. Access to grid electricity and having a high income to spend per month both have a positive impact on the willingness to pay for a SHS at the 1% significance level across specifications. The effect is consistently at about 1100 rupees (~USD 16). This effect is not large enough to make an otherwise uninterested household to purchase, but it can shape the purchasing decision at the margin. Theoretically, it is interesting that households that already have electricity are more interested in a SHS, even controlling for wealth and kerosene expenditures. This result suggests that previous experience with electric appliances generates demand for a reliable source of backup power. It is consistent with the case of Tanzania, where early adopters of solar panels tend to have access to grid electricity, as reported in Smith and Urpelainen (2014). The variable for knowing what a SHS, which we only include in the last model since it may be endogenous, is strongly statistically significant, but including it in the specification does not change the substantive conclusions for other models. While most of the independent variables are not statistically

Table 3
Descriptive statistics for variables on willingness to pay (rupees). The exchange rate to USD is 62.555.

	Mean	SD	Min	Max	Count
Estimate of SHS price	7525.5	5305.0	500	50,000	717
Willingness to pay for SHS	4209.3	3268.1	0	32,000	728
Payment gap	3287.7	3838.9	−4000	37,500	702
Highest willingness to lease SHS	152.3	169.5	0	2000	706

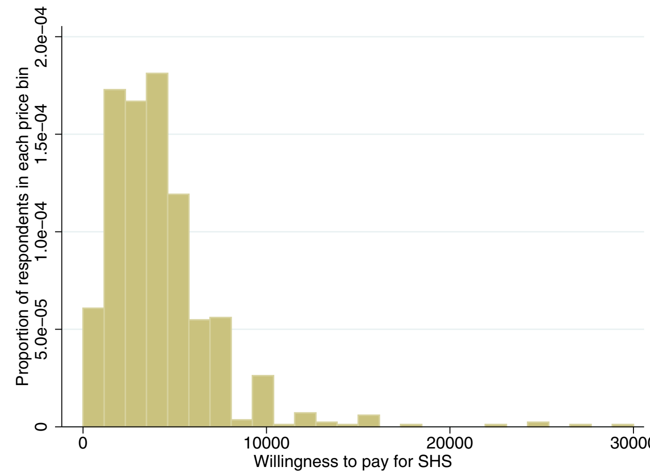

Fig. 1. Histogram of the willingness to pay (rupees). Outlier observations with values higher than 30,000 (~USD 480) rupees are excluded.

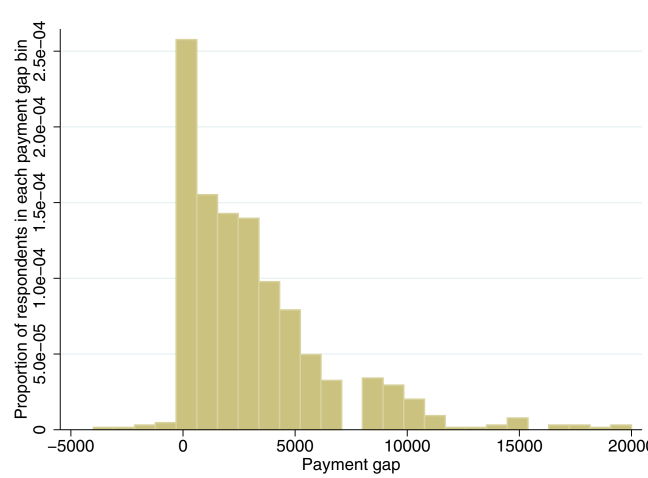

Fig. 2. Histogram of the payment gap (rupees). Outlier observations with values higher than 20,000 (~USD 320) rupees are excluded.

Table 4
Odds ratios of logistic regressions of various awareness indicators (knows SHS, has seen SHS, knows someone with SHS) on household characteristics. Positive coefficients indicate higher awareness. Fixed and random effects are at the village level. For these regressions, the values of monthly household expenditure and kerosene spending are reported in thousands of rupees to make the coefficients legible.

