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Abstract

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Keywords: Clean energy, indoor air pollution, randomized control trials, solar light
JEL classification: I15, O13, Q42

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We implemented a 16-month randomized field experiment in unelectrified areas of Bangladesh to identify health impacts of solar lanterns among school-aged children. Our analysis of various health-related indicators—self-reporting, spirometers, and professional medical checkups—showed modest improvements in eye redness and irritation but no noticeable improvement in respiratory symptoms among treated students. Varying the number of solar products received within treatment households did not alter these results. This limited health benefit was not caused by nonutilization of the products by treated children, spillover effects from treated to control students, or treatment heterogeneity resulting from unfavorable family cooking environments.

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Indoor air pollution (IAP) is responsible for about 4.3 million deaths annually, and considered a leading environmental cause of deaths in the developing world (WHO 2014; Hanna et al. 2016). IAP is mainly caused by use of kerosene and biomass fuels (e.g., wood, crop residues, cow dung), which emit considerable amounts of fine particulates, particulate matters (PM), carbon monoxide (CO), nitric oxides (NOx), and sulfur dioxide (SO2).

Children in poor households are among the most susceptible groups to unfavorable health impacts of IAP for biological, environmental, and behavioral reasons (e.g., WHO 2005; Nandasena, Wickramasinghe and Sathiakumar 2013). For example, children require higher ventilation rates to absorb the required amount of oxygen compared to adults, because of their smaller alveoli (i.e., a hollow cavity found in the lung parenchyma). This leads them to breathe air pollutants deeply into their underdeveloped lungs (e.g., Bateson and Schwartz 2008; Saadeh and Klaunig 2014). In addition, children in developing countries—especially girls—often help their parents with cooking, thus spending long hours inside houses not equipped with chimneys or smoke hoods, highly exposing them to toxic IAP (e.g., Lam et al. 2012). The relevant smoke inhalation is often associated with a range of serious health problems, including respiratory/pulmonary diseases (e.g., asthma, bronchitis, chronic obstructive pulmonary disease (COPD), lung cancer, pneumonia, and wheezing) and some other symptoms (e.g., burn, eye strain, and cardiovascular disease) (e.g., Schwartz 2004). As a result, respiratory illnesses are listed as a major cause of child mortality and morbidity in developing countries (Pandey et al. 1989; Liu et al. 2015).

Despite the significance of child health in the process of economic development (e.g., Currie 2009), economic studies on IAP and child health have lagged behind the epidemiological and medical literature (e.g., Smith-Sivertsen et al. 2004;

Díaz et al. 2007; Smith-Sivertsen et al. 2009). A handful of economic studies have emerged recently, most involving randomized control trials (RCTs). Examples of these efforts to date include investigations on the impact of improved cooking stoves, focusing on children as part of the targeted population (e.g., Duflo, Greenstone and Hanna 2008; Burwen and Levine 2012; Beltramo and Levine 2013; Bensch and Peters 2015; Silwal and McKay 2015; Hanna, Duflo and Greenstone 2016). In contrast, very few empirical studies have examined the adverse health impacts of fuel-based lighting, which is another traditional source of IAP in developing countries (Apple et al. 2010). To the best of our knowledge, the only exception is a small-scale pilot project implemented by Furukawa (2012), who studied the health impacts of solar lanterns for 155 upper primary school students in Uganda.

To fill this significant knowledge gap, we conducted an RCT in the river islands located in northern Bangladesh (locally known as *Chars*), an area where most residents use kerosene-based equipment as a lighting source, to evaluate the impacts of solar lanterns on children's respiratory function and a range of other health indicators. More precisely, we provided solar lanterns to a randomly selected 882 students belonging to the fourth to eighth grades in primary and secondary schools for 16 months (September 2013 to December 2014). We implemented a within-grade randomization at each school, and separated the sample students into three groups, i.e., those who received a bundle of a main high-capacity solar device along with two smaller lanterns, those who received only one main high-capacity solar device, and the remaining control students that received no devices. The ratio of these students was approximately 5:4:9 and no students that were offered solar products refused to take the offer in our experiment.

This particular study setting was purposely selected for the following reasons.

First, while our sample students may not necessarily belong to age cohorts that are the most biologically vulnerable to adverse effects of IAP, children in the fourth to eight grades rely on fuel-based traditional lighting sources (e.g., kerosene lamps) for nighttime study, which may have significant negative effects on children's health (e.g., Pinkerton and Joad 2000; Selevan, Kimmel and Mendola 2000; Schwartz 2004; Saadeh and Klaunig 2014). To successfully progress to the next grade, students in these grades need to study harder at night than elementary grade children. Consequently, their exposure to health-related risk attributed to traditional lighting devices is likely to be more serious, which may increase marginal health returns for solar products.

Second, because *Chars* are prone to cyclical river erosion and floods, the Rural Electrification Board (REB) of Bangladesh has no plans to expand national grid-based electricity to this region. Since solar products should be provided for people in such geographically challenged areas according to the present policy discourse, our study area has direct policy relevance (UNEP 2014). Moreover, as portable solar lamps were unavailable when we started this experiment, any potential contamination would be less serious in our study setting.

Third, we expect that providing multiple solar lanterns and differentiating treatment intensity would increase the likelihood of intended use of solar products by targeted students, as other family members may also want to use the solar products for their own purposes.

To assess the research outcomes, we collected a wealth of information on children's health by utilizing numerous data collection opportunities, including a standard household survey module (July-August 2013 for the baseline and July-August 2014 for the follow-up), periodic (repeated) health surveys (October 2013, January 2014, and April 2014), and doctors' health checks (i.e., health camp) (November-December

2014). Spirometers were also utilized to measure respiratory capacity. This abundance of health indicators allowed our study to analyze trends of health conditions, making the analysis highly fruitful. In addition, during the health camp, we did not disclose the treatment status of the sample students to the medical professionals. Therefore, there is no systematic error in their diagnosis that may be correlated with personal views on the effectiveness of solar lanterns.

A companion paper of this study (Kudo, Shonchoy and Takahashi, forthcoming) revealed that treated households utilized the solar products primarily for children's study. Households that received solar products reduced annual kerosene expenditure by more than 50% compared with control households. Treated students also significantly reallocated time use for home study, reducing daytime while increasing the nighttime hours. This reallocation resulted in a net increase in total hours studied at home. Most notably, treated students substituted kerosene lamps with solar lanterns almost "perfectly" in order to study at night. This behavioral change encouraged us to expect sizable health impacts from solar products on the treated children.

However, the findings yielded by the present study were not as encouraging as expected. As a set of positive results, we found treated students who received solar lanterns had significantly reduced eye problems, such as eye redness and irritation. Frequency of fire-related injuries, such as burns, was lower for students who received a bundle of three solar products. However, treated students (and their families) did not significantly improve in subjectively and objectively measured health outcomes related to respiratory and pulmonary symptoms. Our field observations and a range of robustness checks suggest that these limited impacts on respiratory systems are not attributable to nonutilization of the solar products, spillover effects resulting from the within-grade randomization, or treatment heterogeneity by use of unfavorable cooking technologies that tend to worsen IAP.

Overall, our study finds that solar lanterns have modest impacts on child health, at least in the short term. This finding is consistent with Furukawa (2012), who showed modest health improvements among treated students, especially during exam periods, compared to control students using kerosene candles. Solar lamps relax only one type of exposure risk to indoor air pollutants. Consequently, our findings may suggest that improving the home-energy environment only through provision of solar lanterns may have a limited impact on children's health unless other types of exposure risk are simultaneously addressed (Nandasena et al. 2013).

This study mainly contributes to two strands of the extant economic literature. First, given unfavorable effects of air pollution on child health (e.g., Currie and Neidell 2005), we address this issue with a focus on home environments. Second, while research on improved cook stoves has been increasing as described above, we explore the health issue of IAP by conducting a large-scale RCT relevant to fuel-based lighting sources for the first time.

The rest of the paper is organized as follows. Section I explains the study setting, sampling framework, and experimental design. Section II describes the data and summary statistics, followed by the estimation strategies in Section III. Section IV discusses the estimation results and implements robustness check. Section V provides our conclusions.

I. Survey and Experimental Design

A. The Study Area

Our study area is the river islands, locally known as *Chars*, located in northern Bangladesh, which are formed by sediments and silt depositions. These islands are extremely vulnerable to flooding and erosion, periodically during the rainy season (June to October) as monsoon precipitation coupled with excessive glacier melting of the Himalayas usually results in overflows of the major river channels of Bangladesh. Floods frequently result in loss of economic activity, possessions and earnings of *Char* dwellers, who need to escape to emergency shelters during floods.

