Poor Sleep: Sunset Time and Human Capital Production*

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Abstract

This paper provides the first evidence on the long run importance of child sleep for learning outcomes. I show later sunset reduces children's sleep: when the sun sets later, children go to bed later; however, children fail to compensate by waking up later. Sleep-deprived students decrease time spent studying and increase time allocated to sedentary and compensatory leisure activities. Overall, sustained sunset-induced sleep deficits translate into fewer years of education and decrease primary and middle school completion rates among school-age children.

JEL Codes: O15, I00, O43, D02, J13, J22, J24

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1 Introduction

People in poorer countries tend to get less sleep.[1] If sleep deprivation is associated with cognitive underperformance (Killgore, 2010; Lim and Dinges, 2010), chronic sleep deficits could impede human capital development and deepen poverty (Barro, 2001; Deaton, 1997; Fogel, 2004; Nelson and Phelps, 1966; Romer, 1986). However, we know little about the long-run effect of child sleep on learning outcomes that is net of all accumulative effects and adaptive behavior, which is what we care about for policy (Das et al., 2013; Muralidharan, 2017). Using sunset time as a source of exogenous variation, I provide the first estimates of the effects of chronic sleep deficits on children's learning outcomes in the long run.

As the sun sets and the sky grows darker, the human brain releases melatonin, a hormone that facilitates sleep (Roenneberg and Merrow, 2007). Yet social norms or uniform policy choices at the federal or state level – for example, start times for school and work – may dictate wake-up times that do not co-vary with sunset time (Hamermesh, Myers and Pocock, 2008). As a result, children exposed to later sunsets may get less sleep. Experiments in sleep laboratories that assess the impact of short-term sleep loss on attention, memory, and cognition, find very large effects: the typical elasticity is roughly four (see Gibson and Shrader, 2018, for a brief review of short-run causal studies). Therefore, children exposed to later sunsets may have non-trivial sleep deficits with real human capital impacts.

However, how children trade-off sleep with other time uses may have multiplicative or compensatory effects on education production. If sleep makes study effort more productive, later sunset may not only reduce sleep but also make studying less effective, decreasing study time. In a context where child labor is common – lower income countries – any complementarities between sleep and study effort may also depend on the marginal increase in children's labor productivity with respect to sleep. Sleep deprivation may also make labor effort less productive, decreasing the opportunity cost of study time. Therefore, any trade-offs between study time and work time will depend on the relative decrease in study productivity and labor productivity with respect to sleep deprivation.

In the first part of the paper, I use a unique time use data set, the 1998-99 Indian

[1] Tozer, James. 2018. "Which countries get the most sleep?" The Economist/1843, April/May 2019. https://www.1843magazine.com/data-graphic/what-the-numbers-say/which-countries-get-the-most-sleep.

Time Use Survey (ITUS), to evaluate the effect of later sunset on children's time use. ITUS provides 24-hour time use data, collected with less than a 24-hour recall lapse, allowing me to assign each observation sunset time at the district-interview-date level. My baseline econometric specification exploits seasonal variation in *daily sunset time* at the district level after controlling for fixed district-specific characteristics (e.g., district school governance) via district fixed effects and seasonal confounders common across all districts in the sample (e.g., national festivals) via week-of-the-year fixed effects. The identification assumption underlying this research design is that there exist no district-specific seasonal characteristics that co-vary with both children's time use and sunset time. This assumption may be violated for a few reasons like provincial weather or provincial school- or agricultural calendar. I use two approaches to examine the validity of this assumption: (i) control for seasonal observables at the district level (e.g., temperature, precipitation), and (ii) flexibly control for district-specific seasonal unobservables via district-by-season fixed effects such that any omitted variables must operate within a season for specific districts.

I show that an hour delay in sunset time reduces children's sleep by roughly 30 minutes: when the sun sets later, children go to bed later; however, children fail to compensate by waking-up later. Sleep-deprived children decrease time spent on homework or studying; they instead increase time spent on sedentary (talking) and compensatory (daytime naps) leisure, precisely as predicted by numerous sleep and pediatric studies.

These aggregate results mask substantial heterogeneity by children's primary activity: sleep-deprived *students* decrease time spent on homework or studying. Sleep-deprived *child laborers* decrease time spent on formal and informal work. These results suggest sleep is relatively more study-productivity enhancing than labor-productivity enhancing for students, and relatively more labor-productivity enhancing than study-productivity enhancing for child laborers.

This is the first paper to examine how children trade off productive sleep against time allocated to study and work effort. Biddle and Hamermesh (1990) model sleep as a choice variable that affects productivity. However, they focus on the causal mechanism operating in the opposite direction. They find time spent in the labor market reduces sleep duration. Gibson and Shrader (2018) investigate how sleep deprivation induces trade-offs between productive sleep and work effort; however, they fail to find conclusive evidence on said trade-offs. Furthermore, their findings relate only to adults: the American Time Use Survey does not collect time use data for children. Because sleep is the largest use of non-market time, these results also relate to seminal papers of Mincer (1962) and Becker (1965), as well as recent work by Aguiar et al. (2016), that emphasize that labor supply is influenced by how time is allocated outside of market work. Lastly, these results also relate to a new literature that investigates the determinants of lack of study time among students (Oreopoulos and Petronijevic, 2019; Oreopoulos et al., 2018).

The second part of the paper examines the consequent effects of sunset-induced sleep deficits on learning outcomes in the short- and long run. Using an individual level longitudinal panel from Andhra Pradesh, India, the Young Lives Survey (YLS), wherein the same child is administered low-stakes math tests at different days of the year across survey rounds, I provide evidence for the deleterious effects of short-term sunset-induced sleep deficits on children's test scores. I leverage seasonal variation in *daily sunset time* at the district level; I compare test scores between children from eastern and western districts, who were administered the math test in the same week. I show an hour delay in sunset time reduces math scores by roughly 0.6 standard deviations (sd). To test robustness, I control for fixed child-specific characteristics via lagged test scores and child fixed effects.

