Analyzing the impact of solar lanterns in rural Haitian schools

Matthew Mleczko

Advised by Kevin Donovan

April 27, 2015

Abstract

This study analyzes the impact of solar-powered lanterns—products designed specifically to provide several hours of lighting—and whether they cause an improvement in after-school educational activity among secondary students in Haiti. 100 solar lanterns were randomly distributed among two rural, private schools in Haiti. Several weeks of self-reported data by students in the sample population captured reading, homework and studying times before and after the intervention. I find that students with a solar lantern read an average of 19 minutes more and complete homework for an average of 22 minutes longer each day than peers without solar lanterns. I find no statistically significant impact of solar lanterns on a student's studying time. I explore these results further, paying close attention to spillover effects and interaction effects of both gender and parental assistance with studies. I find that the treatment impact is much more pronounced for male students, but find no significant interaction effect between solar lanterns and parental assistance. Moreover, I find a significantly negative impact on those who read with a student in the treatment group. No conclusive evidence exists for the impact of completing homework and studying with a treatment student, potentially due to the constraints of a small sample size.

Acknowledgements

A countless number of people made this research possible. Professors Donovan, Buckles and Sullivan supported me throughout the planning process. Working with Professor Donovan has been a wonderful experience and I am eternally grateful for him believing in me and in this project.

I will forever be indebted to the assistance, encouragement and accompaniment that I received from the Alliance for Catholic Education, especially from Gena Robinson and T.J. D'Agostino. This project would not be a reality without the financial support I received from CUSE. I also want to recognize the Notre Dame International staff and their instrumental support in getting the project approved.

The success of this project also rests on the collaboration and partnership of Bill and Nancy Jordan of the Let’s Share the Sun Foundation and I am grateful for their willingness to engage in this research.

There are other individuals who assisted me throughout this process in many, many ways. But, Tim Gailius and his family lie at the heart of this project and the journey it has become. I dedicate this work to him, his mother Sheila and the whole family--the starting point of this whole adventure.

1. Introduction

Electricity access represents a key challenge in the developing world. Efforts in this area have increasingly included solar microgrids or individual photovoltaic (PV) systems to provide electricity in rural areas where it is unreliable or nonexistent. This process of rural electrification has been a priority for the World Bank for the past few decades. Objectives for these projects range from welfare considerations such as providing lighting to environmental considerations like reducing a household's reliance on biomass for its energy needs (IEG, 2008: 31-33). From 1980-2006, the World Bank financed 120 rural electrification projects totaling 5.97 billion USD (IEG, 2008: 10). Countries like Haiti demonstrate the need for these electrification projects. In Haiti, only 28 percent of households—8 percent for rural households—have access to the electricity grid (IEA, World Energy Outlook 2014). Since 44 percent of the population lives in rural areas, most of the country lives out of the reach of the grid and consequently, without access to electricity (World Development Indicators, 2014).

Moreover, efforts to improve educational outcomes by nongovernmental organizations and governments garner plenty of attention from development economists. Studying the effectiveness of interventions in the classroom remains a priority largely due to the widely accepted view of education as a human capital investment. According to the theory, children whose parents or guardians invest in education accumulate human capital, improving their employability prospects and in turn, their productivity (Becker, 1962). Moreover, recent research has emphasized not just the quantity, but quality of education in determining differences in output per worker across countries (Manuelli and Sheshadri, 2014). This is particularly problematic in Haiti, where 60 percent of students failed to earn primary certification in 2007 and only 61 percent of the country is currently literate (Haiti Ministry of Planning and External Cooperation, 2008: 22; UNESCO Institute for Statistics, 2015).

Two seemingly separate development priorities—electricity access and education—intersect when considering the role of lighting during the evening as enabling after-school educational activity beyond the classroom. For instance, products like solar lanterns can be used in rural development projects to increase the amount of time students spend in after-school educational activity by providing lighting in households with no electricity.

In this paper, I conduct a randomized controlled trial to determine the impact of increased access to electricity on educational outcomes. Partnering with the Let's Share the Sun Foundation (LSS), I randomly distributed 100 Phocos Pico solar lanterns across two secondary schools in Haiti. These Pico lanterns have three settings corresponding to the intensity of lighting. The low setting at 20 lumens provides 55 hours of lighting without a charge. The standard setting (50 lumens) and high setting (120 lumens) provide 16.5 and 5.5 hours without a charge, respectively. The lanterns last for over 500 charges—27,500 hours at the low setting over the lifetime of the product. A full charge takes anywhere from 3 to 5 hours depending on incident solar radiation (Pico Lamp/System). This charging typically takes place during the school day while students attend class. Along with the charging panels, they cost about 114 USD, but LSS procures them for 50 USD as a solar product distributor.

Beginning in October 2014, students completed one baseline survey and four weeks of surveys in which they indicated the amount of time they spent reading, completing homework and studying each day. The baseline survey was completed on October 10th and the weekly surveys were completed over the weeks of October 12-18, October 19-25, October 26-November 1 and November 9-15 at school one and October 19-25, November 2-8 and November 23-29 at school two. 50 lanterns were randomly distributed on October 20 in school two and October 22 in school one. Students were instructed by teachers and principals to begin using the solar lanterns in the following week. These lanterns could potentially have a considerable impact since only five percent of the sample has over one hour of electricity at home per day. If this lack of electricity among the sample creates an after-school activity time constraint, the lanterns could provide a solution. At the baseline, students in the sample spend about an average of 75 minutes reading, 70 minutes completing homework or 99 minutes studying each day, respectively.

I find a positive impact of the solar lanterns on a student's time spent in after-school educational activity. A student with a solar lantern both reads for an average of 19 minutes more and completes homework for an average of 22 minutes more each day than a peer without a solar lantern. These increases in average reading and homework times correspond to a 25 and 30 percent increase over the baseline averages, respectively. The impact of solar lanterns on students' studying times is positive and similar in magnitude to reading and homework, but not statistically different from zero.

I further investigate other potential factors affecting the impact of solar lanterns with special attention to possible spillover and interaction effects. For instance, students in the treatment group share lanterns with their friends in the control group, which potentially allows for greater cost-effectiveness of the lanterns. I find evidence on the contrary for reading times, but no evidence of spillover effects for homework and studying times. Though no statistically significant relationship exists between the lanterns and parental involvement, one does exist between the lanterns and gender. Male students who receive a lantern read an average of 31 minutes, complete an average of 39 more minutes of homework and study for an average of 27 more minutes each day than male students who do not. Female students who receive lanterns complete similar amounts of reading, homework and studying relative to girls in the control group.

The rest of this paper proceeds as follows: Section 2 discusses related literature. Section 3 covers the background on the landscape of electricity access and educational outcomes in Haiti. Section 4 introduces the design of the experiment while Section 5 details the methodology behind the experiment. Main results are detailed in Section 6 while the potential heterogeneity of the impact is explored in Section 7. The paper concludes with the main implications of the study in Section 8.