The provision of electricity is almost nonexistent in *Char* areas. Several NGOs, such as Grameen Shakti, have tried to provide Solar Home Systems (SHS), but so far these have not been adopted widely in *Chars* for at least two reasons: first, SHS is generally quite expensive for the ultra-poor *Char* dwellers; and second, since SHS is not a mobile utility, *Char* dwellers cannot remove it during flood-induced relocations—when the demand for electricity is high—or they may lose it following land erosion. Thus, investment in SHS in *Char* remains uncommon. Some households use battery–powered torchlights to supplement their emergency use, but these lights provide insufficient illumination to undertake most productive activities at night and the cost of batteries is generally too expensive for *Char* dwellers. Hence, most *Char* residents rely heavily on kerosene-based equipment as their main source of lighting.

B. Solar Devices

To study the impact of portable solar lanterns on child health, we used d.light solar lanterns, which are certified and recognized under the World Bank Lighting Global Project (https://www.lightingglobal.org/). d.light design, a social enterprise in California, US, has recently released a series of low cost, portable solar lights that are durable, weather resistant and have the capacity to produce bright white light through LED bulbs. We introduced the following three types of solar lanterns in this study (see also Figure I):

S250 is d.light's flagship product, providing bright white light for a maximum of 4 hours and illuminating a room to the same degree as a 3 to 5-watt compact fluorescent lamp (CFL). It could provide on an average 110 lumens of light based on top brightness setting after a full day's solar charge, and has the functionality of charging cellular phones. The S250 has a separate lightweight solar panel that needs to be used to recharge the unit.

S10 is a high-quality solar light-emitting diode (LED) lamp that provides approximately 29 lumens of light for a maximum of 4 hours. This unit is handy, and can be used for studying or working as a portable flashlight, but it cannot be used to charge mobile phones. The solar panel of the S10 is embedded in the main unit.

S2 is the simplest LED, which provides a focused, approximately 25 lumens of light for a maximum of 4 hours. The illumination capacity of this unit is lower than that of the other two units. Like the S10, this unit also cannot be used for charging mobile phones. The solar panel of the S2 is also embedded in the core unit.

The product costs of S250, S10, and S2 are about 40, 13.5 and 10 USD, respectively. Most of the poor in rural Bangladesh can pay these costs under a flexible or installment-based payment system, successfully implemented by NGOs like Grameen Shakti. In total, we obtained 500 units of the d.light S250, along with additional 300 units of the S10 and the S2. The procurement of those devices was supported by a generous contribution from BRAC, one of the world's largest NGOs based in Bangladesh, and social business funds from Daiwa Securities through collaboration with Kopernik. Gana Unnayan Kendra (GUK), a northern-based NGO in Bangladesh, served as our implementation partner of this research.

C. Sampling Structure and Experimental Design

We targeted children attending primary (4th to 5th grades) and secondary (6th to 8th grades) schools as the main sample for this study. To minimize contamination effects, those who lived in regions with limited access to modern electricity were given priority. We initially listed up all primary and secondary schools located in eight *Chars* of the Gaibandha and Kurigram districts of northern Bangladesh and implemented initial quick inspections with School Management Committees (SMCs) on the accessibility of electricity in April 2013. Out of a total 28, 17 primary or secondary schools in two *Chars* were found to have limited coverage of SHS. From 1,665 total students belonging to the fourth to eighth grades in those 17 schools, we selected 1,292 students as potential candidates for this study, whose homes (including school dormitories) had not been already electrified, whose siblings were not in the 1,292 students already chosen (i.e., for each household, we included only one child in our study sample) and whose school attendance rates in the past four months were not less than 80% (so that we can trace students with higher probability). We then interviewed all 1,292 children at his or her home and identified that 911 had actually no access to modern clean electricity at the time of survey. Of those, 882 became the effective sample; the rest dropped out of school before the implementation of the detailed household survey due to marriage or forced relocation resulting from flooding and river erosion.

The baseline survey was implemented in July-August 2013 for 882 children and their households. The survey collected detailed data pertaining to household demographic characteristics, health conditions of each household member, details of energy use and its sources, and expenditures. Health outcomes were elicited on a self-reporting basis; respondents (usually a household head or her/his spouse) reported disease experiences of all household members for the three months prior to the interview.

Once we completed the baseline household survey, we organized a public lottery at each sample school for each grade separately, to randomly allocate to the eligible students access to solar lights for 16 months (September 2013-December 2014). Students and their parents drew a lottery by themselves in the presence of other parents, teachers and village elites. Based on the lottery, students were assigned to one of the following three groups: (1) Treatment A, which received all the d.light solar products, i.e., the S250, the S10, and the S2, altogether providing approximately 164 lumens of lighting capacity at top brightness settings; (2) Treatment B, which received only the S250 solar lantern, providing lighting capacity of 110 lumens at the maximum brightness setting; and (3) the control group that did not receive any solar lantern.

By differentiating the number of solar products across treatment arms, we intended to examine whether the provision of smaller lanterns had any additional impacts. For example, if other members of the treated households were willing to use the solar lanterns for their own use (for example, for nighttime social interaction), the impact of the solar lanterns on the targeted students would be reduced. Hence, bundling additional solar products may have increased the probability that target students enjoy the benefits of solar products.

The ratio of Treatment A, Treatment B, and control groups was kept at approximately 5:4:9 for each grade at each school. After the public lottery, we ended up with 248 students in Treatment A, 198 students in Treatment B, and 436 students in the control group. In our experiment, no students that were offered solar products refused the offer.

One potential threat to our experiment was failure to fully re-charge solar products, which can decrease the impact. To effectively recharge them, obstructions to sunlight (e.g., walls, trees) needed to be avoided. Furthermore, the tilt angle of the panel under sunlight was also important for adequately recharging the lanterns. To facilitate proper maintenance and the correct recharging practice, we invited a product manager from the capital city, Dhaka to the study site to train our enumerators, who in turn instructed the survey respondents and their children. Furthermore, to ensure that these instructions were readily available for sample households, we provided a detailed pictorial manual to each household. This manual contained elaborate information on the adequate use/maintenance and recharging techniques of the solar lanterns.

One year after the baseline survey, we implemented a follow-up study of the same children and their households in July-August 2014 to examine whether any welfare and behavioral changes had taken place over one year. During the follow-up phase, we could trace 852 of these households; the rest were lost due to attrition for such reasons as relocation or marriage.

II. Data

A. Health Indicators

With respect to outcomes, we first focus on respiratory symptoms and lung functioning of the target students that might be improved if solar lanterns successfully reduce their exposure to indoor air pollution. To examine this hypothesis, we use information measured in three different ways as follows.

First, we use self-reported outcome indicators, such as cough, runny nose, and phlegm for the target students, collected in the July-August 2014 follow-up household survey.

Second, we visited sample schools every three months from October 2013 to April 2014 to objectively measure lung capacities of students, such as forced expiratory volume in one second (FEV1)[1] and forced vital capacity (FVC),[2] using a spirometer.

Third, we implemented an independent "health camp" at each sample school 16 months after initial distribution of solar lanterns in November to December 2014. These health camps were held to measure the following: FEV1, FVC, lung noise, postnasal drip, breath-holding time (in seconds), and heart beats per minute after a short run. These "health camps" were administered with professional doctors and health practitioners. Importantly, as the doctors were unaware of the treatment status of the sample students, their beliefs about effectiveness of solar products were less likely to affect their diagnosis in a systematic manner.

While respiratory symptoms and lung functioning were our primary outcomes of interest, we also examined how treatment status changes the incidence of injuries and symptoms often associated with use of kerosene-based lighting devises, such as eye health, burns, skin diseases, headache and dizziness. To do this, we utilized both self-reported and health camp data. Annual medical expenditures spent on targeted children were also analyzed.

B. Summary Statistics and Balancing Test

By treatment arms, Table I and Table II present summary statistics of key household-level characteristics of the sample students at baseline. On average, a household consists of slightly less than five members, and is headed mostly by males with minimal education. Households in the study site seem to be extremely poor because their average total farm land area is about 10 decimals (about 1/10 acre), along with annual per-capita household expenditures of 16 thousand Taka (about 208 USD as

[1] This is the amount of air one can blow out within one second.
[2] The total amount of air that one can blow out in one breath.

of July, 2013).

[Table I and II about here]

By experimental design, no sample household had prior access to solar lanterns in the baseline; instead they relied heavily on kerosene-based products (Table II). Almost all households owned kerosene-based lighting devices, such as open-wick kerosene lamps and covered-wick kerosene lanterns, known as “Hurricanes.” As kerosene lanterns are more expensive than lamps, most households possess and use the latter lighting devices rather than the former. Annual expenditure on kerosene is about 1,600 BDT, accounting for approximately 10% and 2% of nonfood and total household expenditure, respectively.