This result relates to several U.S. studies that examine short-run effects of sleep deprivation on test scores using variation provided by school start times (Carrell, Maghakian and West, 2011; Edwards, 2012; Heissel and Norris, 2017; Hinrichs, 2011; Wahlstrom, 2002) and daylight savings time transitions (Gaski and Sagarin, 2011; Herber, Quis and Heineck, 2017). These studies find mixed results. These effects – or lack thereof – are mediated through changes in children's time use, although, unlike my paper, the above-mentioned papers do not observe children's sleep or consequent trade-offs with other uses of time. Furthermore, to my knowledge, this paper provides the first well-identified estimates of the short-run consequences of lower sleep duration for children's learning outcomes in a lower-income country. A priori there is no reason to expect similar short-run effects of sleep deprivation in developed and developing countries. For instance, unlike experiments in developed countries that assess the impact of short-term sleep loss, a new experiment in India finds increasing sleep had no productivity effects in the short run, presumably due to the highly fragmented and inefficient nature of baseline sleep among the study population: low-income urban adults in Chennai (Bessone et al., 2019). Lastly, if one were to compare short-run effects of sleep deprivation to the long-run effects of sleep deprivation at issue in this paper, two differences have offsetting effects. First, effects of sleep deprivation on education production could accumulate (Basner et al., 2013; Van Dongen et al., 2003). Second, short-run impacts may be mitigated in the long-run by individuals' adjustments (Barreca et al., 2016; Samuelson, 1947; Zivin, Hsiang and Neidell, 2018).

Using nationally-representative data from the 2015 India Demographic and Health Survey (DHS), I provide first evidence on long run importance of child sleep for learning outcomes. I examine how children's education outcomes co-vary with *annual average sunset time* across eastern and western locations within a district.[2] I find that an hour delay in annual average sunset time reduces years of education by 0.8 years. School-age children in geographic locations that experience later sunsets are less likely to complete primary and middle school as well as are less likely to be enrolled in school. I replicate these results using a nationally representative rural sample of Indian households, the 2006 Rural Economic and Demographic Survey (REDS). Lastly, analogous to the effects of chronic sunset-induced sleep deficits on children's learning outcomes in the long run, I show annual average sunset time is negatively associated with wages paid to child laborers.

The difference between short- and long-run estimates reflects the accumulated impacts of chronic sunset-induced sleep deficits on learning plus the impacts of any ex post compensatory behaviors (e.g., daytime naps). To shed light on which effect dominates, I convert the short-run estimate, captured via decrease in test score standard deviations, to equivalent years of schooling (-3.5 years) following Evans and Yuan (2019), and compare it to the long-run effect (-0.8 years). Difference between the two estimates suggests individuals' adaptation is partially successful in mitigating the accumulative effects of chronic sunset-induced sleep deficits. Yet, the unmitigated effects are quantitatively significant.

This result relates to two recent papers that examine long-run implications of sleep

[2] A one hour difference in annual average sunset time between two locations indicates that on average the sun sets an hour later *everyday* in one location compared to the other location.

deprivation using exogenous variation provided by sunset time. Gibson and Shrader (2018) estimate the effects of sleep deprivation on both short- and long-run wages for U.S. adults, while Giuntella and Mazzonna (2018) investigate the effects on long-run health outcomes among adults in the U.S. Of these, only Gibson and Shrader (2018) evaluates how individuals trade-off sunset-induced sleep deficits with other activities. However, unlike Gibson and Shrader (2018), I use time-of-day activity data to provide evidence for a causal chain linking sleep and productivity, and rule out alternative explanations. Furthermore, in contrast to these studies, I provide suggestive evidence in support of individual adaptation in mitigating the accumulative productivity effects of chronic sleep deprivation, and generate back-of-the-envelope estimates that quantify the impacts of said adaptation. Lastly, a growing body of work suggests education offers a wide-range of benefits that extend beyond increases in labor market productivity: improvements in education can lower crime, improve health, and increase voting and democratic participation (Lochner, 2011). Therefore, the association between sunset-induced sleep deficits and educational attainment may, at least partially, explain long-run effects of sleep deprivation on both adult wages and health outcomes.

The rest of the paper is organized as follows. Section 2 provides a brief background on children's sleep in India and the relationship between sunset time and sleep. Section 3 describes the data. Section 4 investigates the effects of later sunset on children's sleep and examines how children trade off sleep against other time uses. Section 5 investigates the effects of sunset-induced sleep deficits on children's learning outcomes in the short- and long run. Section 6 concludes.

2 Background

Children's Sleep in India: Medical experts recommend *at least* 9 hours of sleep for school-age children.[3] However, roughly 40% of school-age children in the ITUS sample get less than 9 hours of daily sleep, the minimum recommended sleep duration. In fact, the

[3]Unfortunately, medical experts do not agree on how much sleep children need (see Matricciani et al. (2013) and Ohayon, Carskadon and Guilleminault (2004) for a systematic review): The National Heart, Lung and Blood Institute (NHLBI) and the Harvard Medical School recommend 10 hours and 9 hours of sleep for children between 5-18 years of age, respectively. Recently, a NSF assembled multidisciplinary expert panel recommended that school-age children sleep 9 to 11 hours (Hirshkowitz et al., 2015). The American Academy of Sleep Medicine issued a similar recommendation (Paruthi et al., 2016).

median school-age child in the ITUS sample gets 9 hours of daily sleep. Therefore, the returns to an additional hour of sleep may be particularly large for children in India.

There may be numerous reasons why most school-age children in India do not get more sleep. Living conditions in developing countries are associated with noise, heat, mosquitoes, overcrowding, and overall uncomfortable physical conditions, that may inhibit sleep; for instance, 900 million Indians, or nearly 75% of India's households, with an average family size of five, live in two rooms or less (Census, 2011). In fact, a recent survey of >1000 children between 8 and 13 years of age in India finds on average 4.5 (2.6) individuals sleep in a single room in rural (urban) areas; moreover, nearly three-fourth children in the survey shared their bed (Gupta et al., 2016). Like the median child in ITUS, children in the survey get approximately 9 hours of daily sleep. This reflects as their "need for the sleep" during the day and results in napping. Similarly, a survey of school-age children in China finds bed- and room-sharing is positively correlated with six types of sleep problems: bedtime resistance, sleep anxiety, night waking, parasomnia, sleep-disordered breathing, and daytime sleepiness (Li et al., 2008).