	(1)	(2)
	RE	FE
Knows SHS		
Electricity	1.06	1.19
	(0.24)	(0.28)
Monthly kerosene spending (1000)	11.97	5.86
	(19.45)	(9.55)
Monthly household expenditures (1000)	1.10***	1.10***
	(0.04)	(0.04)
School completed	1.52***	1.50***
	(0.11)	(0.11)
Female	0.51*	0.52
	(0.20)	(0.22)
Household size	0.99	1.00
	(0.04)	(0.04)
Birth year	1.02**	1.02**
	(0.01)	(0.01)
Observations	760	650
Has seen SHS		
Electricity	1.01	1.32
	(0.34)	(0.47)
Monthly kerosene spending (1000)	1.83	0.41
	(4.43)	(1.02)
Monthly household expenditures (1000)	1.06	1.05
	(0.06)	(0.06)
School completed	1.69***	1.69***
	(0.20)	(0.21)
Female	0.45	0.29**
	(0.23)	(0.17)
Household size	1.01	1.05
	(0.06)	(0.06)
Birth year	1.02**	1.02**
	(0.01)	(0.01)
Observations	760	380
Knows a person with SHS		
Electricity	0.86	1.09
	(0.23)	(0.30)
Monthly kerosene spending (1000)	9.05	4.80
	(17.62)	(9.43)
Monthly household expenditures (1000)	1.02	1.01
	(0.04)	(0.04)
School completed	1.53***	1.50***
	(0.13)	(0.13)
Female	0.78	0.64
	(0.37)	(0.33)
Household size	1.00	1.01
	(0.04)	(0.05)
Birth year	1.00	1.01
	(0.01)	(0.01)
Observations	760	490

Exponentiated coefficients; standard errors in parentheses.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

significant, it is again important to remember that the village fixed effects already subsume most of the relevant variation.

Spending on kerosene and the willingness to pay have negative relationship among non-outlying households that report a willingness to pay less than 30,000 rupees. The effect itself is not particularly large, as increasing kerosene expenditures by one rupee decreases willingness to pay by less than six rupees. Households that do not spend much on kerosene may consider a SHS as a potential energy source to fulfill their lighting needs. Conversely, households that spend more on kerosene may have less interest in the solar alternative.

As with awareness, both income and education are relevant. Every thousand rupees earned per month increases willingness to pay by 120–210 rupees, suggesting a relatively modest effect, given that the average household in the sample earns less than 6000 rupees per month. Every level of additional education increases willingness to pay between 440 and 570 rupees. While this effect is also modest, together these different factors could again be important at the margin. Female respondents report lower willingness to pay across all models, but the effect is not significant. Household size, age, and caste do not have explanatory power for willingness to pay.

Finally, Table 6 focuses on the effect of household characteristics on the payment gap. The explanatory factors are largely the same as with willingness to pay. The substantive effects are smaller and less consistent than those for willingness to pay, however, which makes sense since the market price estimate and willingness to pay are positively correlated. In line with previous findings from the literature, reliance on kerosene does not drive the households' non-adoption of a SHS. Households are willing to pay for a SHS as source of energy, especially if they have experienced using off-grid electricity. However, they are unable to make the transition because they have high expectations about the price of a SHS. The small R^2 statistics again reflect the inclusion of village fixed effects, which subsume most of the relevant variation.

Regression analysis of split samples

Since we have a relatively large sample of households, we can also verify the robustness of the results by considering various subgroups of people. Table 7 reports the results from various subsamples. In Models 1–2, we distinguish between electrified and unelectrified households. In Models 3–4, we distinguish between households that have less or more than secondary school education. Models 5–6 distinguish between households below and above the median expenditure in the sample. Models 7–8 do the same for households below and above the median kerosene expenditure in the sample.

The main results are robust across the subgroups, validating our basic approach. Household expenditure is a robust predictor of willingness to pay across all models and the coefficient does not vary much. Education is always positively associated in the models that do not group households by education, and the coefficient is mostly consistent, though slightly lower among poor households. Electricity has a positive and statistically significant effect among households with at least a secondary education and among households with an income above the median in the sample. The coefficient is also positive and significant, though at a lower level, for households regardless of their kerosene expenditure. Overall, the results indicate that the effects of key variables are not conditional on household characteristics, with the partial exception of electrification. It seems as though having a grid connection has a larger and more consistent effect on willingness to pay for a SHS among wealthier and more educated households.