2. Related literature

A growing body of research has highlighted other positive educational outcomes correlated with access to electricity for households in the developing world. A Human Development Research Center analysis of the Bangladesh Rural Electrification Program revealed that average annual education expenditures for electrified households were 87 percent higher than those in non-electrified households in electrified villages (WE-EV) and 135 percent higher than those in non-electrified households in non-electrified villages (WE-NEV). Expenditures for male students were 100 and 170 percent higher than for other male students in WE-EV and WE-NEV, respectively. Expenditures for female students in electrified households were 66 and 89 percent higher than for other female students in WE-EV and WE-NEV, respectively (Barkat et al, 2002: 62-63). The same study points to significantly higher literacy rates among electrified households as compared to WE-EV and WE-NEV—70.8 percent as opposed to 54.3 and 56.4 percent, respectively. Interestingly, the male-female and rich-poor gap in literacy rates was far less pronounced in electrified households, suggesting that electricity access and literacy has an especially strong association for female students and poor students (Barkat et al, 2002: 80-81).

Similar work has documented and analyzed the growing interest in PV system applications among the rural poor and development practitioners. Research conducted in Zambia indicates that 75 percent of survey respondents confirm changes to daily routines as a result of acquiring electricity from PV systems—manifested, for instance, in completing domestic work at night or listening to a radio. Moreover, the same research showed that school-aged children (5-12 years) in households with access to solar electricity read at night in 80 percent of cases compared to 53 percent of cases in households without similar access (Gustavsson, 2008: 67-68). A UNDP and World Bank study shows that a child in a solar electrified household reads 48 minutes longer per day than a child in a house with no access to electricity, controlling for income, type of house and price of electricity (ESMAP, 2002: 43-45).

Research on the contrary suggests that while solar lighting can provide additional hours of productivity in the evening and deliver higher quality lighting than kerosene lamps, the limited electricity provided by small PV systems must be distributed among several energy priorities, with electronics such as televisions and radios often using up most of the available wattage (Jacobson, 2007: 147, 153). Studies such as this suggest that some solar systems can be more effective than others in achieving positive social outcomes—such as an increase in reading among students at night—if they can effectively overcome the issue of household energy allocation (Jacobson, 2007: 155).

This study contributes to the growing body of literature on rural electrification, in part, by attempting to solve this issue. The most distinguishing factor of this research is the random distribution of the solar lanterns to students and the attempt to unearth causal evidence between lighting and after-school educational activity in the form of reading, completing homework or studying. Additionally, the solar system utilized is a product meant specifically for lighting or charging electronics with USB compatibility, so competition with television or radio usage is all but eliminated. Finally, the distribution mechanism relies on schools as the channel linking lanterns to students, further emphasizing the lanterns' intended purpose as a means of improving educational outcomes.

3. Background

Haiti, the poorest country in the Western hemisphere, represents a country with high solar radiation and an opportunity for rural electrification. Its total per capita energy consumption in 2000 registered at 84 kilowatt hours—last in the Caribbean. At this time, biomass like firewood and charcoal compromised 75 percent of that total energy consumption, most of which was used for household uses like cooking. Motor and fossil fuels made up another 20 percent, leaving four and one percent of the country's total energy consumption to electricity and feedstock, respectively (Haiti Bureau of Mines and Energy, 2007: 3).

Less than 30 percent of households were connected to the main power grid in 2000 and only 12.5 percent were regularly connected (Haiti Bureau of Mines and Energy, 2006: 3). As of 2012, that number dropped to 28 percent, most likely due to destruction caused by the 2010 earthquake. Perhaps more concerning is the gap between urban and rural electrification. In 2012, 44 percent of the urban population had access to electricity compared to 8 percent of the rural population. All told, 7.3 million Haitians lacked access to electricity in 2012 (IEA, World Energy Outlook 2014). Of the energy consumed by Haitians at this time, 22 percent of it came from fossil fuels. Thus, the landscape of electricity in Haiti has not changed much since 2000.

Moreover, 44 percent of the population lives in rural areas today, precisely where grid access is limited (World Development Indicators, 2014). Some 9.4 million in Haiti, an overwhelming 93 percent of the population, still rely on traditional biomass (IEA, World Energy Outlook 2014). A limited national power grid, then, partially explains the reliance on biomass to fulfill the population's energy needs.

Much of Haiti's population lacks access to electricity, yet demand for energy in general is clearly high, evidenced by the population's reliance on biomass which has resulted in a significant deforestation rate. The World Bank estimates indicate that Haiti depleted more than half of its wood stock from 1982 to 2000 and at that rate, complete deforestation of the country seems almost inevitable. Broader impacts include low conversion factors of about 40 percent from wood to charcoal and the amount of pollution created from the extensive use of biomass. Furthermore, without any significant domestic energy production, the government has turned to costly petroleum imports to fulfill its energy needs. 35-50 percent of Haiti's imports in 2000 consisted of petroleum that only compromised about 25 percent of the country's energy supply—mostly for domestic transportation (Haiti Bureau of Mines and Energy, 2006: 3-5).

The government of Haiti has been making efforts to improve the prospects for the nation's energy supply since 2000. The Ministry for Public Works, Transportation and Communications along with the Bureau of Mines and Energy and the state electricity utility commissioned a comprehensive, ten-year energy sector development plan to include objectives such as increasing access to electricity within the country and improving the quality of electricity delivered (Haiti Bureau of Mines and Energy, 2006: iv). Additionally, several projects with donor and development agencies such as the Clinton Foundation and the Inter-American Development Bank were completed throughout the 2000s to assist with these objectives. Yet, the devastating earthquake of 2010 mostly sidelined these efforts, leaving the government to recover pre-earthquake energy consumption levels. No data from The World Bank or International Energy Agency on electricity access in Haiti exists beyond 2012, but five years after the earthquake, it seems reasonable to assume that most of the country's rural population still has relatively little access to electricity.

Figure 1 provides a particularly instructive illustration of the problem. The small cluster of light in the Port-au-Prince area is quite less pronounced than the lighting present in the Dominican Republic to the east. It pales in comparison to the lighting seen in Puerto Rico. Using this night lighting as a proxy for electricity access, it seems clear that Haiti performs poorly compared to its neighbors.

Figure 1: Satellite Image of Night Light in the Caribbean, 2012 (NASA/NPR)

Along with its energy woes, Haiti faces considerable obstacles in providing quality primary, secondary and tertiary education. Haiti's primary school system consists of three cycles. The first two cycles—a basic cycle for grades 1-4 and another cycle for grades 5-6—form the primary system while the third cycle for grades 7-9 begin the secondary education system, which includes up to grade 12—also referred to as rheto (Demombynes, Holland and León, 2010: 4). Philo represents the final year of secondary school. In 2007, at least one-third of

6-12 year old students did not attend school—a number that increased to 40 percent for 5-15 year old students. 29 percent of students did not complete the basic cycle of education and 60 percent failed to earn primary certification. 56 percent of first cycle students were considered on track to graduate. As for 2007 projections beyond primary school, 21.5 percent of the population over the age of five was expected to be educated at the secondary level and only 1.1 percent at the tertiary level—1.4 and 0.7 percent for men and women, respectively (Haiti Ministry of Planning and External Cooperation, 2008: 22).