Sunset Time and Sleep: The relevance of sunset time for sleep stems from the biological relationship between sleep patterns and daylight. Human circadian rhythm is synchronized with the rising and setting of the sun through a process known as entrainment. As the sun sets and the sky grows darker, the human brain releases melatonin, a hormone that facilitates sleep (Roenneberg, 2013; Roenneberg and Merrow, 2007). In a vacuum, later sunset time might cause children to go to bed later and also rise later, leaving sleep duration unchanged. Yet morning coordination constraints – due to start times for school or work – may dictate wake-up times that do not co-vary with sunset time (Hamermesh, Myers and Pocock, 2008), especially in overcrowded environments, where bed- and room-sharing is common.

In this paper, I take advantage of both seasonal variation in daily sunset time at the district level as well as geographic variation in annual average sunset time at the village level. Figure B.1 shows variation in daily sunset time for four ITUS districts: The amplitude of the wave is determined by the latitude of the location, and the vertical translations are due to longitude or east-west variation in sunset time across India. Figure B.2 shows variation in annual average sunset time for four DHS villages: India covers a vast east-west range – spanning roughly 30° longitude – but follows a standard time zone across her territorial boundaries – corresponding with a two-hour difference in annual average sunset time.

3 Data

I use a unique 24-hour time use data set and multiple education data sets from India to analyze how later sunset affects children's sleep and how children trade-off sleep with other uses of time as well as the effects of sunset-induced sleep deficits on learning outcomes in the short- and long run. The features of the core data sets that are most relevant for my analysis are described below.

3.1 India Time Use Survey (ITUS)

ITUS is the first time use survey of its size and coverage amongst developing countries. Over 18,000 households were surveyed in 52 districts across 6 states between July, 1998 and June, 1999. States were selected to give geographical representation to each region of the country. Within each state, households were randomly selected based on a sampling procedure designed to ensure a representative sample at the state level. The survey was spread over one year to account for seasonal variation in activity patterns.

Time use data were collected for all household members over five years of age. Thus, ITUS collects time use data for children, which is rare amongst such surveys. For instance, the American Time Use Survey only collects data for individuals over fourteen years of age. For each household, time use data were collected for three types of days: normal (usually weekdays), weekly variant (usually Sundays), and abnormal (festivals or holidays). Initially, an investigator collected information for these three types of days within the week from different members of the selected households. Then, the investigator revisited households accordingly and interviewed individuals about their time allocation decisions for those particular days.[4] Using the interview date and district identifiers, I determine sunset time for

[4]For instance, if the normal date for an individual was a Monday, the investigator visited the individual on Tuesday of the same week to collect time use data for that prior Monday. That is, interviews were conducted such that time use data could be collected with less than a 24-hour recall lapse. See Pandey (1999), for a detailed overview of the sampling strategy and data

each individual corresponding to the date for which the time use data were collected.[5,6]

To examine the effects of later sunset on children's time use, I restrict the sample to school-age children less than 17 years of age. 55% of children in the sample are male, and 70% reside in rural areas. Importantly, the primary activity for only 8 out of 10 children is schooling; 19% of the sample of school-age children primarily engages in some form of child labor. On average, 6 out of 7 days in a week are normal days, while only 1 day is a weekly variant suggesting 6-day work/study weeks. Correspondingly, time use data for only 4% of the normal day sample were collected for a Sunday, while time use data for 66% of the weekly variant sample were collected on a Sunday.[7] Therefore, I will restrict my analysis to the normal day sample. I will refer to the normal day sample as the 'weekday' sample and the weekly variant sample as the 'weekend' sample.

In the survey, daily activities were classified in 152 activities across 9 broad categories: 1) primary production, 2) secondary production, 3) trade, business and services, 4) household maintenance, management and shopping for own households, 5) care for children, sick and elderly, 6) community services and help to other households, 7) learning, 8) social and cultural activities, mass media etc., and 9) personal care and self-maintenance. I further grouped these categories into five brackets: sleep, study, school, leisure, and work. 'Work' includes categories 1 to 6,[8] while 'leisure' includes all items from categories 8 and 9 except sleep. Category 9 includes 'sleep and related activities', or all sleep during the course of a 24-hour period. I include nighttime sleep or any sleep that starts and ends between 6 pm and 12 pm in the variable 'sleep' and not 'leisure'. Daytime naps, however, are included in 'leisure'.[9]

collection methods.

[5]Table B.1 presents the monthly distribution of interview dates by state. Figure B.3 shows districts in ITUS. Figure B.4(a) shows variation in daily sunset time for all 52 ITUS districts, while Figure B.4(b) shows variation in daily sunset time for dates for which time use data was collected in the sampled districts. There is no reason to believe that the date of time use data would be correlated with sunset times. However, I examine this assumption explicitly, and fail to find evidence for any such relationship (Table B.2).

[6]Self-reported time use data may be prone to measurement error. For example, self-reported sleep tends to overestimate objective measures of sleep duration (Lauderdale et al., 2008). However, it is unlikely that any measurement error is systematically correlated with the sunset time. In addition, it is reassuring that I obtain similar results from time use surveys in both India and China.

[7]Table B.3 presents summary statistics for both the normal day and the weekly variant sample.

[8]Both market work and home production are included in 'work' for convenience as female child laborers tend to work at home while male child laborers typically perform outdoor tasks.