Most households under study have a single-room house, where they do cooking and other activities simultaneously. Only a quarter of households have any windows in the kitchen space. In the rainy season (June to October), almost all households cook inside in an enclosed area, which may intensify smoke exposure, while in the off-rainy season (November to May), approximately 60% of households cook outside.

Table III reports summary statistics of individual characteristics of the targeted students. They were, on average, 12 years old with about 5.6 years of the highest education attained. Approximately 27% of students reported having some respiratory problems (i.e., cough, sore throat, runny nose, and phlegm) within the three months preceding the baseline survey. Headaches, a runny nose, and coughs were among the major health problems students had suffered. In contrast, very few students reported experiencing burns or skin diseases. The bottom of Table III indicates the baseline outcomes of FEV1 and FVC, measured by spirometer. The mean of FEV1/FVC×100 is less than 60%,[3] indicating that many students suffered COPD at the moderate level at the baseline.[4]

[Table III about here]

To assess whether the randomization worked well, Table I, II and III also report *p*-values on the difference in means between treated and control households/students. While a few variables reveal statistically significant differences across the treatment arms, most variables are reasonably well balanced. Hence, we ascertain that the randomization in this study was overall successful.

III. Empirical Framework

Providing solar lamps may affect children's health both directly and indirectly. Solar lanterns may reduce indoor smoke emissions if they effectively replace kerosene lamps. Solar lamps may also induce changes in students' time use. For example, as found in Kudo, Shonchoy and Takahashi (forthcoming), our treated students significantly reduced daytime study hours while increasing nighttime study. This behavioral change might have increased children's daytime activities outside their homes and thus, their exposure to outdoor air pollutants even if the risk of exposure to indoor air pollutants decreased due to the use of the solar products. Therefore, this study only identifies the total effects of these two forces on children's health.

Our experimental design enabled us to overcome a potential endogeneity problem often embedded in observational studies. We estimate an intention-to-treat (ITT) effect to identify the causal relationships between the provision of solar lanterns

[3] FEV1 divided by FVC (FEV1/FVC) shows the proportion of air that one can exhale in one second, of the total amount of air that the person can blow out in one breath.
[4] Based on the estimation of Global Lung Function (GLF)-2012, the lower limit of normal (LLN) values for males aged 10-15 is 0.73-0.81 and for females is 0.77-0.84.

and outcomes of interest. Since no household refused our offer of solar lanterns, our ITT estimates are equivalent to the average treatment effect (ATE).

Depending on the availability of the relevant baseline information, the following two reduced-form empirical models are employed. First, for health-related outcomes whose pre-experimental information is unavailable (e.g., data via medical health checkup), we estimate the following model:

$$Y_{ij,A} = \alpha_0 + \alpha_1 D1_{ij} + \alpha_2 D2_{ij} + X_{ij,B}\delta + \mu_j + \varepsilon_{ij},$$

where $Y_{ij,A}$ is postexperimental health conditions of a student i (or a household member i for some outcomes) living in a village j; D1 (D2) is an indicator for the treated households that received Treatment A (Treatment B); the vector $X_{ij,B}$ contains several baseline characteristics of the respondents, including students' age (years); their gender (dummy); their completed education (years) (which is nearly equivalent to the child's grade); household size; the number of males in a household; age of household heads (years); head's gender (dummy); head's education attainment (years); and household land size. The village- and school-grade fixed effects and a stochastic error term are represented by μ_j and ε_{ij}, respectively.

When both the pre- and post-experimental health measures of students (or household members) are available, we apply an analysis of covariance (ANCOVA) model, following McKenzie (2012), which can be written as:

$$Y_{ij,A} = \beta_0 + \beta_1 D1_{ij} + \beta_2 D2_{ij} + X_{ij,B}\delta + \gamma Y_{ij,B} + \mu_j + \varepsilon_{ij},$$

where $Y_{ij,B}$ is the pretreatment outcome variable.

The random assignment of treatment arms should make the treatment and controls groups similar across all dimensions, according to expectation. Therefore, including the baseline controls $X_{ij,B}$ in regressors and/or applying the ANCOVA model would not affect the consistency of the estimated treatment effects. However, when exploiting sub-samples that include some baseline differences across treatment arms, the inclusion of additional controls is expected to lend greater credit to internal validity of the estimates of interest. Thus, this study presents the results with baseline controls.[5]

Throughout the study, we exploit ordinary least squares (OLS) estimations. Standard errors are adjusted for clustering in grades within the same school (39 groups) for outcomes of the target students, while plausibly avoiding a statistical inference problem arising from exploiting few clusters (Cameron and Miller 2015). For the sake of brevity, coefficients on several controls are suppressed when reporting the estimation results.[6]

The number of observations differs equation by equation due to the different timing of data collection. Some students temporarily failed to attend school because of sickness or assistance with housework, while others left school due to relocation, marriage, and so on. This sample attrition may be problematic for our analysis if it is correlated with treatment status. Thus, we investigate whether this attrition issue reduces the internal validity of our estimates in Section IV. D, which addresses a range of robustness checks.

IV. Estimation Results

A. Respiratory Systems

Table IV presents the estimation relevant to the targeted students, separately for self-reported outcomes, collected in July-August 2014 (Panel A), objective lung capacity measures, repeatedly collected every three months following the baseline

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5 It should be noted, however, that exclusion of these controls had a negligible effect on the implications obtained from the regression analysis.

6 Full estimation results are available upon request.

survey (Panel B), and doctors' evaluation in December, 2014 (Panel C). For Panel A and B, we have pretreatment outcome variables to control for, whereas for Panel C, we do not.

The results in Table IV show that, overall, solar products do not significantly improve students' recent respiratory symptoms. Indeed, as seen from Panel A, we find no average treatment effect on self-reported cough, sore throat, runny nose, or phlegm one year after the intervention.

[Table IV about here]

Similarly, we do not find any improvement in objectively measured lung functioning, such as FEV1 and FVC, for most observation periods.[7] However, FVC among students that received all solar devices (Treatment A) moderately improved in January 2014, although this positive effect did not persist, and the statistical significance disappeared in April 2014. This finding is plausible because students tend to intensively study at night in November to December to pass the annual examination held in December (Kudo, Shonchoy and Takahashi, forthcoming), which makes them highly exposed to IAP just before January if they do not have solar lamps. This temporary health improvement detected in January is also in line with Furukawa's (2012) finding that solar lanterns improved child health in Uganda during (or just after) the exam periods. However, as discussed in Section IV. D, this FVC improvement in January might also have resulted from a possible selection problem attributed to sample attrition.

Finally, similar to the influence on self-reported respiratory problems, Panel C illustrates that professional medical practitioners also did not detect any significant improvements in a wide range of respiratory systems among treated students, including

[7] While not shown in Table, FEV1/FVC did not improve statistically significantly in all observation periods.

FEV1, FVC, lung noise, postnasal drip, the time of length (seconds) students can hold their breath, and heart beats per minute after a short run.

B. Other Symptoms Related to Fuel-Based Lighting Use

Turning to other health hazards relevant to the targeted children, Panel A of Table V shows null impact of solar lanterns on self-reported symptoms, such as headache and skin diseases, as well as annual medical expenditure. On the contrary, Panel B reveals that the incidence of burns detected by doctors is negative and statistically significant for treated students who obtained all three solar devices (Column (e)). Moreover, regardless of receiving all three devices or only main device, a statistically significant improvement is observed for eye-related problems, such as red eyes and eye irritation (Columns (f) and (g)), which were reduced by approximately 14% and 10-14% points, respectively.[8] This reduction is not negligible, as the proportion of controlled students that suffered from these symptoms was about 26% and 22%, respectively.

[Table V about here]

Overall, our results suggest that providing solar lanterns have negligible impacts on respiratory symptoms and lung functioning, but have moderate positive impacts on other kerosene-related problems, such as eye redness and burns. Similar implications are obtained in regressions pooling the two treatment arms into one (see Appendix A for details).

C. Heterogeneity: Age, Gender and Cooking Environments

[8] F-test on the equality of the coefficient fails to reject the null hypothesis that the coefficients on the treatment A and B are statistically equivalent in Columns (f) and (g) in Panel B.

One of the potential reasons for the overall insignificant impacts on most health indicators is that health benefits of solar lanterns are observed only for a subset of our sample. We presume that there are three main sources of treatment heterogeneity that deserves attention.