Conclusion

This article has analyzed awareness and interest in SHS in rural Uttar Pradesh. We surveyed a large number of villagers in the Unnao district, fielding a detailed survey on the public's knowledge and views of SHS products. We focused on relatively large villages, where solar companies could potentially market and sell their products without incurring prohibitive transaction costs.

We found awareness of SHS to be relatively high in general, and after the concept was explained to the respondents in particular. In addition to high education levels, we found household expenditures and young age to predict awareness. However, most of the households are willing to provide less than 10,000 rupees. Considering that the real market price of a 40-watt SHS is about 13,000 rupees, there is clearly a gap between the market price of SHS and the perceived price of SHS. Consequently, the difference between the market price and the willingness

Table 5
Linear regression of willingness to pay on household characteristics. Positive coefficients indicate a lower willingness to pay relative to the estimated market price. Models 3–5 exclude outlier observations with a willingness to pay higher than INR 30,000 (~USD 480). Random and fixed effects are set at the village level.

	(1)	(2)	(3)	(4)	(5)
	RE	FE	FE	FE	FE
Electricity	1113.56***	1085.24**	1172.95***	1178.41***	1128.63***
	(415.56)	(454.36)	(389.72)	(392.88)	(390.51)
Monthly kerosene spending	−0.31	−0.93	−5.71**	−5.87**	−6.24**
	(2.77)	(2.87)	(2.49)	(2.50)	(2.49)
Monthly household expenditure	0.21***	0.16***	0.12***	0.12***	0.11**
	(0.05)	(0.05)	(0.04)	(0.04)	(0.04)
School completed	570.81***	571.56***	445.24***	438.36***	374.44***
	(124.87)	(128.83)	(110.60)	(114.70)	(115.75)
Female	−913.21	−1021.01	−903.79	−903.78	−739.57
	(767.67)	(789.80)	(675.64)	(678.24)	(675.66)
Household size	−55.40	−27.09	19.18	19.65	21.35
	(66.96)	(68.71)	(59.05)	(59.23)	(58.82)
Birth year	10.14	8.39	10.79	10.96	6.95
	(13.34)	(13.74)	(11.77)	(11.84)	(11.82)
Scheduled caste				−225.28	−249.89
				(533.89)	(530.29)
Scheduled tribe				−931.19	−719.93
				(1587.19)	(1577.79)
Other backward caste				174.97	269.43
				(413.45)	(411.74)
Knows SHS					1202.27***
					(386.51)
Constant	−15,644.97	−11,987.32	−16,086.02	−16,408.25	−8983.56
	(26,277.04)	(27,063.56)	(23,183.44)	(23,278.68)	(23,242.18)
Observations	717	717	713	713	713
R^2		0.09	0.09	0.09	0.11

Standard errors in parentheses.
Models 3, 4 and 5 for price estimate <30,000.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Table 6
Linear regression of the difference between estimated SHS price and willingness to pay on household characteristics. Positive coefficients indicate a lower willingness to pay relative to the estimated market price. Models 3–5 exclude outlier observations with a payment gap higher than INR 20,000 (~USD 320). Random and fixed effects are set at the village level.

	(1)	(2)	(3)	(4)	(5)
	RE	FE	FE	FE	FE
Electricity	594.74*	249.03	476.07	503.83*	494.36*
	(318.48)	(360.67)	(293.17)	(295.65)	(295.85)
Monthly kerosene spending	1.20	0.76	0.30	0.34	0.23
	(2.17)	(2.29)	(1.89)	(1.90)	(1.91)
Monthly household expenditure	0.06	0.04	−0.01	−0.01	−0.01
	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)
School completed	197.07**	229.15**	107.15	118.46	103.62
	(97.38)	(102.32)	(83.34)	(86.32)	(87.77)
Female	−996.71*	−782.61	−744.11	−763.48	−724.94
	(595.26)	(623.07)	(505.08)	(507.29)	(509.00)
Household size	−22.20	−5.17	−6.50	−7.02	−6.19
	(52.54)	(54.75)	(44.76)	(44.92)	(44.93)
Birth year	5.54	0.12	6.38	6.14	5.19
	(10.48)	(10.99)	(8.95)	(9.00)	(9.06)
Scheduled caste				226.25	219.01
				(402.21)	(402.33)
Scheduled tribe				−609.22	−576.10
				(1389.93)	(1390.51)
Other backward caste				182.11	200.40
				(311.14)	(311.78)
Knows SHS					275.97
					(294.35)
Constant	−8803.50	1979.51	−9899.97	−9573.02	−7813.17
	(20,653.42)	(21,655.74)	(17,629.83)	(17,707.31)	(17,808.27)
Observations	702	702	696	696	696
R^2		0.02	0.02	0.02	0.02