[9]Like Gibson and Shrader (2018), I exclude naps or daytime sleep from 'sleep'. I define daytime sleep or naps as sleep that starts and ends during afternoon hours (between 12 pm and 6 pm). I include naps in 'leisure', but daytime naps may be an adaptation to later sunset, undertaken for the compensatory effects rather than because it is pleasurable. Thus, I examine the nighttime to daytime sleep trade-offs. Indeed, I show that later sunset increases nap time by roughly 15 minutes, precisely as predicted by sleep and pediatric studies. As discussed in Section 4, daytime naps may momentarily increase basic concentration under conditions of sleep deprivation, but may not salvage more complex functions of the brain, including learning. However,

'Study' includes time spent on homework, tuition, and course review, while 'school' includes time spent in an educational institution like a school or university.

On weekdays, school-age children spent on average 9 hours/day on sleep, 7.5 hours/day on leisure activities, and almost 4 hours/day in school. School-age children spent over 2 hours/day on average on work, but less than 1.5 hours/day on educational activities outside of school. On weekends, children don't have school, so they allocate more time to sleeping at night, studying, and on leisure activities.

School-age children tend to go to bed after 7 pm, and wake up by 7 am on weekdays. They also tend to self-study (e.g., homework) early in the morning, before school, and then after school, later in the afternoon. Time allocation to recreational activities is spread throughout the day. Work schedules are similar to school schedules but not as intensive, on average.[10] Given such prevalence of child labor, I also examine time allocations by primary activity: 'student' or 'worker', which is indicated in ITUS. Students spend roughly 1 hour/day on work, 5 hours/day in school, and 2 hours/day studying outside of school.[11] However, child workers allocate almost 6 hours/day on average to work. Finally, children engaged in child labor allocate more time to leisure than children who were primarily students.[12]

3.2 2015 India Demographic and Health Surveys (DHS)

The DHS are nationally-representative demographic surveys collected for USAID in collaboration with governments of the countries where the surveys are fielded. These data represent the widely-accepted gold standard for demographic and health data in the developing world. The DHS collects basic education data for every member in the sample household. In ad-

ultimately, whether daytime naps mitigate the accumulative effects of sunset-induced sleep deficits on learning outcomes in the long-run – at issue in this paper – is an empirical question.

[10]Figure B.5 presents the average time spent by children on sleep, study, school, leisure and work, respectively. Figure B.6 describes sleep patterns on a weekday among children. I also directly examine the average bed- and wake-up times for children for both weekdays and weekends in Figure B.7. I find no differences in bedtimes, and only a small increase in wake-up times during weekends. Figure B.8 examines time allocation patterns for other activities within a weekday.

[11]Figures B.9 and B.10 describe how students and child laborers spend their time on weekdays and weekends.

[12]Figures B.11 and B.12 present correlations between sunset time and children's time use using the raw data. Within each district, I disaggregate children into two groups: children interviewed when seasonal sunsets were below 25th percentile (early sunset), and those interviewed when seasonal sunsets were above 75th percentile (late sunset). Compared to days with early sunset, on late sunset days children start sleep later, but wake-up times remained unaffected. Furthermore, children spend less time studying, and more time on leisure. Importantly, while effects on sleep patterns are similar for both students and workers (Figure B.13), late sunset reduces study time for students, but work time for workers, with comparatively modest effects on work time for students and study time for workers (Figure B.14).

dition, DHS data also contain a variety of household-level survey data related to assets and household physical infrastructure. Importantly, DHS data includes geolocation information allowing me to generate annual average sunset time at the primary sampling unit (PSU) level. PSUs correspond to a village in rural areas and city blocks in urban areas. Because my core time use data are from India, I primarily draw on the 2015 India DHS. I restrict the sample to household members between 6 and 16 years of age.[13] The average school-age child has roughly 4.5 years of schooling; 48% have completed primary school and 21% completed middle school.

4 Effect of Later Sunset on Children's Time Use

In this section, I examine how later sunset affects children's sleep and how children trade off sleep against other uses of time.

4.1 Empirical Model

To identify the average effect of an hour delay in sunset time (β), time allocated to sleep, study, leisure or work (y_{idwt}), by child i, in district d, during week-of-year w, on date of interview t, is regressed on sunset time observed in district d, during week-of-year w, on date of interview t ($Sunset_{dwt}$):

$$y_{idwt} = \beta Sunset_{dwt} + \mu_w + \mu_d + \epsilon_{idwt} \tag{1}$$

I control for fixed district-specific characteristics (e.g., district school governance) via district fixed effects (μ_d) and seasonal attributes common across all districts in the sample (e.g., national festivals) via week-of-the-year fixed effects (μ_w). Therefore, the parameter of interest (β) that relates sunset time to children's time use are identified from district-specific seasonal variation in daily sunset time after controlling for seasonal confounders common across all

[13]Table B.4 presents summary statistics for outcomes of interest. In India, the levels of the education system are as follows: primary school ranges from grade 1 to grade 5 and middle school ranges from grade 6 to grade 8. Figure B.15 presents the location of PSUs across India, while Figure B.16 shows the distribution of annual average sunset time across these PSUs.

districts in the sample. I cluster standard errors by district-week for three reasons: to allow for arbitrary spatial correlation across children within a district, to allow for autocorrelation in time allocation within a week, and to account for the fact that the same sunset time can be assigned to multiple children.

The identification assumption underlying this research design is that there exist no district-specific seasonal characteristics that co-vary with both district-specific seasonal variation in children's time use and daily sunset time. This assumption may be violated for a few reasons like provincial weather, provincial school- or agricultural calendar, or provincial festivals. I use two approaches to examine the validity of this assumption: (i) control for seasonal observables at the district level (e.g., temperature, precipitation), and (ii) flexibly control for district-specific seasonal unobservables via district-by-season fixed effects such that any omitted variables must operate within a season for specific districts.