The non-public sector provides the overwhelming majority—90 percent in 2010—of education services within Haiti (Action Plan for National Recovery and Development of Haiti, 2010: 62). Religious groups operate 47 percent of all primary schools alongside the 28 percent of schools run by what are referred to as independent secular organizations. Non-governmental and community groups manage a smaller, but still non-trivial number of schools (Demombynes, Holland and León, 2010: 2). Up until the early 1960s, the public sector operated the majority of schools in Haiti. By 1980, the public sector accounted for 21 percent of all schools and only eight percent in 2003. In contrast, the private sector very much replaced the public sector, accounting for 92 percent of Haitian schools and 80 percent of school enrollment. One explanation of this trend rests in a policy instituted by Jean-Claude “Baby Doc” Duvalier which required religious missionaries to build a school to accompany the construction of a new church (Demombynes, Holland and León, 2010: 4-5). Regardless of the causes, the Haitian education system has become an undeniably private operation in which most schools charge tuition, possibly creating cost barriers for some households (Adelman and Holland, 2015: 2).

The set of hurdles associated with educating the rural population represents another focal point of education in Haiti. The provision of education is divided among communal sections—

akin to a school board—23 of which had no school in 2000. Of the estimated 37.7 percent of the student population not enrolled in 2000, about 83 percent were located in rural areas (Haiti Ministry of Planning and External Cooperation, 2008: 38). The lack of resources in rural areas could be one potential explanation for the disparity in urban-rural educational outcomes. Nearly 43 percent of students not attending school in 2010 were absent because of cost barriers (Demombynes, Holland and León, 2010: 3).

Much of the literature points to the poor quality of schools and teachers as the cause of Haiti's poor educational outcomes. Haiti has a dearth of appropriate facilities for instruction. As of 2008, 58 percent did not have toilets, 23 percent had no running water and 5 percent were simply housed in a church or an open-air shaded area (Haiti Ministry of Planning and External Cooperation, 2008: 22).

Haiti's education system also suffers from a lack of teacher quality, an issue the 2010 earthquake exacerbated. 2007 Inter-American Development Bank research indicates that about 70-80 percent of Haitian teachers lacked accreditation from the Ministry of Education (MENFP) and about 25 percent of Haitian teachers received less than nine years of education (IDB 2010 as cited in Crane et al. 2010: 105). Similar research has called into question the language and mathematical abilities of a large segment of the teaching population (Salmi 2008 as cited in Crane et al. 2010: 105).

Haiti also simply lacks teachers, which partly explains the low instruction quality. The average pupil/teacher ratio reached 73 in 2007. During the same year, the average teacher was responsible for 1.87 grades (Haiti Ministry of Planning and External Cooperation, 2007: 39). About 1,000 teachers lost their lives in the 2010 earthquake, which only worsened the already high pupil/teacher ratio (Crane et al. 2010: 105-106). Poor teacher pay represents another issue in addressing teacher quality. Though public school teachers earned two to three times more than private school teachers, both earn low salaries. Public school teachers in particular have experienced delayed payments or received no payment at all from the government (Crane et al. 2010: 105). Moreover, costs associated with funding replacement teachers for 18 months after the earthquake reached about 2.1 million USD, placing even more burden on funding a beleaguered profession (Action Plan for National Recovery and Development of Haiti, 2010: 63).

The struggles of education in Haiti underscore the importance of the opportunity for students to learn outside of the classroom. Yet, a lack of electricity could hinder this opportunity, especially during the evening hours. This research attempts to quantify whether this lack of electricity acts as a barrier to learning outside of the classroom.

Pre-existing data motivates such a hypothesis. Data from the World Bank's 2012 Demographic and Health Survey in Haiti contains observations for the overall health of respondents, but also includes variables for the rate of literacy, the frequency of reading among respondents and a dummy variable for access to electricity. When controlling for variables such as wealth index, frequency of reading, urban-rural differences and which parent is head of the household, multivariate regression analysis for children specifically (respondents under the age of 18) indicates statistically significant associations between electricity access and literacy, but especially between no electricity access and illiteracy. As one can see from **Table I**, a Haitian child with electricity access, all else equal, is about 11 percentage points more likely to be literate than those without access to electricity **(1)**. Conversely, children with electricity access are approximately 13 percentage points less likely to be illiterate than children without electricity access **(3)**. Given that 46 percent of those in sample without electricity are considered illiterate, these results suggest that electricity is associated with 33 percent higher literacy.

Table I: World Bank DHS 2012 Data

N	1177	1177	1177
	(1) Literacy	(2) Partial literacy	(3) Cannot read
Electricity	0.107*	0.00973	-0.129***
	(2.33)	(0.26)	(-3.43)
Poor	0.103**	0.0531	-0.159***
	(2.89)	(1.91)	(-4.69)
Middle	0.228***	0.00922	-0.236***
	(5.25)	(0.28)	(-6.16)
Rich	0.300***	-0.0222	-0.272***
	(4.95)	(-0.45)	(-5.41)
Richest	0.279***	-0.0334	-0.238***
	(4.10)	(-0.60)	(-4.70)
Little read	0.364***	-0.0197	-0.344***
	(12.75)	(-0.79)	(-18.95)
Some read	0.291***	0.00961	-0.299***
	(6.67)	(0.23)	(-14.10)
Frequent read	0.377***	-0.0995***	-0.277***
	(10.55)	(-3.46)	(-12.94)
Urban	-0.0342	-0.0193	0.0549
	(-0.84)	(-0.63)	(1.70)
Male HH head	-0.0202	0.0354	-0.0174
	(-0.75)	(1.67)	(-0.71)
Adjusted R^2			
F-statistic	58.71	3.26	59.11

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Such results are promising, but in no way definitive when considering a policy of providing Haitian households with PV units to encourage reading and other educational activities. Measures of literacy are limited to the ability of children to read pamphlets or other materials provided by field researchers. Additionally, the survey results do not offer much indication of how students use electricity, much less how much time they spend doing some after-school educational activity if electricity is used for lighting.

4. Experimental Design

This research aims to more fully understand the impact of electricity—provided exclusively through solar lanterns—on a Haitian student's time in after-school educational activity by utilizing a randomized controlled trial and using solar lanterns as the treatment. By partnering with the Let's Share the Sun Foundation (LSS), over 300 students from two Haitian schools were surveyed over the course of four weeks starting in October 2014. These schools, chosen in consultation with LSS, are both private and located in rural areas. School one is located in Plaisance and school two in the outskirts of Carrefour. The surrounding areas of both schools have very little local access to electricity. Beyond their location and general lack of electricity, the two selected schools have student bodies of similar demographics.

On October 10th, 2014, participants completed an initial baseline survey along with a weekly survey indicating the amount of daily time spent reading, completing homework or studying over the course of the week. These weekly surveys were completed over the weeks of October 12-18, October 19-25, October 26-November 1 and November 9-15 at school one and October 19-25, November 2-8 and November 23-29 at school two. During week two of surveys, 50 lanterns were randomly distributed on October 20th in school two and October 22nd in school one, establishing a treatment group of 100 total students. A random number generator selected the 100 treatment students from the school enrollments. Students were instructed by teachers and principals to begin using the solar lanterns in the following week. The same surveys continued for two more weeks after the treatment distribution. The survey timeline is presented in **Figure II** below.