Standard errors in parentheses.
Models 3, 4 and 5 for price estimate <20,000.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Table 7
Linear regression of the willingness to pay on household characteristics. Fixed effects are set at the village level. Models 1–2 are for electrified and unelectrified households, respectively. Models 3–4 are for households without and with secondary school education, respectively. Models 5–6 are for households below and above the median monthly expenditure, respectively. Models 7–8 are for households below and above the median monthly kerosene expenditure, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	No elec	Elec	Low educ	High educ	Poor	Rich	High kero	Low kero
Monthly kerosene spending	0.00	−3.56	−0.54	−1.86	−4.26	1.31		
	(2.90)	(2.42)	(2.85)	(2.37)	(2.81)	(2.44)		
Monthly household expenditure	0.11**	0.09*	0.13***	0.13***			0.11**	0.13***
	(0.05)	(0.05)	(0.04)	(0.05)			(0.04)	(0.05)
School completed	382.10***	338.78***			245.68*	449.71***	390.72***	388.21***
	(131.13)	(105.90)			(126.27)	(113.06)	(115.70)	(115.80)
Female	886.27	−985.15*	−73.24	−245.57	70.39	−145.15	−268.52	626.62
	(997.19)	(546.62)	(527.33)	(876.50)	(549.35)	(880.06)	(625.62)	(796.30)
Household size	−39.10	16.25	85.14	−57.52	103.30	−21.19	2.55	−29.92
	(66.06)	(60.95)	(63.95)	(60.35)	(74.35)	(54.61)	(68.83)	(57.88)
Birth year	3.20	3.26	6.20	16.01	10.59	10.87	8.55	−2.57
	(14.20)	(11.46)	(11.78)	(12.23)	(12.44)	(12.19)	(12.33)	(12.77)
Electricity			294.02	1134.84***	184.92	1291.15***	796.24*	699.71*
			(396.23)	(386.93)	(387.66)	(410.96)	(414.03)	(402.22)
Constant	−3491.93	−3776.72	−10,108.21	−27,710.72	−18,412.98	−18,906.93	−14,886.93	7074.85
	(27,953.22)	(22,554.38)	(23,190.96)	(24,184.58)	(24,468.74)	(24,016.21)	(24,255.16)	(25,183.81)
Observations	315	413	247	481	296	432	362	366
R^2	0.07	0.07	0.10	0.05	0.05	0.10	0.12	0.11

Standard errors in parentheses.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

to pay by households for solar energy as source of lighting is even greater than what we measure in the baseline. As to the predictors of willingness to pay, we found that grid electricity, high income, kerosene expenditures, and high levels of education increase this willingness. These findings are broadly in line with the existing literature, except that the result on household electrification is new.

Our survey methodology can be easily used to evaluate SHS awareness and willingness to pay in other contexts. Our survey is simple to execute and largely independent of the specific context, and yet it seems to produce interesting and plausible results on the determinants of awareness and willingness to pay. An important next step would be to conduct an experimental study of actual, as opposed to stated, willingness to pay for solar products. For example, the Becker–DeGroot–Marschak method based on second-price auctions could be used to elicit true willingness to pay and construct a demand curve (Becker et al., 1964). This has been done for cookstoves in Uganda by Levine et al. (2012).

From a policy perspective, our results suggest that there is plenty of scope for improving awareness. Another interesting finding is the positive effect of rural electrification on willingness to pay, probably because the quality of power supply in rural Uttar Pradesh is so weak. This finding indicates that, while the central and state governments in India continue to invest in rural electrification through programs such as the Rajiv Gandhi Rural Electrification Scheme, they should also capitalize on the opportunity to create robust solar markets, as there seem to be complementarities between solar and grid electricity. Another important question is whether or not smaller SHS would be of interest to many villagers. While they cannot power the same electric appliances as the 40-watt system under consideration in this study, their price would be lower.

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