Balance on (Time-Invariant) Observables: I use district-specific variation in daily sunset time because 24-hour time use data were collected, for a particular date, with less than a 24-hour recall lapse for individuals from a cross-section of households across 52 – geographically dispersed – districts. In every district, the survey was spread over one year to account for seasonal variation in activity patterns: e.g., some households in a district were interviewed in May while other households from the same district were interviewed in November. However, the ITUS was not designed to be representative at the district-interview-date level. Therefore, I demonstrate balance by examining the relationship between sunset time on the interview date and *time-invariant* socioeconomic factors at the individual or household-level: e.g., I evaluate if compared to individuals from poorer households, individuals from wealthier households were interviewed on dates when the sun set later. I fail to find evidence for a statistically significant relationship between sunset time at the district-interview-date level and any time-invariant individual- or household-level attributes (Tables C.1).

Sunset Time and Other Solar Cues: Sunrise time and daylight duration are almost perfectly correlated with sunset time after absorbing district and week-of-year fixed effects: Seasonal variation in daily sunset time is negatively correlated with seasonal variation in daily sunrise time (correlation = -0.990), and positively correlated with daylight duration (correlation = 0.997). That is, the sun rises early on days when the sun sets later, increasing total daylight duration. Therefore in purely statistical terms, all results could be recast in terms of either of these other variables (Table C.2, Columns 1, 2, and 3).

I focus on sunset time rather than sunrise time or daylight duration because of the link between sunset time and sleep as emphasized by the existing medical literature (Roenneberg, 2013). In fact, I show sunrise time and daylight duration, like sunset time, influence bedtimes (Table C.2, Columns 4, 5, and 6), but do not affect wake-up times (Table C.2, Columns 7, 8, and 9); this suggests onset of evening darkness and not onset of morning light affect sleep, precisely as the medical literature would predict. However, if there exist other time-use responses associated with onset of evening darkness (e.g., outdoor leisure), the effect of later sunset on bedtimes may instead be mechanically driven by said time-use responses. In Section 4.2, I fail to find evidence for such an explanation.

Lastly, because almost all locations in the world experience approximately the same average daylight duration over the year, daylight duration is not an omitted variable in Appendix B, where I examine the effects of later *annual average sunset time* on children's time use in China, and find quantitatively similar results for children's sleep.

4.2 Results

In Table 1, I investigate the effect of later sunset on children's bedtime and wake-up time. Later sunset delays bedtimes: one hour (approximately two standard deviation) delay in sunset delays bedtime by an estimated 0.36 hours (Table 1, Column 1). However, children fail to compensate by waking up later (Table 1, Column 6). Consistent with the results on children's bedtime and wake-up time, Table 2 shows a one hour delay in sunset reduces sleep by 0.47 hours or roughly 30 minutes (Table 2, Column 1).[14] Furthermore, later sunset reduces self-investment in study effort (Table 2, Column 6), but increases time spent on leisure (Table 2, Column 11). An hour delay in sunset reduces study time by 0.67 hours, increasing leisure by 1.65 hours. Indeed, sleep complements study effort and substitutes with

[14] I estimate the effects of later sunset on non-linear metrics of sleep duration (Table C.3). I find that an hour delay in sunset decreases the likelihood of getting 9 hours of sleep by at least 14 percentage points.

Table 1: Effect of Later Sunset on Bedtime and Wakeup Time (Hours)

	(1) Bedtime β / SE	(2) Bedtime β / SE	(3) Bedtime β / SE	(4) Bedtime β / SE	(5) Bedtime β / SE
Sunset Time (Hours)	0.36***	0.36***	0.45***	0.59***	0.58***
	(0.10)	(0.09)	(0.12)	(0.19)	(0.21)
Mean	21.33	21.33	21.33	21.33	21.33
Observations	13863	13863	13863	13863	13863
R^2	0.178	0.315	0.179	0.185	0.223
	(6) Wake-up Time β / SE	(7) Wake-up Time β / SE	(8) Wake-up Time β / SE	(9) Wake-up Time β / SE	(10) Wake-up Time β / SE
Sunset Time (Hours)	-0.13	-0.14*	-0.04	-0.11	-0.13
	(0.08)	(0.08)	(0.09)	(0.15)	(0.16)
Mean	6.43	6.43	6.43	6.43	6.43
Observations	13911	13911	13911	13911	13911
R^2	0.250	0.312	0.252	0.264	0.301
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes
HH/Individual Controls	No	Yes	No	No	No
Weather Controls	No	No	Yes	No	No
State-by-Season FE	No	No	No	Yes	No
District-by-Season FE	No	No	No	No	Yes

Notes: This table presents the effect of an hour delay in sunset time on bedtime and wakeup time for children between 6 and 16 years of age on weekdays. Columns 1 and 6 include district and week-of-year fixed effects. Columns 2 and 7 include district and week-of-year fixed effects and household- and individual level controls. Columns 3 and 8 include district and week-of-year fixed effects and weather controls. Columns 4 and 9 include state-by-season, district, and week-of-year fixed effects. Columns 5 and 10 include district-by-season and week-of-year fixed effects. I generate bedtimes using ITUS for all children who started sleep between 6 pm and 12 am such that they slept continuously for at least two hours. While wake-up times are generated for all children who ended sleep between 4 am and 10 am such that they were continuously awake for at least two hours. Unfortunately, this means that I am unable to generate bedtimes (wakeup times) for 101 (53) school-age children out of the 13,964 in the entire sample. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

leisure. I fail to find evidence for a relationship between sunset time and work time in the aggregate (Table 2, Column 16).[15] However, I examine and show heterogeneous effects on both study time and work time by children's primary activity in Section 4.2.5.

4.2.1 Robustness Checks

The identification assumption underlying this research design is that there exist no district-specific seasonal characteristics that co-vary with district-specific seasonal variation in both children's time use and daily sunset time. This assumption may be violated for a few reasons like provincial weather, provincial school- or agricultural calendar, or provincial festivals.

In robustness checks, I control for socioeconomic factors at the individual- and household-level (e.g., wealth, sex, age) as well as interview date characteristics (e.g., day-of-week) (Table 1, Columns 2 and 7; Table 2, Columns 2, 7, 12, and 17). These observables explain meaningful variation in children's time use. However, my point estimates remain unaffected.