If randomization had been conducted correctly, one would expect comparable baseline characteristics between both treatment and control groups. A straightforward balance check can assess this. **Table II** contains these results. The characteristics of the control and treatment groups mirror each other, indicating that the randomization process succeeded in creating a comparison group. For instance, the average age of 16.3 for students in the treatment group closely compares to the age of 16.2 for students in the control group. Again, both the control and treatment group contain 61 percent male students and 39 percent female students. The percentages of students across grades in both treatment and control groups vary slightly more, but still remain close in comparison. One important caveat to note is the lack of data for one school in the sample. Several baseline characteristics in **Table II** are limited to one school due to data collection issues in the other school. This is not too concerning since when data for both schools exists, the control and treatment groups are comparable.

Figure 2: Survey Distribution Timeline

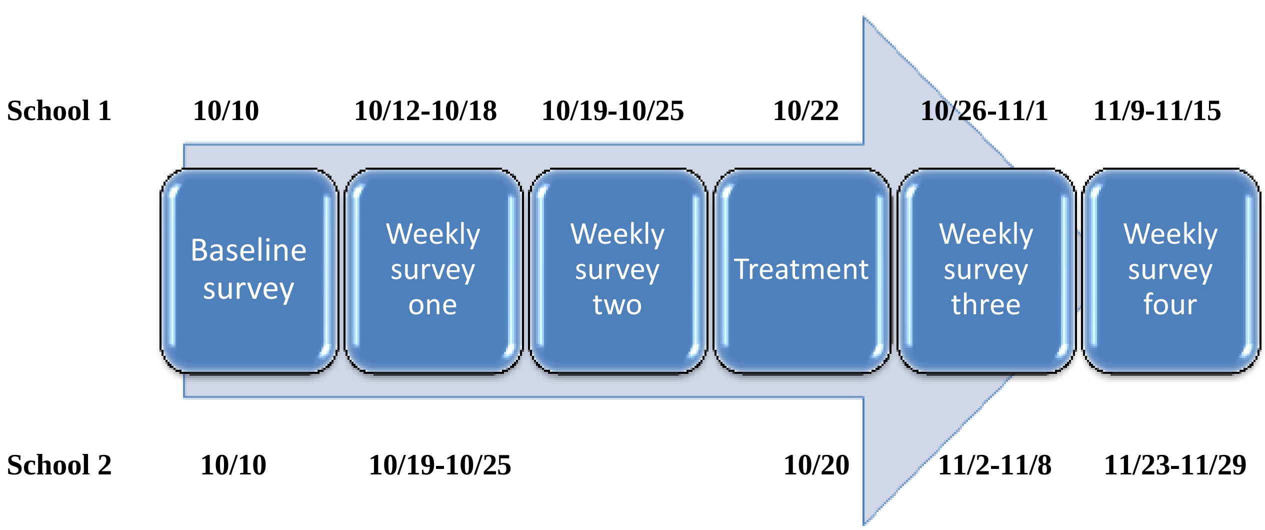


Table II: Balance Check

	Treatment	**Control**
N	**100**	**217**
Age (average)	16.3	16.2
Gender (%)		
Male	61	61
Female	39	39
Grade (%)		
7th	23	29
8th	19	17
9th	19	18
10th	26	22
11th	8	7
Rheto	3	5
Philo	3	3
N	**50**	**102**
How long to school? (%)		
1-30 minutes	46*	53*
30 minutes-1 hour	30*	27*
1-2 hours	12*	11*
>2 hours	6*	4*
Hours of electricity at home (%)		
0-1	92*	91*
1-2	2*	1*
>2	2*	5*
Father works (%)		
Yes	90*	81*

No	0*	4*
Mother works (%)		
Yes	68*	73 *
No	16*	12*
Books to read at home? (%)		
Yes	28*	29*
No	68*	65*

* Indicates statistics from one school

5. Methodology

The panel data resulting from the surveys sent to both schools offers close to 5,000 observations of reading, homework and studying time to analyze. The panel data was collected daily, but averaged for the sake of creating weekly variables. To determine the impact of solar lanterns in the surveyed schools, I estimate a fixed effects model of the form:

$$Y_{it} = \alpha_0 + \alpha_1 T_{it} + a_2 \delta_t + a_3 X_i + \varepsilon_{it}$$

where *i* represents an individual student, *t* represents the week of the survey, Y_{it} equals the averaged outcome of interest across each week—time spent reading, completing homework and studying. T_{it} represents the treatment variable. It takes a value of 1 if the student owns a lantern at week *t* and 0 if the student does not. δ_t is a time fixed effect. X_i is a vector for controls including gender, age and whether or not parents assist their children with homework. The vector X_i also includes fixed school and grade effects which essentially hold constant the unobserved differences between schools and across grades that could influence the dependent variable. The standard errors of this model are clustered at the school-grade level.

The regression framework, then, follows a difference-in-difference approach. Since the treatment for both schools was introduced after week 2, the regressions during weeks 1 and 2 take the following form:

$$Y_{i2} = \alpha_0 + a_1\delta_t + a_2X_i + \varepsilon_{i2}$$

After week 2, the regressions take a slightly different form, now reflecting the distribution of the treatment:

$$Y_{i3} = \alpha_0 + \alpha_1 T_{i3} + a_2\delta_3 + a_3X_i + \varepsilon_{i3}$$

Thus, the effects of the lanterns can be ascertained by differencing the two models:

$$(Y_{i3}T - Y_{i3}C) = (Y_{i2}T - Y_{i2}C)$$

$$[(\alpha_0 + \alpha_1 T_{i3} + a_2\delta_3 + a_3X_i + \varepsilon_{i3}) – (\alpha_0 + a_1\delta_3 + a_2X_i + \varepsilon_{i3})]-$$

$$[\ (\alpha_0 + a_1\delta_2 + a_2X_i + \varepsilon_{i2}) – (\alpha_0 + a_1\delta_2 + a_2X_i + \varepsilon_{i2})]$$

$$\Delta Y = \alpha_1$$

Because the lanterns were distributed randomly within the schools, the estimate of the treatment effect—α_1—represents the average weekly change in reading, homework or studying time that is attributed to the lanterns over the four week time period. Put differently, this regression framework isolates α_1 as the average causal effect of providing solar lanterns to the students in the treatment group.

Two caveats are worth noting. The sample size is relatively small for an experiment of this type. Only two schools were available and eligible to take part in the study. Moreover, the study takes place over only a few weeks, a somewhat short period of time to fully realize the impact of the treatment. Additionally, missing survey data simply limits what data can be analyzed. In an ideal scenario, several more schools would be involved in the study and the sample population would be surveyed for months, rather than weeks. The availability of only

100 solar lanterns and general limitation of time and resources made these two schools and the time period of analysis the most realistic option for the study.

Another potential issue with this study involves reporting error. Admittedly, no incentive exists for the students to report their reading, homework and study times accurately. I conduct a robustness exercise in which I eliminate outliers in the data and find that it does not alter the results much. Additionally, teachers in these two schools administered the surveys and kept the charging panels for the lanterns at the schools, to serve as a check on the students to make sure they brought back the lamps for charging and were using them for after-school educational activity. Yet, I realize these checks do not fully eliminate the possibility of reporting error. If reporting error in the dependent variable exists, it likely increases the variance and standard errors of the coefficients in the regression model.