First, the negligible effects in our regressions might be because students' respiratory capacities were too weak to recover immediately, due to their long-term exposure to IAP in early childhood. If this is true, we may observe impact heterogeneity across age, where older students are less likely to benefit from our interventions. To check this formally, we ran additional regressions with treatment status interacted with age. The results in Appendix B show that treatment effects, such as improved FVC in October 2013 and reduced eye problems in December 2014, decrease with age, providing supporting evidence on the above hypothesis. However, given that most coefficients remain statistically insignificant, age heterogeneity may not be a major reason for the overall absence of improvements in respiratory functions and other symptoms among treated students.

Second, treatment effects may differ by gender of the students. For example, since females are mostly responsible for cooking in the study area, girls may be more exposed than boys to air pollutants caused by unfavorable indoor cooking technologies. In such a case, only replacing kerosene lamps/lanterns (for nighttime study) with solar products might not have been sufficiently effective to improve girls' health conditions such as respiratory function. However, this conjecture is not supported in Appendix C, which investigates gender-differentiated impacts of solar lanterns. The table shows that the previously obtained implications remain unchanged, although we observed some evidence that suggests treated girls enjoy additional benefits in terms of reducing teary eyes.

Third, heterogeneity may also exist in terms of family cooking environments. As we argued previously, replacing kerosene lamps/lanterns with solar products might not be sufficient if PM concentrations associated with fuel-based cooking are responsible for most respiratory problems. To explore this conjecture, we construct interaction terms between treatment status and baseline cooking conditions, such as a typical place of cooking (inside or outside) in the off-rainy season, and whether a kitchen has a window. The estimated results, presented in Appendix D, show that impacts of solar lanterns do not substantially differ by cooking conditions, except for FEV1 that improved among treated households with all three products and no window in a kitchen space. In the absence of no other notable effects, we might say that treatment heterogeneity by unfavorable cooking environments may be less responsible for the overall null impacts.

D. Robustness Check

Hitherto, we have found limited effects of solar lanterns on health outcomes of the targeted students, especially for respiratory symptoms. Several potential threats to our findings are discussed here from the perspectives of (1) student usage of solar products, (2) sample attrition, (3) spillover effects, and (4) multiple-hypothesis testing.

First, it is possible that treated students did not use solar lanterns properly or regularly. However, as briefly summarized in the Introduction, the treated households indeed utilized the solar products, primarily for children's study (Kudo, Shonchoy and Takahashi, forthcoming). Nevertheless, to further address this concern, the present study also examined whether health outcomes of household members excluding the targeted students were significantly different between the treated and control groups. Significant health improvement of those members belonging to treated households may suggest that they primarily utilized solar lamps, rather than the targeted students. We used the self-reported data from the follow-up survey in July-August 2014. The standard errors were clustered at the village level (42 groups) here, as not all family members currently attend school and this treatment allows for arbitrary correlations across households within a village. Baseline controls included only household level variables. Results in Table VI provide no evidence suggesting that other family members prevented treated students from using solar lamps. On respiratory-related and other symptoms in Panel A, we find no significant difference between treated and control households for most outcome variables. Gender-differenced effects in Panel B and C also show that the obtained implications are almost similar to the previous ones, although we see some reductions in runny nose among males as well as dizziness and skin disease among females.

[Table VI about here]

Second, sample attrition occurred: while we could trace most households in the follow-up survey (i.e., 96% of the 882 original sample students), the number of observations dropped sharply when the health camp was conducted. Our statistical inference may not be valid if attrition changes the composition of treatment and control students in a systematically different manner. Lee (2009) demonstrated that in RCT settings, if the sample attrition rates are similar between the treatment and control groups, a simple comparison between these groups can still be interpreted as a valid average treatment effect on the sub-population that would always be observed regardless of the treatment assignment. Accordingly, we examined whether the rate of sample attrition differed by treatment status for each timing of the data collection. We estimate a linear probability model with baseline controls, where the dependent variable takes one if an individual is observed at the time of survey. The results in Appendix E indicate that except for January 2014 (i.e., FEV1 and FVC data collection), there is no differential attrition across the treatment and control groups. This indicates that attrition can be a source of bias for weekly positive impacts on FVC found in January 2014 (Column (h) in Table IV), whereas it does not affect our statistical inference in most other outcomes.

Third, given that our randomization is conducted within a specific grade level at each sample school, an obvious concern is spillover. For example, if treated students share their solar devices with control students for study or other purposes at night, the impacts can be attenuated. However, we do not believe that this is valid for our study, as visiting a friend's home at night in unelectrified river islands is quite risky for both boys and girls. Indeed, in the follow-up household survey, we collected information on whether treated students shared solar lamps with nonhousehold members, and identified only three such cases, where solar lamps were shared with cousins. This field observation and side evidence support that negligible impacts on health outcomes cannot be attributed to spillover effects from treated to control students. Moreover, unlike infectious illnesses such as intestinal parasites (e.g., Miguel and Kremer 2004), disease externality is not a serious concern for health outcomes of our interest.

A final robustness check is to determine whether we have mistakenly detected significant positive impacts on eye problems and burns. Since many outcome variables are analyzed, we might obtain statistically significant effects simply by chance. We apply correction methods for multiple-hypothesis-testing. To do so, first, we reduced the number of tests being performed by pooling the two treatment groups into one and reported the estimation results for the overall treatment effect (Appendix A). Second, we employed the adjusted *p*-values following Theorem 3.1 of List, Shaikh and Xu (2016), along with a well-known Bonferroni procedure and Holm (1979)'s stepdown adjustment procedure. Since the latter two procedures do not account for a dependency structure across tests when controlling a familywise error rate, they tend to reveal low statistical power. Nevertheless, we still observe significant solar impacts in relation to eye problems in Appendix F reporting the adjusted p-values. Overall, the previous findings still hold in this consideration of multiple-hypothesis testing.

In summary, we find modest improvements in child health caused by the introduction of solar lanterns. While it was hypothesized that substitution of solar lanterns for kerosene-based lighting mitigates respiratory symptoms by decreasing exposure to indoor air pollution, there was virtually no such effect for target students or their family members. Robust positive health effects we observe are limited to the reduction of eye problems, such as eye redness and irritation, among treated students.

V. Conclusions

It has been recognized that the widespread use of biomass and kerosene fuels for the source of lighting in developing countries have adverse impacts on pulmonary health, especially among children. Governments, policy makers and international donors have started to pay attention to finding effective ways to mitigate such adverse impacts. One approach towards such a goal is the provision of solar lanterns, which are clean, renewable, and relatively less expensive products, even for the poor, who rely heavily on traditional biomass based lighting sources.

To evaluate the impact of solar lanterns on child health, we conducted a randomized field experiment in river islands of northern Bangladesh, where off-grid electricity is not available, and both susceptibility to climate risks and underdevelopment of transport infrastructure make its development difficult in the near future. 882 students are selected as a sample for this study, who attended the primary and secondary schools and who had no access to modern electricity during the baseline survey. After random allocation of three solar products, only one product, and no products to a subset of sample students, we traced all students for 16 months from September 2013 to December 2014 and collected detailed information on health indicators.

We obtained two major findings from this study. First, provision of solar lanterns resulted in, on average, no detectable improvement in a wide range of respiratory symptoms or lung capacity. Second, however, solar lanterns significantly decreased the presence of eye problems among treated students. The negligible impact we found on respiratory conditions is not entirely attributed to nonutilization of the solar products or treatment heterogeneity resulting from use of traditional cooking technologies. Through robustness checks, we also showed that spillover effects benefitting control households, intensive usage of solar products by other family members, and sample attrition do not explain our main results.

Our findings suggest that health effects, especially those on respiratory symptoms, are unlikely to immediately improve through simply substituting solar lanterns for kerosene-based lighting. Although there is a growing enthusiasm for the promotion of solar portable lights as a useful alternative to off-grid electricity and solar home systems in unelectrified areas (World Bank 2010), we may caution that impacts of solar lanterns on child health could be smaller than expected.

Nonetheless, we admit that our experiment is contingent on and specific to the area and the period of study. Moreover, the ways of obtaining a new technology (e.g., either through leasing, free distribution, or purchasing from the market) could also affect use and socio-economic impacts. Thus, our results may not necessarily be generalizable. However, note that our experiment was conducted in a setting where marginal returns to solar lanterns are likely to be large because of limited availability of other modern electricity and behavioral characteristics of the target students. Considering this point, it might be difficult to expect sizable health impacts in more modestly disadvantaged settings unless complementary health investments using savings from the reduced kerosene expenditures are made. Similarly, complementary interventions addressing other possible environmental and behavioral factors relevant to child health (e.g., cook stoves) may also be required. Since our data do not allow us to investigate this pathway further, we cannot rule out the possibility that solar lanterns can have positive effects on child health in long terms. Further research and longer-term evidence are clearly needed before asserting more concrete conclusions.