There exists considerable district-specific seasonal variation in weather across India. The identifying variation in daily sunset time may be correlated with seasonal variation in temperature or precipitation unique to certain districts. For example, if hot days negatively affect sleep, and coincide with later sunset for certain districts, my estimates may be biased. I control for daily rainfall and daily temperature at the district level and show my estimates remain unaffected (Table 1, Columns 3 and 8; Table 2, Columns 3, 8, 13, and 18).[16]

Lastly, I control flexibly for location-specific seasonal unobservables by including state-by-season (Table 1, Columns 4 and 9; Table 2, Columns 4, 9, 14, and 19) and district-by-season (Table 1, Columns 5 and 10; Table 2, Columns 5, 10, 15, and 20) fixed effects.[17] Separately, these control for unobservable state- and district-specific seasonal confounders, respectively. For instance, provincial festivals that coincide with summer months may in-

[15] A large fraction of observations have values of zero for the time spent on study and work effort. Thus, Table C.4 also presents the Tobit estimates and find that these results are in line with the OLS estimates, although the point estimate for 'Study' is significantly larger. However, Stewart (2009) notes that zeros in time use data may arise from a mismatch between the reference period of the data (the interview date) and the period of interest, which is typically much longer. He finds that in such a context the marginal effects from Tobit are biased and that only OLS generates unbiased estimates.

[16] I use the ERA-Interim daily temperature and precipitation data on a 1 x 1 degree latitude-longitude grid. These data are matched with ITUS at the district-date level.

[17] The Indian Meteorological Department (IMD) designates four climatological seasons for the country: Winter (December-March), Summer (April-June), Monsoon (July-September), Autumn (October to November).

Table 2: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Sleep β / SE	(2) Sleep β / SE	(3) Sleep β / SE	(4) Sleep β / SE	(5) Sleep β / SE
Sunset Time (Hours)	-0.47***	-0.48***	-0.48***	-0.53*	-0.62**
	(0.14)	(0.13)	(0.17)	(0.27)	(0.29)
Mean	9.07	9.07	9.07	9.07	9.07
Observations	13964	13964	13964	13964	13964
R^2	0.091	0.247	0.091	0.095	0.140
	(6) Study β / SE	(7) Study β / SE	(8) Study β / SE	(9) Study β / SE	(10) Study β / SE
Sunset Time (Hours)	-0.67***	-0.64***	-0.70***	-0.53	-0.76
	(0.24)	(0.23)	(0.26)	(0.49)	(0.50)
Mean	1.50	1.50	1.50	1.50	1.50
Observations	13964	13964	13964	13964	13964
R^2	0.169	0.365	0.169	0.181	0.221
	(11) Leisure β / SE	(12) Leisure β / SE	(13) Leisure β / SE	(14) Leisure β / SE	(15) Leisure β / SE
Sunset Time (Hours)	1.65***	1.54***	1.99***	0.82	1.09*
	(0.41)	(0.40)	(0.44)	(0.60)	(0.60)
Mean	7.60	7.60	7.60	7.60	7.60
Observations	13964	13964	13964	13964	13964
R^2	0.294	0.348	0.295	0.313	0.347
	(16) Work β / SE	(17) Work β / SE	(18) Work β / SE	(19) Work β / SE	(20) Work β / SE
Sunset Time (Hours)	0.10	0.05	0.12	-0.06	-0.13
	(0.33)	(0.26)	(0.38)	(0.60)	(0.63)
Mean	2.05	2.05	2.05	2.05	2.05
Observations	13964	13964	13964	13964	13964
R^2	0.070	0.554	0.071	0.076	0.106
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes
HH/Individual Controls	No	Yes	No	No	No
Weather Controls	No	No	Yes	No	No
State-by-Season FE	No	No	No	Yes	No
District-by-Season FE	No	No	No	No	Yes

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure and work (in hours) for children between 6 and 16 years of age on weekdays. Columns 1, 6, 11, and 16 include district and week-of-year fixed effects. Columns 2, 7, 12, and 17 include district and week-of-year fixed effects and household- and individual level controls. Columns 3, 8, 13, and 18 include district and week-of-year fixed effects and weather controls. Columns 4, 9, 14, and 19 include state-by-season, district, and week-of-year fixed effects. Columns 5, 10, 15, and 20 include district-by-season and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

crease children's time allocation to leisure and in turn decrease the time allocated to sleep, study effort, and work effort. Albeit noisier,[18] I show the magnitudes remain relatively unaffected by the inclusion of these fixed effects.[19]

In sum, any omitted variable that generates bias in the baseline estimates must operate within a season for specific districts and be orthogonal to seasonal observables at the district level. Plausible omitted variables are unlikely to have both these properties, and therefore my baseline estimates are likely unbiased.

4.2.2 Effect of Later Sunset on Type of Leisure

The ITUS collects information on whether any activity was performed inside the house or outside the house. Therefore, I decompose the net effect of later sunset on (total) leisure into the effect on indoor leisure and the effect on outdoor leisure. I find later sunset increases time spent on indoor leisure with comparatively modest effects on outdoor leisure (Table 3). Next, I examine the effect of later sunset on specific leisure activities. I find the increase in leisure is driven by sedentary (talking) and compensatory (daytime naps) leisure activities (Table C.7): an hour delay in sunset time increases both time allocated to naps and time spent talking by roughly 15 minutes.

Overall, these results are consistent with several sleep and pediatric studies that show sleep deprived children increase time spent on sedentary and compensatory leisure activities (Carskadon, Harvey and Dement, 1981*a*,*b*; Fallone et al., 2001; Jae Lo, 2016; Owens, Belon and Moss, 2010; Sadeh, Gruber and Raviv, 2003).

Daytime Naps: Crucially, the compensatory increase in daytime naps reinforces the core result presented in this section: later sunset decreases children's productive sleep. However, two concerns remain: First, if children are more likely to nap when the sun sets later due to factors unrelated to the effect of later sunset on sleep, the effects on children's sleep may

[18]The point estimate for study is not statistically significant when I include both district-by-season and week-of-year fixed effects. However, it is statistically significant when I estimate this specification to (i) examine heterogeneity by children's primary activity or (ii) evaluate effects of later sunset on children's study time by hour-of-day.