6. Main Results

Table III contains the results for the impact of solar lanterns on a student's average daily reading, homework and study times. The unit of observation is a student's self-reported daily entry for reading, homework and study times averaged across each week. Thus, a student can have up to four observations, one for each week of the experiment. Of course, missing data and the trimming of outliers in the sample limit the number of observations used in this analysis. Observations from students beyond four hours of reading, completing homework or studying were dropped from the sample. In **Appendix A-Table IX,** I present the same regressions without trimming the outliers and find that it does not impact the results much. The sample averages for each outcome are higher in **Table IX** than in **Table III** as are the point estimates, but not drastically so. Additionally, the number of observations between **Tables III** and **IX** do not deviate much. With controls, the results of the regression including outliers indicate that students in the treatment group read an average of 23 minutes more, complete an average of 23 more minutes of homework and study an average of 19 more minutes each day than students in the control group. The estimates for the average treatment effect on studying times in **Table III**, however, are not statistically significant while they are in **Table IX**.

Columns 1-3 present the fixed effects regression results for reading, homework and studying times, respectively. The remaining columns correspond to a fixed effects regression controlling for several background characteristics. For this set of regressions, columns 4-6 again correspond to reading, homework and studying times, respectively. The estimates on fixed effects variables are omitted for simplicity.

Table III: Main Fixed Effects Regression

N	714	719	712	655	660	654
	(1)	(2)	(3)	(4)	(5)	(6)
	Reading	Homework	Studying	Reading	Homework	Studying
Average outcome for sample	80.52	75.65	106.20	80.52	75.65	106.20
Treatment	18.84*	19.06***	14.73	19.48*	22.21**	16.76
	(3.01)	(4.37)	(1.94)	(2.71)	(4.20)	(2.16)
Age				2.91	3.06*	-0.16
				(2.35)	(2.48)	(-0.11)
Gender (Male=1)				5.19	3.78	15.70
				(0.64)	(0.42)	(2.15)
Parental assistance				-2.50	0.52	-3.68
				(-0.58)	(0.12)	(-1.06)
Controls	N	N	N	Y	Y	Y

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

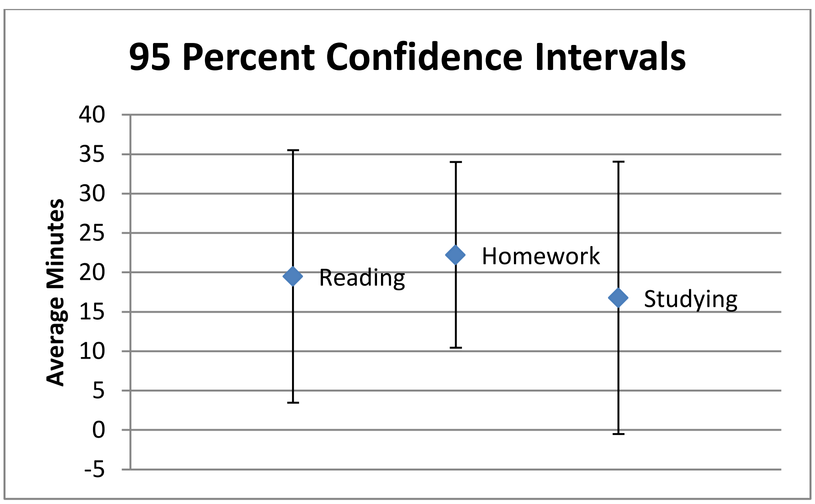
Row 1 of **Table III** captures the treatment's impact on a student's time in after-school educational activity. In analyzing the standard fixed effects regression, one can see that the treatment causes a student with a solar lantern to read close to an average of 19 minutes longer **(1)**, complete homework for an average of 19 minutes longer **(2)** and study for an average of 15 minutes longer **(3)** each day. The reading and homework regression return results with statistical significance, but the results from the studying regression do not.

Columns 4-6 correspond to a series of regressions including controls for a student's age, gender and a dummy variable indicating whether or not the student's parents assist with studies. As expected due to the randomization, adding the controls does not alter the results dramatically. When including these controls, a student with a solar lantern still reads an average of 19 minutes more **(4)**, completes an average of 22 more minutes of homework **(5)** and studies an average of 17 more minutes each day **(6)** than students without a solar lantern. Again, the reading and homework regression results have statistical significance, while the results of the studying regression do not. Therefore, the solar lanterns have a meaningful impact on reading and homework times, but not enough evidence exists to say the same for studying times.

A few more findings emerge upon further analysis. The comparability of the results between the regressions with and without controls represents another check on the effectiveness of the random distribution of lanterns. The treatment still explains a comparable amount of variation in after-school educational activity when including controls. Moreover, a comparison of the reading and homework times between the treatment and control groups helps give further context to the impact of the solar lanterns. A student in the sample without a lantern will read an average of 77 minutes per day, suggesting that a student with a lantern will read an average of 96 minutes per day. Similarly, a student in the sample without a lantern will complete homework for an average of 73 minutes per day. The results indicate that a student with a solar lantern will complete an average of about 95 minutes of homework per day. Overall, the solar lanterns cause an average increase in reading and homework times by 25 and 30 percent over the baseline, respectively.

Interpreting the regression results in a slightly different light, **Figure 3** presents the 95 percent confidence intervals for reading, homework and studying regressions. The intervals of likely values for reading and homework times illustrates that the solar lanterns are positively impacting these student outcomes. Confirming the earlier results, the interval for studying ranges past zero into the negatives, indicating that the null hypothesis cannot be rejected. The results for the solar lanterns' impact on a student's studying times are inconclusive.

Figure 3: 95 Percent Confidence Intervals for Reading, Homework and Studying



	Coefficient	5%	95%
Reading	19.48	3.44	35.52
Homework	22.21	10.42	34.01
Studying	16.76	-0.53	34.04

Worth mentioning is the possibility of double or triple counting present here. All three confidence intervals share a range of average daily minutes in the graph, which further confirms that the solar lanterns are causing some sort of increase in after-school educational activity. However, these measures might overlap in that students double or triple-count reading, homework and study times. For instance, in studying 30 minutes one day, a student may have counted 20 minutes of reading towards reading and studying. Though this possibility might complicate the interpretation of the results, it does not obscure the main finding of the experiment: the solar lanterns cause students in the sample population to spend more time in some after-school educational activity.

Using a slightly different approach, I estimate the impact of the solar lanterns on reading, homework and studying times within each week. **Tables IV**, **V** and **VI** contain the regression results for reading, homework and studying times, respectively. Columns 1-4 correspond to weeks 1-4. Since no student receives a treatment until after week 2, the treatment estimate is unsurprisingly zero for weeks 1-2. As opposed to the average effects seen in **Table III**, these estimates offer a clearer picture as to how the treatment effects evolve over the course of the experiment.

Viewing the results from **Table IV**, it seems clear that the treatment impact more than doubles from week three to week four. Moreover, the treatment and gender estimates for reading times become statistically significant and quite pronounced in magnitude in week four **(4)**. A lower survey response rate in week four may explain this considerable gap. As seen in **Table V**, the treatment estimate for homework times generally follows the same trend of increasing in magnitude from the week three regression to the week four regression, though at a much smaller rate. Moreover, the treatment estimate in **Table V** is statistically significant in week three, but not in week four. The same can be said for the treatment estimates for studying times in **Table VI**. Although the average effects in **Table III** fail to determine a statistically significant impact of the solar lanterns on a student's study times, **Table VI** shows with statistical significance that a student in the sample with a solar lantern studied an average of 29 minutes more than a student without a solar lantern in week four. This finding demonstrates how analyzing the results from a week-to-week perspective nuances the interpretation of the treatment impact. **Figure 4** contains the 95 percent confidence intervals for these regressions. As one can see from the intervals of likely values for the average treatment effects, the intervals increase considerably in week four. That is, the standard errors increase in the week four regressions. The reported reading, homework and studying times cluster together in week three and begin to deviate in week four.