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Figure I: d.light Products

<S250> <S10> <S2>

Table I. Baseline Summary Statistics of Sample Students (Household-level), 2013

	Total	All three products	Only one product	Control	*p* -value	
	(1)	(2)	(3)	(4)	(2)-(4)	(3)-(4)
Household size	4.908	4.948	4.788	4.940	0.946	0.153
	(1.284)	(1.380)	(1.106)	(1.301)		
Head's age	41.793	41.847	41.990	41.672	0.802	0.658
	(8.604)	(9.200)	(8.104)	(8.491)		
Head's education	1.266	1.185	1.197	1.344	0.484	0.554
	(2.833)	(2.666)	(2.792)	(2.945)		
Head is male	0.916	0.915	0.929	0.911	0.832	0.430
	(0.277)	(0.279)	(0.257)	(0.286)		
Total land (decimal)	10.112	10.323	10.475	9.828	0.820	0.729
	(25.996)	(34.581)	(21.025)	(22.120)		
Total expenditure per capita (000BDT)	16.181	16.529	16.386	15.890	0.149	0.288
	(5.647)	(6.131)	(5.934)	(5.209)		
Sample size	882	248	198	436		

Note: Figures in parentheses are standard deviations. *** denotes significance at 1%, ** at 5%, and * at 10%.

Table II. Use of Electricity and Household Expenditure, Baseline 2013

	Total	All three products	Only one product	Control	*p* -value	
	(1)	(2)	(3)	(4)	(2)-(4)	(3)-(4)
No. of light sources						
# Flashlight	0.113	0.089	0.111	0.128	0.142	0.556
	(0.335)	(0.312)	(0.315)	(0.355)		
# Kerosene lanterns	0.244	0.242	0.253	0.241	0.976	0.768
	(0.465)	(0.474)	(0.490)	(0.449)		
# Kerosene lamps	1.671	1.726	1.662	1.644	0.087*	0.725
	(0.586)	(0.628)	(0.544)	(0.579)		
Per-day hours using light sources						
Off-rainy season						
Flashlight	0.414	0.329	0.414	0.462	0.182	0.661
	(1.249)	(1.175)	(1.221)	(1.302)		
Kerosene lanterns	0.786	0.855	0.828	0.727	0.306	0.450
	(1.610)	(1.730)	(1.748)	(1.469)		
Kerosene lamps	5.391	5.481	5.587	5.252	0.234	0.105
	(2.417)	(2.435)	(2.427)	(2.399)		
Rainy season						
Flashlight	0.295	0.226	0.313	0.327	0.149	0.862
	(0.886)	(0.792)	(0.906)	(0.926)		
Kerosene lanterns	4.131	4.198	4.236	4.045	0.287	0.212
	(1.787)	(1.815)	(1.761)	(1.783)		
Kerosene lamps	0.629	0.692	0.669	0.576	0.248	0.378
	(1.290)	(1.420)	(1.391)	(1.159)		
Cooking environsment						
Any window in a kitchen	0.226	0.206	0.192	0.252	0.167	0.096*
	(0.418)	(0.405)	(0.395)	(0.435)		
Kichen is indoor (rainy season)	0.974	0.988	0.980	0.963	0.060*	0.272
	(0.159)	(0.110)	(0.141)	(0.188)		
Kichen is indoor (off-rainy season)	0.410	0.415	0.369	0.427	0.774	0.170
	(0.492)	(0.494)	(0.484)	(0.495)		
Household expenditure (000 BDT)						
Kerosene	1.621	1.544	1.553	1.695	0.184	0.264
	(1.307)	(0.700)	(0.735)	(1.710)		
Other energy	0.022	0.014	0.023	0.026	0.143	0.719
	(0.101)	(0.060)	(0.084)	(0.124)		
Medical fee	2.173	2.119	2.206	2.188	0.644	0.916
	(1.879)	(1.652)	(1.888)	(1.996)		
Total nonfood expenditure	17.345	17.425	17.046	17.436	0.981	0.374
	(5.250)	(5.608)	(4.358)	(5.413)		
Total food expenditure	59.841	62.010	59.820	58.617	0.083*	0.582
	(26.061)	(27.463)	(30.649)	(22.754)		
Total expenditure	77.186	79.435	76.866	76.053	0.114	0.728
	(28.092)	(30.045)	(31.985)	(24.864)		

Note: Figures in parentheses are standard deviations. *** denotes significance at 1%, ** at 5%, and * at 10%.

Table III. Baseline Characteristics of Sample Students (Individual-level), 2013

	Total	All three products	Only one product	Control	*p* -value	
	(1)	(2)	(3)	(4)	(2)-(4)	(3)-(4)
Age	12.383	12.347	12.465	12.367	0.787	0.358
	(1.523)	(1.554)	(1.611)	(1.465)		
Education	5.627	5.641	5.646	5.610	0.722	0.666
	(1.397)	(1.393)	(1.409)	(1.398)		
Male	0.438	0.411	0.429	0.456	0.287	0.401
	(0.496)	(0.493)	(0.496)	(0.499)		
Cough (=1)	0.100	0.117	0.107	0.087	0.130	0.313
	(0.300)	(0.322)	(0.309)	(0.282)		
Sore throat (=1)	0.012	0.004	0.020	0.014	0.218	0.561
	(0.111)	(0.064)	(0.141)	(0.117)		
Runny nose (=1)	0.209	0.238	0.239	0.179	0.032**	0.062*
	(0.407)	(0.427)	(0.427)	(0.384)		
Phlegm (=1)	0.034	0.028	0.025	0.041	0.361	0.304
	(0.181)	(0.166)	(0.158)	(0.199)		
Headache (=1)	0.241	0.266	0.264	0.216	0.118	0.175
	(0.428)	(0.443)	(0.442)	(0.412)		
Dizziness (=1)	0.003	0.004	0.000	0.005	0.905	0.337
	(0.058)	(0.064)	(0.000)	(0.068)		
Skin disease (=1)	0.009	0.004	0.010	0.011	0.308	0.866
	(0.095)	(0.064)	(0.101)	(0.107)		
FEV1	1.050	1.053	1.003	1.070	0.691	0.154
	(0.542)	(0.558)	(0.514)	(0.546)		
FVC	1.853	1.818	1.809	1.894	0.147	0.119
	(0.632)	(0.633)	(0.581)	(0.653)		
N	882	248	198	436		

Note: Figures in parentheses are standard deviations. *** denotes significance at 1%, ** at 5%, and * at 10%.

Table IV. Impacts on Students' Health: Respiratory Symptoms and Lung Function

Panel A (Self-report)	Jul/Aug- 14					
Outcome	Cough (=1)	Sore throat (=1)	Runny nose (=1)	Phlegm (=1)		
	(a)	(b)	(c)	(d)		
All products	0.008	0.000	-0.039	-0.005		
	(0.028)	(0.016)	(0.030)	(0.004)		
One product	-0.031	-0.009	-0.043	-0.003		
	(0.027)	(0.013)	(0.037)	(0.003)		
N	816	816	816	816		
Adjusted R-squared	0.108	0.100	0.101	0.097		
Mean y (control)	0.134	0.037	0.192	0.005		
Panel B (Repeated survey)	Oct-13		Jan-14		Apr-14	
Outcome	FEV1	FVC	FEV1	FVC	FEV1	FVC
	(e)	(f)	(g)	(h)	(i)	(j)
All products	-0.043	-0.057	0.044	0.116**	0.035	0.003
	(0.043)	(0.043)	(0.045)	(0.055)	(0.028)	(0.032)
One product	0.010	-0.039	0.004	0.098	-0.009	-0.008
	(0.045)	(0.046)	(0.045)	(0.070)	(0.035)	(0.043)
N	789	789	667	667	771	771
Adjusted R-squared	0.270	0.452	0.244	0.144	0.204	0.105
Mean y (control)	1.050	1.887	1.042	1.806	1.263	1.713
Panel C (Health camp)	Dec-14					
Outcome	FEV1	FVC	Lung noise (=1)	Postnasal drip (=1)	Hold breath (sec)	Heart beat per min after a short run
	(k)	(l)	(m)	(n)	(o)	(p)
All products	-0.036	0.012	0.007	-0.019	-0.265	0.001
	(0.046)	(0.057)	(0.010)	(0.027)	(0.975)	(0.696)
One product	0.000	-0.008	0.008	-0.049	-1.605	-0.065
	(0.051)	(0.052)	(0.010)	(0.030)	(1.066)	(1.043)
N	753	753	525	525	525	525
Adjusted R-squared	0.269	0.239	0.113	0.137	0.287	0.243
Mean y (control)	1.158	1.742	0.004	0.079	21.067	81.826

Notes: Figures in parentheses are clustered standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. The baseline controls include age (years); education (years); gender (dummy); household size; no. of males; head age (years); head education (years); head gender (dummy); and land size (natural number). Pretreatment outcomes are controlled for panel A and B.