[19]In Table C.5 I adjust standard errors to reflect spatial dependence as modeled in Conley (1999), and implemented by Hsiang (2010). I allow errors to be spatially auto-correlated within a distance of 500 km. The point estimates remain precisely estimated. In Table C.6, I cluster standard errors at the district level to allow errors to be temporally correlated across weeks within a district. The coefficients remain precisely estimated.

Table 3: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Indoor Leisure β / SE	(2) Indoor Leisure β / SE	(3) Indoor Leisure β / SE	(4) Indoor Leisure β / SE	(5) Indoor Leisure β / SE
Sunset Time (Hours)	1.42***	1.32***	1.62***	1.09**	1.18**
	(0.34)	(0.32)	(0.37)	(0.54)	(0.55)
Mean	5.06	5.06	5.06	5.06	5.06
Observations	13964	13964	13964	13964	13964
R^2	0.273	0.332	0.273	0.288	0.319
	(1) Outdoor Leisure β / SE	(2) Outdoor Leisure β / SE	(3) Outdoor Leisure β / SE	(4) Outdoor Leisure β / SE	(5) Outdoor Leisure β / SE
Sunset Time (Hours)	0.23	0.22	0.36	-0.27	-0.09
	(0.24)	(0.24)	(0.28)	(0.42)	(0.40)
Mean	2.54	2.54	2.54	2.54	2.54
Observations	13964	13964	13964	13964	13964
R^2	0.132	0.218	0.132	0.142	0.179
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes
HH/ Individual Controls	No	Yes	No	No	No
Weather Controls	No	No	Yes	No	No
State-by-Season FE	No	No	No	Yes	No
District-by-Season FE	No	No	No	No	Yes

Notes: This table presents the effect of an hour delay in sunset time on time allocated to indoor leisure and outdoor leisure (in hours) for children between 6 and 16 years of age on weekdays. Columns 1 and 6 include district and week-of-year fixed effects. Columns 2 and 7 include district and week-of-year fixed effects and household- and individual level controls. Columns 3 and 8 include district and week-of-year fixed effects and weather controls. Columns 4 and 9 include state-by-season, district, and week-of-year fixed effects. Columns 5 and 10 include district-by-season and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

be driven by daytime naps and not the other way around. To alleviate this concern, I show the effects of later sunset on children's time use are robust to dropping 'nappers' from the sample (Table C.8).

Second, how might naps affect long-run learning outcomes at issue in this paper? Naps may not provide the same biochemical therapeutic effects on the brain as longer periods of nocturnal sleep, and do not make up for inadequate nighttime sleep (The National Sleep Foundation).[20,21] Naps may momentarily increase basic concentration under conditions of sleep deprivation, as caffeine can up to a certain dose. For instance, a recent field experiment among low-income adults in India finds afternoon naps improve cognition and productivity in the short run (Bessone et al., 2019). But, naps may not salvage more complex functions of the brain, including learning, memory, emotional stability, complex reasoning, or decision-making (Walker, 2017). In addition, daytime naps take place after school hours. Thus, any short-term benefits of daytime naps on cognition will not mitigate the negative effect of (nighttime) sleep deprivation on learning in school. That is, while post-learning sleep (naps) may help consolidate memories, pre-learning sleep (nighttime sleep) is crucial for the encoding of new memories (Antonenko et al., 2013; Van Der Werf et al., 2009; Walker, 2010; Yoo et al., 2007). In fact, the effect of pre-learning sleep is precisely what is observed by studies investigating the impact of later school start times on test scores (Carrell, Maghakian and West, 2011; Edwards, 2012; Heissel and Norris, 2017; Wahlstrom, 2002). However, ultimately, whether daytime naps mitigate the accumulative effects of chronic sunset-induced sleep deficits on learning outcomes in the long-run is an empirical question.

4.2.3 Effect of Later Sunset on Children's Time Use by Hour of Day

Next, I examine the effect of later sunset on children's time use by hour of day; I estimate the most robust specification, including both district-by-season and week-of-year fixed effects (Figure 1). I present a stylistic interpretation of the results most consistent with the data. I categorize the 24-hour time use data into two days, Day T and Day T+1, and examine the

[20] See https://www.sleepfoundation.org/sleep-topics/napping.

[21] Studies conducted among preschool-aged children show that daytime naps are negative correlated with performance on cognitive tasks, while nighttime sleep is positive correlated. One interpretation of these results is that children who receive inadequate sleep at night are more likely to take daytime naps (Lam et al., 2011, 2015), which is consistent with my findings.

effects of an hour delay in sunset time on Day T on children's time use on Day T as well as on children's time use on Day T+1.

Sleep: Figure 1, Panel (a) shows that an hour delay in sunset time on Day T has a statistically significant decrease in children's sleep between 7 pm and 9 pm on Day T: when the sun sets later, children go to bed later. Since the average daily sunset time observed in the ITUS sample is 6.20 pm, the timing of these effects are precisely what sleep and medical studies on human circadian rhythm would predict. Importantly, I fail to find a statistically significant effect on children's wake-up times. A one hour delay in sunset time on Day T does not affect children's morning sleep on Day T+1: children are unable to compensate for later bedtimes by waking up later.

Sunset Time vs. Sunrise Time: This result also validates the paper's focus on sunset time instead of sunrise time: seasonal variation in daily sunset time is negatively correlated with seasonal variation in daily sunrise time. I focus on sunset time rather than sunrise time because of the link between sunset time and sleep as emphasized by the existing medical literature. In addition, if sunrise time and not sunset time were responsible for my results, I would expect exactly the opposite effect on children's bedtime and wake-up time. Instead, consistent with medical studies on human circadian rhythm, I show later sunset delays children's bedtime but has no influence on wake-up time.