Table IV: Week-by-Week Regression for Reading Times

N	284	805	176	80
	(1)	(2)	(3)	(4)
Average outcome for sample	75.01	80.89	86.72	84.92
Treatment	0	0	15.87 (1.96)	36.42* (2.77)
Age	3.72* (3.01)	4.26 (1.22)	1.98 (1.37)	-2.94 (-0.71)
Gender (Male=1)	-1.41 (-0.17)	13.28 (0.86)	0.62 (0.06)	31.89** (5.04)
Parental assistance	-7.12* (-2.73)	-3.39 (-0.31)	-3.11 (-0.35)	1.98 (0.17)
Controls	Y	Y	Y	Y

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table V: Week-by-Week Regression for Homework Times

N	289	115	176	80
	(1)	(2)	(3)	(4)
Average outcome for sample	69.14	81.17	77.40	86.53
Treatment	0	0	22.61***	24.80
			(4.81)	(2.12)
Age	2.80*	4.83	1.74	1.02
	(2.70)	(1.11)	(0.72)	(0.33)
Gender (Male=1)	-0.65	1.89	4.45	14.04
	(-0.09)	(0.08)	(0.45)	(0.88)
Parental assistance	-1.04	2.61	-8.22	10.70
	(-0.26)	(0.23)	(-0.96)	(1.24)
Controls	Y	Y	Y	Y

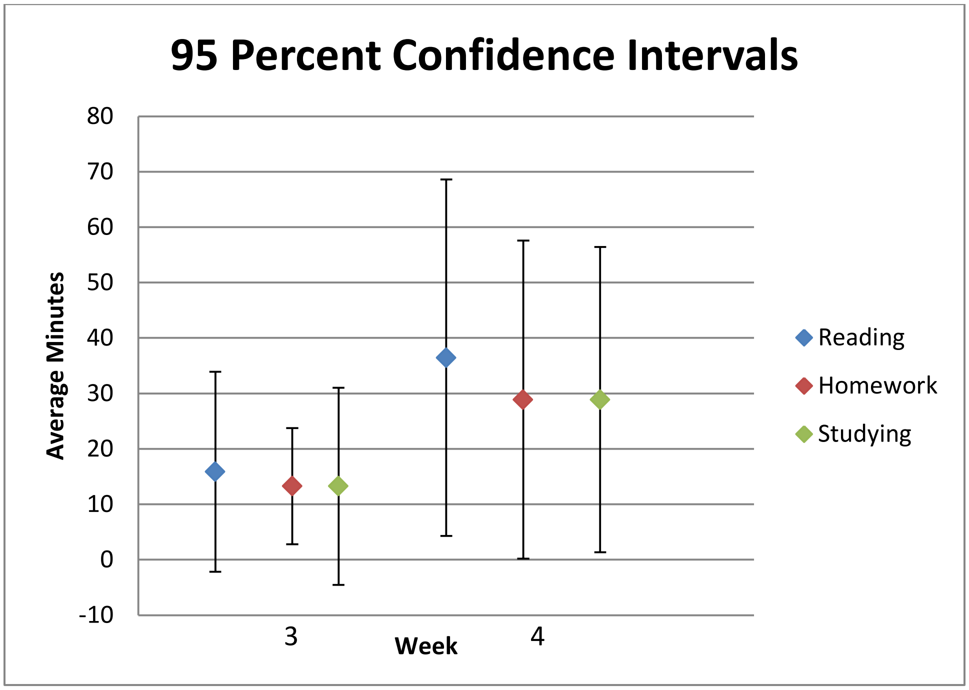
t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table VI: Week-by-Week Regression for Studying Times

N	288	116	170	80
	(1)	(2)	(3)	(4)
Average outcome for sample	99.45	110.75	111.12	112.44
Treatment	0	0	13.25	28.87*
			(1.66)	(2.56)
Age	-0.30	-0.72	-0.58	-0.56
	(-0.16)	(-0.61)	(-0.23)	(-0.16)
Gender (Male=1)	2.95	33.68	23.24*	17.94
	(0.45)	(1.64)	(3.04)	(1.30)
Parental assistance	-9.76	-5.56	-2.75	2.82
	(-1.84)	(-0.78)	(-0.45)	(0.25)
Controls	Y	Y	Y	Y

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 4: Week by Week 95 Percent Confidence Intervals



	Coefficient	5%	95%
Week 3			
Reading	15.87	-2.17	33.91
Homework	22.61	12.14	33.09
Studying	13.25	-4.53	31.04
Week 4			
Reading	36.43	4.28	68.58
Homework	24.80	-3.88	53.48
Studying	28.87	1.33	56.41

Overall, the results show that students with a solar lantern read an average of 19 minutes more and complete homework for an average of 22 minutes longer each day than peers without solar lanterns. Given that LSS can procure these lanterns for 50 USD and each lantern provides at least 27,500 hours over its lifetime, an investment of 50 USD could grant a Haitian student an additional 21,774 hours of reading and 25,212 hours of homework completion over the lifetime of a lantern. This is a back of the envelope calculation, but still illustrates the cost effectiveness of this technology.

7. Potential heterogeneity of impact

Due to the reality of resource-scarcity in these schools, materials are often shared among students. Since lanterns were randomly distributed within classes, friends of students in the treatment group could have access to solar lanterns due to this sharing. From a cost-effectiveness perspective, more sharing of the solar lanterns comes with better access to electricity for more students. If these positive spillover effects exist, solar distributors such as LSS might not need to distribute a lantern to each student. Distributing lanterns to networks of students that work together might achieve the same impact.

These positive spillover effects can be accounted for by including what I will call social network effects into the regression. In the week one survey, students were asked to list five students in their class whom they worked with on homework. I then match those listed with student ID numbers to create a network of study partners. Thus, using that data, I can track possible spillover effects for those in the treatment group and account for said effects with the following model:

$$Y_{it} = \alpha_0 + \alpha_1 T_{it} + a_2 \gamma_i + a_3 X_i + \varepsilon_{it}$$

where γ_i captures these social network effects. In other words, $\gamma_i$captures the spillover effects of the solar lanterns. It takes a value of 1 if a student is in the control group and has a study partner in the treatment group. Otherwise, the value is 0 for all students in the treatment group and all students in the control group with no partner in the treatment group or no partner at all. The estimate on γ_i measures how much sharing a solar lantern will impact reading. In week one, 53 percent of students (167) reported having study partners and 17.5 percent of students in the control group (38) reported that they study with a student in the treatment group.

The results of the regressions when including these social network effects are shown in **Table VII**. Interestingly, the estimate on social network effects on a student's reading time registers at a significantly negative average of 17 minutes per day **(1)**. In other words, a student in the control group who studies with a student from the treatment group will read, on average, 17 fewer minutes per day. The possible explanation for this is not entirely clear, but perhaps these students choose to complete homework or study more when in the presence of study partners, viewing reading as an individual task. Put differently, students with partners in the treatment group could be trading reading time for homework and studying time.