Table V. Impacts on Students' Health: Other Diseases

Panel A (Self-report)	Jul/Aug- 14				
Self-report	Headache (=1)	Dizziness (=1)	Skin disease (=1)	Medical expenditure (BDT)	
	(a)	(b)	(c)	(d)	
All products	-0.037	0.000	0.009	10.545	
	(0.037)	(0.001)	(0.007)	(17.684)	
One product	-0.024	0.005	0.000	27.310	
	(0.036)	(0.005)	(0.001)	(33.445)	
N	816	816	816	813	
Adjusted R-squared	0.137	0.056	0.048	0.084	
Mean y (control)	0.366	0.000	0.000	396.5	
Panel B (Health camp)			Dec-14		
Health camp	Any visible burn (=1)	Eye redness (=1)	Eye irritation (=1)	Teary eyes (=1)	Dimness of vision (=1)
	(e)	(f)	(g)	(h)	(i)
All products	-0.045**	-0.143**	-0.137**	-0.020	0.006
	(0.022)	(0.053)	(0.051)	(0.022)	(0.009)
One product	-0.001	-0.141***	-0.103*	-0.034	0.002
	(0.033)	(0.051)	(0.053)	(0.020)	(0.009)
N	525	525	525	525	525
Adjusted R-squared	0.130	0.228	0.232	0.099	0.123
Mean y (control)	0.075	0.257	0.217	0.043	0.004

Notes: Figures in parentheses are clustered standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. The baseline controls include age (years); education (years); gender (dummy); household size; no. of males; head age (years); head education (years); head gender (dummy); and land size (natural number). Pretreatment outcomes are controlled for panel A.

Table VI. Impacts on Other Household Members' Health

	Self-report Jul/Aug- 14						
	Cough (=1)	Sore throat (=1)	Runny nose (=1)	Phlegm (=1)	Headache (=1)	Dizziness (=1)	Skin disease (=1)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
All (Panel A)							
All products	0.007	0.003	-0.026	0.001	-0.006	-0.000	0.002
	(0.017)	(0.004)	(0.019)	(0.002)	(0.018)	(0.004)	(0.003)
One product	0.015	0.010*	-0.012	0.008	0.007	-0.005**	-0.003
	(0.015)	(0.006)	(0.020)	(0.006)	(0.023)	(0.002)	(0.002)
N	3208	3208	3208	3208	3208	3208	3208
Adjusted R-squared	0.045	0.021	0.031	0.03	0.04	0.014	0.021
Mean y (control)	0.108	0.021	0.184	0.021	0.280	0.005	0.007
	(h)	(i)	(j)	(k)	(l)	(m)	(n)
Male (Panel B)							
All products	0.017	0.003	-0.040**	0.002	-0.000	0.002	0.004
	(0.017)	(0.004)	(0.019)	(0.004)	(0.017)	(0.004)	(0.004)
One product	0.003	0.009	-0.022	0.013*	0.044	0.001	-0.002
	(0.019)	(0.007)	(0.023)	(0.007)	(0.036)	(0.004)	(0.004)
N	1617	1617	1617	1617	1617	1617	1617
Adjusted R-squared	0.046	0.03	0.045	0.032	0.043	0.03	0.025
Mean y (control)	0.113	0.022	0.182	0.021	0.276	0.002	0.004
	(o)	(p)	(q)	(r)	(s)	(t)	(u)
Female (Penel C)							
All products	-0.001	0.003	-0.014	0.000	-0.011	-0.003	-0.000
	(0.018)	(0.008)	(0.028)	(0.004)	(0.037)	(0.004)	(0.003)
One product	0.031	0.008	0.002	0.004	-0.019	-0.012***	-0.004*
	(0.019)	(0.010)	(0.031)	(0.008)	(0.024)	(0.003)	(0.002)
N	1590	1590	1590	1590	1590	1590	1590
Adjusted R-squared	0.064	0.021	0.045	0.041	0.057	0.022	0.052
Mean y (control)	0.102	0.020	0.186	0.020	0.282	0.009	0.010

Notes: Figures in parentheses are clustered standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. The baseline controls include household size; no. of males; head age (years); head education (years); head gender (dummy); and land size (natural number). Pretreatment outcomes are also controlled for.

Appendix A. Impacts on Students' Health: Any Treatment vs Control

Panel A	Self-report							
	Jul/Aug- 14							
	Cough (=1)	Sore throat (=1)	Runny nose (=1)	Phlegm (=1)	Headache (=1)	Dizziness (=1)	Skin disease (=1)	Medical expenditure (BDT)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Any treatment	-0.009	-0.004	-0.040	-0.004	-0.031	0.003	0.005	17.906
	(0.023)	(0.012)	(0.028)	(0.003)	(0.031)	(0.002)	(0.004)	(18.048)
N	816	816	816	816	816	816	816	813
Adjusted R-squared	0.106	0.100	0.101	0.097	0.137	0.054	0.044	0.084

Panel B	Repeated survey					
	Oct-13		Jan-14		Apr-14	
	FEV1	FVC	FEV1	FVC	FEV1	FVC
	(i)	(j)	(k)	(l)	(m)	(n)
Any treatment	-0.020	-0.050	0.027	0.108**	0.015	-0.002
	(0.039)	(0.040)	(0.038)	(0.052)	(0.026)	(0.028)
N	789	789	667	667	771	771
Adjusted R-squared	0.268	0.452	0.243	0.144	0.203	0.104

Panel C	Health camp										
	Dec-14										
	FEV1	FVC	Lung noise (=1)	Postnasal drip (=1)	Hold breath (sec)	Heart beat per min after a short run	Any visible burn (=1)	Eye redness (=1)	Eye irritation (=1)	Teary eyes (=1)	Dimness of vision (=1)
	(o)	(p)	(q)	(r)	(s)	(t)	(u)	(v)	(w)	(x)	(y)
Any treatment	-0.020	0.003	0.008	-0.032	-0.855	-0.028	-0.025	-0.143***	-0.122**	-0.026	0.004
	(0.043)	(0.049)	(0.008)	(0.025)	(0.874)	(0.767)	(0.021)	(0.047)	(0.046)	(0.020)	(0.007)
N	753	753	525	525	525	525	525	525	525	525	525
Adjusted R-squared	0.268	0.239	0.112	0.136	0.285	0.243	0.126	0.228	0.231	0.098	0.122

Figures in parentheses are clustered standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. The baseline controls include age (years); education (years); gender (dummy); household size; no. of males; head age (years); head education (years); head gender (dummy); and land size (natural number). Pretreatment outcomes are controlled for panel A and B.

Appendix B. Heterogeneous Treatment Effects on Students' Health: By Age

Panel A	Self-report								Panel B	Repeated survey				
	Jul/Aug- 14								Oct-13		Jan-14		Apr-14	
	Cough (=1)	Sore throat (=1)	Runny nose (=1)	Phlegm (=1)	Headache (=1)	Dizziness (=1)	Skin disease (=1)	Medical expenditure (BDT)	FEV1	FVC	FEV1	FVC	FEV1	FVC
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)
All products	-0.136	-0.020	0.257	-0.041	-0.245	-0.003	0.004	-85.981	-0.219	0.358	-0.020	0.332	-0.013	0.021
	(0.218)	(0.096)	(0.231)	(0.073)	(0.343)	(0.005)	(0.039)	(173.055)	(0.348)	(0.399)	(0.390)	(0.430)	(0.239)	(0.297)
One product	0.338	0.109	0.052	-0.027	0.159	-0.019	0.002	-80.179	0.370	0.842**	0.147	-0.014	-0.044	-0.185
	(0.203)	(0.118)	(0.310)	(0.046)	(0.292)	(0.019)	(0.006)	(156.001)	(0.292)	(0.372)	(0.279)	(0.658)	(0.345)	(0.324)
Age														
X All products	0.012	0.002	-0.024	0.003	0.017	0.000	0.000	7.859	0.014	-0.034	0.003	-0.018	0.003	-0.001
	(0.017)	(0.008)	(0.018)	(0.006)	(0.028)	(0.000)	(0.003)	(14.481)	(0.029)	(0.032)	(0.031)	(0.035)	(0.020)	(0.024)
X One product	-0.030*	-0.010	-0.008	0.002	-0.015	0.002	-0.000	8.736	-0.028	-0.070**	-0.013	0.010	0.002	0.014
	(0.016)	(0.010)	(0.024)	(0.004)	(0.023)	(0.002)	(0.000)	(14.508)	(0.025)	(0.030)	(0.023)	(0.054)	(0.027)	(0.026)
N	816	816	816	816	816	816	816	813	753	753	640	640	737	737
Adjusted R-squared	0.112	0.101	0.103	0.098	0.138	0.058	0.048	0.085	0.285	0.462	0.273	0.161	0.218	0.111