However, that explanation is not likely given the results of the social network effects on homework and study times. A student with a study partner owning a solar lantern completes an average of five fewer minutes of homework and three fewer minutes of studying each day. These estimates do not have statistical significance and also fail to confirm the previous hypothesis. Consequently, while there seems to be evidence for negative spillover effects for reading times, there is no conclusive evidence for spillover effects for homework and studying times. Again, the potential explanation is not entirely clear, but it seems that partnering with a student owning a solar lantern decreases the amount of time control students spend reading. This complicates the approach of providing lanterns to networks of students, as it seems the two approaches do not achieve similar average effects.

Finally, I introduce interaction effects into the model to determine whether the treatment impact varies by different groups within the sample population. The first model interacts the treatment with parental assistance to identify any possible differences in the treatment impact among households that vary in parental involvement:

$$Y_{it} = \alpha_0 + \alpha_1 T_{it} + \alpha_2 (T_{it} * parent\ help) + a_3 X_i + \varepsilon_{it}$$

Here, $(T_{it} * parent\ help)$ measures the treatment impact between students who do and do not benefit from parental assistance in their studies. It takes a value of 1 if a student is in the treatment group and has parents that assist with studies. The estimate of this interaction effect, then, measures the impact of solar lanterns on the reading, homework and studying times of a student who benefits from parental assistance.

Table VII: Fixed Effects Regression Including Social Network Effects

N	655	660	654
	(1)	(2)	(3)
	Reading	Homework	Studying
Treatment	16.82*	21.50**	16.33
	(2.40)	(3.90)	(2.20)
Social network effects	-16.68**	-4.65	-2.69
	(-4.23)	(-1.28)	(-0.55)
Age	2.98*	3.08*	-0.15
	(2.44)	(2.48)	(-0.10)
Gender (Male=1)	6.23	4.06	15.89
	(0.77)	(0.45)	(2.16)
Parental assistance	-2.67	0.47	-3.72
	(-0.62)	(0.10)	(-1.07)

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The other model interacts the treatment with gender to identify differences in the treatment impact between male and female students:

$$Y_{it} = \alpha_0 + \alpha_1 T_{it} + \alpha_2 (T_{it} * gender) + a_3 X_i + \varepsilon_{it}$$

The variable $(T_{it} * gender)$ estimates this interaction effect. It takes a value of 1 if the student is a male in the control group. Consequently, the estimate of this interaction effect measures the impact of a solar lantern on the reading, homework and studying times of a male student compared to those of a female student.

Table VIII: Fixed Effects Regression Including Interaction Effects

N	655	660	654	655	660	654
	(1)	(2)	(3)	(4)	(5)	(6)
	Reading	Homework	Studying	Reading	Homework	Studying
Treatment	15.84	24.71^{**}	22.01^{*}	-1.37	-4.01	-1.40
	(1.93)	(3.80)	(2.60)	(-0.11)	(-0.48)	(-0.17)
Age	2.94^{*}	3.03^{*}	-0.22	2.73	2.85^{*}	-0.311
	(2.46)	(2.45)	(-0.50)	(2.09)	(2.30)	(-0.20)
Gender (Male=1)	5.08	3.86	15.82	1.12	-1.28	12.30
	(0.63)	(0.43)	(2.14)	(0.12)	(-0.14)	(1.58)
Parental assistance	-3.61	1.27	-2.14	-3.16	-0.28	-4.16
	(-0.86)	(0.33)	(-0.50)	(-0.74)	(-0.06)	(-1.17)
Treatment and parental effect	8.39	-5.74	-12.20			
	(0.77)	(-0.65)	(-0.98)			
Treatment and gender effect				30.89^{*}	38.84^{***}	27.03^{**}
				(2.27)	(4.46)	(3.37)

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table VIII includes the results of the regressions including interaction effects. When interacting the treatment with parental assistance as in columns 1-3, the combined treatment and parental effect improves daily reading times by an average of eight minutes and with no statistical significance **(1)**. As with the reading regression, the interaction effect between the treatment and parental assistance on homework times fails to register statistical significance.

The interpretation indicates that having a solar lantern in a household with parents that assist their children with schoolwork will cause students to spend an average of six fewer minutes completing homework daily **(2)**. This result comes without statistical significance, possibly due to the fact that the sample only includes two schools. Nevertheless, it introduces an important consideration. These estimates say nothing of the motivation behind this work. Parental assistance could mean that students complete their homework sooner, indicating an improvement in efficiency rather than a negative result. The interaction term between the treatment and parental assistance on study times in **(3)** mirrors the result in the homework regression, only with greater magnitude. No statistical significance can be attached to this estimate.

The estimates on the interaction of the treatment and gender in columns 4-6, however, are statistically significant and significant in magnitude. Contrary to evidence cited earlier, the average impact of solar lanterns on reading seems to be more pronounced for males—in this case, by a daily average of 31 minutes **(4)**. Similarly, the interaction effect between the treatment and gender on homework times generates a high point estimate. The effect of a male student using a solar lantern brings an average of about 39 more minutes of homework time each day, which builds on the results that can be seen from the reading regression **(5)**. The interaction effect between the treatment and gender on study times remains relevant in magnitude and statistically significant. A male student with a solar lantern will study for an additional average of 27 minutes per day **(6)**.

Worth noting is the difference in estimates for average treatment effects between male and female students. In columns 4-6, the treatment row indicates the average treatment effect for female students. All three estimates for reading, homework and studying are negative and much smaller in magnitude than the estimates for the average treatment effect for male students.

Moreover, the estimates for the average treatment effect for female students are not significantly different from zero.

Considering one potential explanation behind this, it could be that education for female students garners less attention that education for males. Perhaps female students are directed towards other activities in the household and thus have less time for after-school educational activity when compared to their male counterparts. Evidence on educational attainment suggests that there are substantially different incentives for boys and girls to finish school. In fact, in 2010, 31.2 percent of the male population in Haiti had completed secondary school compared to 2.1 percent of the female population (Barro and Lee, 2010).

8. Conclusion

In this study, I conducted a randomized controlled trial in which 100 solar lanterns were distributed among a population of Haitian secondary students from two rural schools. Reading, homework and studying times were self-reported on weekly surveys. Three main conclusions can be drawn from this analysis:

1. **On average, solar lanterns cause students to spend more time in daily after-school educational activity**

From the results of this experiment, development practitioners in Haiti who engage in distributing solar lanterns to students have evidence to answer the question posed at the beginning of this paper in the affirmative: the solar lanterns seem to work. Students with a solar lantern read an average of 19 minutes more and complete homework for an average of 22 minutes longer each day than peers without solar lanterns. I failed to uncover conclusive results for the average impact of solar lanterns on a student's studying time. However, further research with larger sample sizes and more data should confirm the general improvement in a student's time in after-school educational activity. Similarly, carrying out such research in other contexts in or outside of Haiti should uphold the external validity of the study.