Panel	Health camp										
	Dec-14										
	FEV1	FVC	Lung noise (=1)	Postnasal drip (=1)	Hold breath (sec)	Heart beat per min after a short run	Any visible burn (=1)	Eye redness (=1)	Eye irritation (=1)	Teary eyes (=1)	Dimness of vision (=1)
	(o)	(p)	(q)	(r)	(s)	(t)	(u)	(v)	(w)	(x)	(y)
All products	-0.109	-0.012	0.031	-0.129	10.908	1.881	0.206	-0.548	-0.506	-0.085	-0.058
	(0.416)	(0.564)	(0.131)	(0.176)	(7.909)	(4.523)	(0.227)	(0.446)	(0.435)	(0.183)	(0.063)
One product	0.246	0.613	-0.015	0.030	8.988	5.876	0.181	-1.092***	-0.873**	-0.205	-0.110
	(0.349)	(0.386)	(0.052)	(0.232)	(9.350)	(6.852)	(0.193)	(0.381)	(0.422)	(0.168)	(0.069)
Age											
X All products	0.006	0.001	-0.002	0.009	-0.922	-0.149	-0.021	0.033	0.030	0.006	0.005
	(0.034)	(0.047)	(0.011)	(0.013)	(0.708)	(0.350)	(0.019)	(0.035)	(0.034)	(0.015)	(0.005)
X One product	-0.022	-0.053*	0.002	-0.007	-0.884	-0.475	-0.015	0.079**	0.064*	0.015	0.009
	(0.026)	(0.030)	(0.005)	(0.018)	(0.820)	(0.507)	(0.016)	(0.030)	(0.034)	(0.014)	(0.006)
N	720	720	501	501	501	501	501	501	501	501	501
Adjusted R-squared	0.28	0.244	0.116	0.142	0.291	0.253	0.148	0.252	0.251	0.106	0.133

Figures in parentheses are clustered standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. The baseline controls include age (years); education (years); gender (dummy); household size; no. of males; head age (years); head education (years); head gender (dummy); and land size (natural number). Pretreatment outcomes are controlled for panel A and B. Since Dizziness for male and Phlegm for female are perfectly predicted, they are dropped.

Appendix C. Heterogeneous Treatment Effects on Students' Health: By Gender

Panel A	Self-report							
	Jul/Aug- 14							
	Cough (=1)	Sore throat (=1)	Runny nose (=1)	Phlegm (=1)	Headache (=1)	Dizziness (=1)	Skin disease (=1)	Medical expenditure (BDT)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Male								
All products	0.011	-0.030	-0.067	-0.020	-0.063	-	0.010	-62.790**
	(0.048)	(0.023)	(0.045)	(0.014)	(0.061)	-	(0.011)	(24.241)
One product	-0.033	-0.005	0.032	-0.011	-0.014	-	-0.000	-23.346
	(0.039)	(0.027)	(0.060)	(0.008)	(0.053)	-	(0.002)	(26.209)
N	361	361	361	361	361	-	361	359
Adjusted R-squared	0.263	0.130	0.196	0.228	0.236	-	0.096	0.235
Female								
All products	-0.003	0.028	-0.030	-	-0.059	-0.001	0.005	45.276
	(0.040)	(0.019)	(0.046)	-	(0.043)	(0.002)	(0.006)	(31.925)
One product	-0.015	-0.001	-0.097**	-	-0.065	0.010	-0.000	69.902
	(0.050)	(0.016)	(0.038)	-	(0.056)	(0.010)	(0.001)	(65.894)
N	453	453	453	-	453	453	453	452
Adjusted R-squared	0.160	0.268	0.152	-	0.188	0.083	0.087	0.096

Panel B	Repeated survey					
	Oct-13		Jan-14		Apr-14	
	FEV1	FVC	FEV1	FVC	FEV1	FVC
	(i)	(j)	(k)	(l)	(m)	(n)
Male						
All products	0.021	-0.014	0.042	0.214***	0.072	-0.045
	(0.063)	(0.063)	(0.085)	(0.072)	(0.043)	(0.050)
One product	0.002	-0.040	-0.032	0.123	-0.040	-0.008
	(0.072)	(0.059)	(0.110)	(0.094)	(0.089)	(0.061)
N	336	336	277	277	337	337
Adjusted R-squared	0.382	0.542	0.317	0.264	0.504	0.189
Female						
All products	-0.070	-0.037	0.033	0.065	-0.018	0.008
	(0.062)	(0.076)	(0.052)	(0.068)	(0.042)	(0.047)
One product	0.042	0.004	0.004	0.079	-0.042	-0.019
	(0.058)	(0.073)	(0.044)	(0.102)	(0.048)	(0.065)
N	445	445	388	388	429	429
Adjusted R-squared	0.253	0.281	0.239	0.185	0.184	0.175

Panel C	Health camp										
	Dec-14										
	FEV1	FVC	Lung noise (=1)	Postnasal drip (=1)	Hold breath (sec)	Heart beat per min after a short run	Any visible burn (=1)	Eye redness (=1)	Eye irritation (=1)	Teary eyes (=1)	Dimness of vision (=1)
	(o)	(p)	(q)	(r)	(s)	(t)	(u)	(v)	(w)	(x)	(y)
male											
All products	-0.105	-0.016	0.012	0.025	-1.567	0.841	-0.042	-0.173*	-0.133	0.014	0.026
	(0.074)	(0.074)	(0.013)	(0.037)	(3.267)	(1.868)	(0.046)	(0.088)	(0.097)	(0.039)	(0.029)
One product	-0.040	-0.075	0.013	-0.017	-3.175*	0.523	0.030	-0.185**	-0.091	-0.019	-0.008
	(0.105)	(0.075)	(0.016)	(0.039)	(1.567)	(2.386)	(0.062)	(0.070)	(0.068)	(0.023)	(0.008)
N	328	328	205	205	205	205	205	205	205	205	205
Adjusted R-squared	0.247	0.199	0.274	0.359	0.347	0.323	0.231	0.342	0.308	0.218	0.594
female											
All products	0.048	0.068	0.007	-0.047	-0.068	-0.252	-0.041	-0.139**	-0.150**	-0.055*	-0.007
	(0.042)	(0.089)	(0.014)	(0.035)	(1.194)	(0.796)	(0.033)	(0.060)	(0.060)	(0.030)	(0.008)
One product	0.031	0.008	-0.003	-0.053	-0.774	-0.330	-0.019	-0.124*	-0.098	-0.053*	-0.011
	(0.043)	(0.060)	(0.005)	(0.034)	(1.219)	(0.900)	(0.041)	(0.066)	(0.073)	(0.027)	(0.010)
N	421	421	319	319	319	319	319	319	319	319	319
Adjusted R-squared	0.288	0.261	0.413	0.205	0.363	0.294	0.258	0.304	0.319	0.183	0.105

Figures in parentheses are clustered standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. The baseline controls include age (years); education (years); gender (dummy); household size; no. of males; head age (years); head education (years); head gender (dummy); and land size (natural number). Pretreatment outcomes are controlled for panel A and B. Since Dizziness for male and Phlegm for female are perfectly predicted, they are dropped.

Appendix D. Heterogeneous Treatment Effects on Students' Health: By Cooking Environments

	Self-report								Repeated survey					
	Jul/Aug- 14								Oct-13		Jan-14		Apr-14	
	Cough (=1)	Sore throat (=1)	Runny nose (=1)	Phlegm (=1)	Headache (=1)	Dizziness (=1)	Skin disease (=1)	Medical expenditure (BDT)	FEV1	FVC	FEV1	FVC	FEV1	FVC
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)
All products	0.045	-0.062	0.017	-0.008	-0.174*	-0.001	0.027	-23.119	-0.193*	-0.108	-0.249**	0.211*	0.018	-0.063
	(0.059)	(0.043)	(0.087)	(0.006)	(0.101)	(0.002)	(0.024)	(60.943)	(0.100)	(0.133)	(0.106)	(0.110)	(0.124)	(0.079)
One product	-0.017	-0.021	0.082	-0.009	-0.101	0.007	-0.002	-28.629	0.101	0.150	0.005	0.320**	0.103	-0.164
	(0.065)	(0.064)	(0.100)	(0.007)	(0.098)	(0.007)	(0.005)	(78.253)	(0.119)	(0.151)	(0.118)	(0.156)	(0.117)	(0.110)
All products														
X No window	-0.020	0.089*	-0.075	-0.001	0.118	0.001	-0.021	-9.848	0.168*	0.033	0.324**	-0.094	0.050	0.048
	(0.058)	(0.047)	(0.091)	(0.004)	(0.100)	(0.002)	(0.027)	(60.257)	(0.097)	(0.137)	(0.121)	(0.115)	(0.138)	(0.087)
X Cook inside	-0.056	-0.018	-0.007	0.008	0.091	0.001	-0.000	76.347*	0.023	0.040	0.001	-0.060	-0.096	0.085
	(0.057)	(0.028)	(0.074)	(0.006)	(0.084)	(0.001)	(0.010)	(38.097)	(0.090)	(0.083)	(0.103)	(0.112)	(0.077)	(0.059)
One product														
X No window	0.040	-0.008	-0.120	0.001	0.090	0.002	0.002	40.834	-0.060	-0.209	0.001	-0.159	-0.117	0.124
	(0.069)	(0.066)	(0.095)	(0.005)	(0.103)	(0.003)	(0.005)	(78.727)	(0.117)	(0.153)	(0.118)	(0.164)	(0.119)	(0.125)
X Cook inside	-0.094	0.050	-0.076	0.010	0.023	-0.009	0.003	67.819	-0.092	-0.025	-0.053	-0.199	-0.059	0.146
	(0.057)	(0.038)	(0.064)	(0.008)	(0.106)	(0.009)	(0.003)	(89.527)	(0.104)	(0.095)	(0.083)	(0.145)	(0.096)	(0.100)
No window	0.013	-0.041	0.037	0.001	-0.067	-0.001	-0.003	-15.659	-0.036	0.056	-0.081	0.049	0.047	-0.107*
	(0.043)	(0.027)	(0.055)	(0.004)	(0.067)	(0.001)	(0.003)	(22.049)	(0.074)	(0.090)	(0.074)	(0.083)	(0.113)	(0.057)
Cook inside	0.081**	-0.019	0.022	-0.008	0.023	0.000	-0.001	-51.558**	0.032	0.063	0.096*	0.111*	0.091*	-0.057
	(0.038)	(0.015)	(0.041)	(0.006)	(0.056)	(0.001)	(0.001)	(20.111)	(0.051)	(0.052)	(0.054)	(0.064)	(0.053)	(0.037)
N	779	779	779	779	779	779	779	776	753	753	640	640	737	737
Adjusted R-squared	0.125	0.120	0.119	0.103	0.147	0.061	0.058	0.084	0.287	0.461	0.285	0.164	0.222	0.116

Appendix D (cont.)

	Health camp										
	Dec-14										
	FEV1 (o)	FVC (p)	Lung noise (=1) (q)	Postnasal drip (=1) (r)	Hold breath (sec) (s)	Heart beat per min after a short run (t)	Any visible burn (=1) (u)	Eye redness (=1) (v)	Eye irritation (=1) (w)	Teary eyes (=1) (x)	Dimness of vision (=1) (y)
All products	-0.217**	-0.084	0.031	0.037	-1.541	-0.363	-0.002	-0.148	-0.135	-0.034	-0.012
	(0.094)	(0.133)	(0.034)	(0.097)	(3.830)	(2.388)	(0.048)	(0.101)	(0.085)	(0.035)	(0.020)
One product	0.140	0.158	0.006	-0.031	-2.962	0.245	0.015	-0.135	-0.062	-0.072**	-0.017
	(0.121)	(0.100)	(0.016)	(0.082)	(3.819)	(2.246)	(0.080)	(0.081)	(0.075)	(0.031)	(0.019)
All products											
X No window	0.211**	0.092	-0.035	-0.048	2.395	-0.417	-0.075	-0.045	0.001	0.017	0.034
	(0.086)	(0.146)	(0.041)	(0.100)	(3.978)	(2.179)	(0.053)	(0.091)	(0.080)	(0.035)	(0.025)
X Cook inside	0.010	0.029	0.014	-0.040	-1.390	2.030	0.042	0.089	-0.023	0.003	-0.024
	(0.080)	(0.137)	(0.024)	(0.069)	(2.713)	(2.266)	(0.047)	(0.092)	(0.074)	(0.032)	(0.021)
One product											
X No window	-0.068	-0.207**	0.008	-0.012	1.036	-1.425	0.025	-0.080	-0.066	0.016	0.029
	(0.100)	(0.098)	(0.015)	(0.081)	(3.695)	(2.017)	(0.079)	(0.093)	(0.077)	(0.031)	(0.023)
X Cook inside	-0.273**	-0.099	-0.010	-0.027	1.173	2.429	-0.075	0.125	0.020	0.067	-0.013
	(0.105)	(0.092)	(0.019)	(0.070)	(2.200)	(1.844)	(0.056)	(0.090)	(0.090)	(0.041)	(0.013)
No window	-0.028	0.016	0.002	0.009	-0.166	-0.600	0.055	0.036	0.042	0.006	-0.028
	(0.041)	(0.077)	(0.009)	(0.062)	(3.399)	(1.551)	(0.033)	(0.066)	(0.060)	(0.035)	(0.021)
Cook inside	0.051	-0.000	-0.001	0.025	-0.096	-1.325	-0.039	-0.133**	-0.047	-0.031*	0.006
	(0.047)	(0.065)	(0.009)	(0.053)	(2.265)	(1.180)	(0.038)	(0.060)	(0.053)	(0.017)	(0.013)
N	720	720	501	501	501	501	501	501	501	501	501
Adjusted R-squared	0.294	0.245	0.124	0.143	0.290	0.258	0.156	0.245	0.243	0.109	0.139

Figures in parentheses are clustered standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. The baseline controls include age (years); education (years); gender (dummy); household size; no. of males; head age (years); head education (years); head gender (dummy); and land size (natural number). Pretreatment outcomes are controlled for panel A and B.

Appendix E. Testing for Sample Attrition

Data type	Follow-up household survey	Repeated survey			Health camp
Data collection period	Jul/Aug- 14	Oct-13	Jan-14	Apr-14	Dec-14
	(a)	(b)	(c)	(d)	(e)
All products	0.007	0.024	0.066*	-0.009	0.029
	(0.021)	(0.020)	(0.035)	(0.025)	(0.030)
One product	-0.003	0.003	0.017	0.003	0.007
	(0.020)	(0.028)	(0.041)	(0.025)	(0.033)
N	882	882	882	882	882
Non-attrition sample	816	789	667	771	525
Adjusted R-squqred	0.099	0.120	0.108	0.103	0.103

Figures in parentheses are clustered standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. The baseline controls include age (years); education (years); gender (dummy); household size; no. of males; head age (years); head education (years); head gender (dummy); and land size (natural number).

Appendix F. Checking on Multiple-hypothesis Testing for Selected Outcomes

Variable	Data collection period	List et al.	Bonferroni	Holm
Cough (=1)	Jul/Aug- 14	1.000	1.000	1.000
Sore throat (=1)	Jul/Aug- 14	1.000	1.000	1.000
Runny nose (=1)	Jul/Aug- 14	0.999	1.000	1.000
Phlegm (=1)	Jul/Aug- 14	0.954	1.000	1.000
FEV1	Oct-13	1.000	1.000	1.000
FEV1	Jan-14	0.999	1.000	1.000
FEV1	Apr-14	1.000	1.000	1.000
FVC	Oct-13	0.972	1.000	1.000
FVC	Jan-14	0.852	1.000	1.000
FVC	Apr-14	1.000	1.000	1.000
FEV1	Dec-14	1.000	1.000	1.000
FVC	Dec-14	0.998	1.000	1.000
Lung noise (=1)	Dec-14	1.000	1.000	1.000
Postnasal drip (=1)	Dec-14	0.998	1.000	1.000
Hold breath (sec)	Dec-14	0.976	1.000	1.000
Heart beat per min after a short run	Dec-14	0.995	1.000	1.000
Headache (=1)	Jul/Aug- 14	1.000	1.000	1.000
Dizziness (=1)	Jul/Aug- 14	0.990	1.000	1.000
Skin disease (=1)	Jul/Aug- 14	0.947	1.000	0.947
Medical expenditure	Jul/Aug- 14	1.000	1.000	1.000
Any visible burn (=1)	Dec-14	1.000	1.000	1.000
Eye redness (=1)	Dec-14	0.000	0.017	0.012
Eye irritation (=1)	Dec-14	0.000	0.017	0.013
Teary eyes (=1)	Dec-14	0.721	1.000	1.000
Dimness of vision (=1)	Dec-14	0.998	1.000	1.000

List et al., Bonferroni and Holm are *q*-values (*p*-values corrected for multiple testing)