2. Electricity plays an important role in improving educational outcomes

The results from the difference-in-difference estimation underscore the role between electricity and positive educational outcomes. Much of development literature points to the many uses of electricity among the rural poor, including lighting during the evening hours. Nevertheless, the electricity from these lanterns helped these students spend more time in after-school educational activity. In this case, electricity improved educational outcomes. This study therefore provides another rationale for rural electrification projects, especially in contexts like Haiti where challenges to providing quality education are significant.

3. Solar lighting can be an effective substitute for the electric grid or diesel generators

The value of the solar lanterns is the electricity they provide. Access to electricity, regardless of the medium, might produce the same results as seen in this experiment. Yet, given the poor reach and general unreliability of the electricity grid and the price of diesel fuel for Haitians, solar electricity seems to be an effective substitute for conventional energy sources. As was mentioned earlier, an investment of 50 USD could grant a Haitian student an additional 21,774 hours of reading and 25,212 hours of homework completion over the lifetime of a lantern.

Adding to the latter point, evidence for the cost-effectiveness of solar vs. diesel electricity exists. The Namibian Ministry of Mines and Energy, together with the Global Environment Facility and the United Nations Development Programme, commissioned a study in 2006 analyzing the cost effectiveness of solar vs. diesel powered water pumps. At low levels of energy demand, the solar powered pump cost about 20 percent of the diesel pump. At higher levels of energy usage, the solar pump costs still approached only about 55 percent of the diesel costs (Namibia Ministry of Mines and Energy, 2006: 8). Other similar studies confirm the findings of this report: solar energy, while associated with high up-front costs, costs less over its lifetime than diesel alternatives. Extrapolating this back into the Haitian context, it becomes clear why solar lanterns deserve so much attention. In the absence of a reliable electricity grid that connects all of Haiti, solar technology seems like a reasonable alternative to providing lighting during the evening, especially for increasing after-school educational activity.

References

Action Plan for National Recovery and Development of Haiti. *Haiti Earthquake PDNA: Assessment of damage, losses, general and sectoral needs*. March 2010. Web. 5 January 2015. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2012/06/19/000333038_20120619012320/Rendered/PDF/701020ESW0P1190R0Haiti0PDNA020100EN.pdf

Adelman, Melissa A.; Holland, Peter A.. 2015. *Increasing Access by Waiving Tuition : Evidence from Haiti.* World Bank Group, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/21392 License: CC BY 3.0 IGO.

Barkat, Abul. "Economic and Social Impact Evaluation Study of the Rural Electrification Program in Bangladesh." *Human Development Research Centre* (2002): 1-668. Web. 28 Feb. 2015.

Barro, Robert and Jong-Wha Lee, April 2010, "A New Data Set of Educational Attainment in the World, 1950-2010." *Journal of Development Economics*, vol 104, pp.184-198.

Becker, Gary S. "Investment in Human Capital: A Theoretical Analysis."*Journal of Political Economy* 70.S5 (1962): 9-49. *JSTOR*. Web. 5 Jan. 2015.

"Children's Recode." No Records. The World Bank, 2012. Web. 18 Apr. 2014. http://dhsprogram.com/data/dataset/Haiti_Standard-DHS_2012.cfm?flag=0

Crane, Keith et al. "Building a More Resilient Haitian State." Santa Monica, CA: *RAND Corporation*, 2010. http://www.rand.org/pubs/monographs/MG1039.

Demombynes, Gabriel; Holland, Peter; Leon, Gianmarco. 2010. *Students and the Market for Schools in Haiti.* World Bank. © World Bank.

https://openknowledge.worldbank.org/handle/10986/3985 License: Creative Commons Attribution CC BY 3.0.

"Electricity Access in Latin America." *World Energy Outlook 2014*. International Energy Agency, Web. 25 Apr. 2015.

"Traditional use of biomass for cooking in Latin America – 2012." *World Energy Outlook 2014*. International Energy Agency, Web. 25 Apr. 2015.

Gustavsson, Mathias. *Solar Energy for a Brighter Life: A Case Study of Rural Electrification through Solar Photovoltaic Technology in the Eastern Province, Zambia*. Dissertation, University of Göteborg: 2008. Web. 13 November 2013.

Haiti Bureau of Mines and Energy. *Haiti Energy Sector Development Plan 2007-2017*. November 2006. Web. 5 January 2015. http://www.bme.gouv.ht/energie/National_Energy_Plan_Haiti_Revised20_12_2006VM.pdf

Haiti Ministry of Planning and External Cooperation. *Growth and Poverty Reduction Strategy Paper 2008-2010*. November 2007. Web. 5 January 2015. http://siteresources.worldbank.org/INTPRS1/Resources/Haiti-PRSP(march-2008).pdf

Independent Evaluation Group. 2008. *The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits.* Washington, DC : World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/6519 License: Creative Commons Attribution CC BY 3.0 Unported.

Jacobson, Arne. "Connective Power: Solar Electrification and Social Change in Kenya." *World Development* 35.1 (2007): 144-62. *Science Direct*. Web. 30 June 2014

Manuelli, Rodolfo E., and Ananth Seshadri. 2014. "Human Capital and the Wealth of Nations."*American Economic Review*, 104(9): 2736-62. Web. 20 April 2015.

Namibia Ministry of Mines and Energy. *Feasibility Assessment for the Replacement of Diesel Water Pumps with Solar Water Pumps*. September 2006. *Emcon*. Web. 15 April 2015. http://www.mme.gov.na/energy/pdf/Solar%20PV%20water%20pumping%20study%20-%20FINAL%20REPORT%20%28Single%20sided%29.pdf

"Pico Lamp/System | Phocos.com." *Pico Lamp/System | Phocos.com*. Phocos, n.d. Web. 26 Apr. 2015. http://www.phocos.com/products/pico-lampsystem

Prince, Andrew. "New NASA Images Show The Earth's Electric Light Show."*NPR.org*. NPR, 5 Dec. 2012. Web. 8 Apr. 2015. http://www.npr.org/blogs/pictureshow/2012/12/05/166587600/new-nasa-images-show-the-earths-electric-light-show

"UNESCO Institute for Statistics." *UNESCO Institute for Statistics*. United Nations, n.d. Web. 25 Apr. 2015.

World Bank. 2002. *Rural Electrification and Development in the Philippines : Measuring the Social and Economic Benefits*. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/19890 License: CC BY 3.0 IGO.

World Development Indicators 2014. Washington, DC: World Bank. doi:10.1596/978- 1-4648-0163-1. License: Creative Commons Attribution CC BY 3.0 IGO

Appendix A

Table IX: Main Fixed Effects Regression Including Outliers

N	703	713	714	645	655	656
	(1)	(2)	(3)	(4)	(5)	(6)
	Reading	Homework	Studying	Reading	Homework	Studying
Average outcome for sample	88.21	80.77	112.02	88.21	80.77	112.02
Treatment	22.9*	20.32**	16.23*	22.51*	22.52**	18.59*
	(2.66)	(4.95)	(2.26)	(2.24)	(3.72)	(2.97)
Age				3.36*	2.79	-0.29
				(2.22)	(2.06)	(-0.16)
Gender (Male=1)				12.12	4.65	17.48
				(1.12)	(0.47)	(2.08)
Parental assistance				-1.82	2.20	-4.07
				(-0.39)	(0.42)	(-1.01)
Controls	N	N	N	Y	Y	Y

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$