Indoor Leisure and Study Time: Figure 1, Panels (b) and (c) examine how children trade-off sleep with indoor leisure and study time, respectively. I show an hour delay in sunset time on Day T increases time spent on indoor leisure between 7 pm and 9 pm on Day T, coinciding exactly with the decrease in sleep on Day T.[22] This result may be consistent with the explanation that children are trying to sleep but are unable to do so when the sun sets later so they allocate time to sedentary leisure activities to sustain their wakefulness (Spaeth, Dinges and Goel, 2013). On Day T+1, sleep-deprived children decrease productive effort (study time); they instead increase time spent on sedentary and compensatory leisure

[22]Note an individual's time constraint always binds with perfect equality. Even in sleep laboratories, it is not possible to change sleep duration without also changing at least one other time use.

Figure 1: Effect of Later Sunset on Children's Time Use by Hour of Day

(a) Sleep

(b) Indoor Leisure

(c) Study

(d) Outdoor Leisure

(e) Work

(f) All

Notes: This figure presents the effect of an hour delay in sunset time on time allocated to sleep, indoor leisure, study, outdoor leisure, and work by time-of-day for children between 6 and 16 years of age on weekdays. I plot coefficients from twenty-four separate regressions – one for each hour in the day – to generate the thick red line in each panel. The shaded red area represents the 95% confidence interval associated with the coefficients of interest. Each panel indicates the average daily sunset time observed in the ITUS data: 6.20 pm. To encourage a stylized interpretation of these estimates, I categorize each coefficient (of the twenty-four) as belonging to one of two days: T or T+1. Coefficients from 7 pm to 12 am are categorized as Day T, while coefficients from 12 am to 7 pm as categorized as Day T+1. All regressions include district-by-season and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

activities, in line with several sleep and pediatric studies.

Later sunset means more daylight after school, which may make it easier for children to self-study in the evening, especially in lower income countries where electricity access is intermittent. However, I fail to find evidence that later sunset increases time allocated to studying in the evening. The quantitatively small increase in study time at 8 pm is not statistically significant.[23]

Outdoor Leisure and Onset of Darkness: Later sunset also means a delay in onset of evening darkness. Later sunset time may induce children to engage in outdoor recreational activities in the evening, and mechanically delay the onset of sleep. I have already shown later sunset does not affect the *total* time allocated to outdoor leisure. However, when the sun sets later children may reallocate outdoor leisure from the morning or early afternoon to late afternoon or early evening, and mechanically delay the start of sleep. Therefore, I examine the effect of an hour delay in sunset time on outdoor leisure by time of day (Figure 1, Panel (d)). I find children trade off indoor leisure and outdoor leisure with each other when the sun sets later: early afternoon (12 pm to 3 pm), sleep-deprived children increase time allocated to compensatory indoor leisure, and decrease time allocated to outdoor leisure. Late afternoon and early evening (5 pm to 7 pm), children increase time allocated to outdoor leisure and decrease time allocated to indoor leisure. Importantly, I fail to find any evidence for substitution between sleep and outdoor leisure.

Yet, one more concern remains. Children may reallocate sedentary indoor leisure from afternoon to evening when the sun sets later because they prefer to allocate time to outdoor recreational activities late afternoon and/or early evening, indirectly delaying the onset of sleep. To alleviate this concern, I show the effects of later sunset on children's time use are robust to dropping children who allocated *any* time to outdoor leisure between 5 pm and 7 pm from the sample (Table C.11). Therefore, substitution between indoor leisure and outdoor leisure between 5 pm to 7 pm is likely an independent response to delay in onset of

[23] In Table C.10 I examine heterogeneous impacts of later sunset on children's time use by value of lights at night at the district level as measured from space in 2001, as a proxy for electrification status. I find the negative effect of later sunset on sleep is larger for children in darker districts. Children's sleep schedules may be more susceptible to the onset of evening darkness in the absence of electricity. Importantly, I find the negative effect of later sunset on study time is larger for children in darker districts. This result is inconsistent with the explanation that later sunset increases time allocated to studying in the evening when electricity access is intermittent. Instead, the larger negative effect on study time is precisely what one would expect if sleep were productivity-enhancing.

darkness.

Overall, the data seem most consistent with the following explanation: when the sun sets later, children go to bed later, due to the aforementioned medical relationship between sunset time and the onset of sleep, and instead spend time on sedentary indoor leisure to sustain their wakefulness. Consequently, sleep-deprived children decrease study time and instead engage in compensatory leisure activities.

4.2.4 China

In the ITUS, I exploit seasonal variation in daily sunset time at the district level to identify the effects of later sunset on children's sleep, and the consequent effects of sunset-induced sleep deficits on other time uses. Seasonal variation in daily sunset time is positively correlated with seasonal variation in daylight duration; that is, the sun rises early on days when the sun sets later, increasing total daylight duration. However, because almost all locations in the world experience approximately the same average daylight duration over the year, daylight duration is not an omitted variable in Appendix B, where I examine the effects of later *annual average sunset time* on children's time use in China. Unlike ITUS, the 2004-2009 China Health and Nutrition Survey collects data on children's time use for a 'typical' day of the year, and not for a particular date. I use cross-sectional variation in annual average sunset time across districts within a state. In line with my India estimates, I find an hour delay in annual average sunset time reduces children's sleep by roughly 30 minutes. Furthermore, I find qualitatively similar effects for study time and leisure.

4.2.5 Students vs. Child Laborers

The baseline results mask substantial heterogeneity by children's primary activity. While effects on sleep are qualitatively similar for both students and child workers, I show later sunset reduces study time for students and work time for workers, with null effects on work time for students and on study time for workers (Table 4).[24] These effects suggest that sleep increases the marginal gains of an extra hour of study effort for students with comparatively

[24]In terms of magnitude, an hour delay in sunset time reduces study time by roughly 40 minutes. This is a large effect. I show that later sunset negatively affects study effort on the extensive margin, presumably because tired students are less likely to study at all (Table C.9).

Table 4: Effect of Later Sunset on Children's Time Use by Primary Activity (Hours)

	(1) Sleep β / SE	(2) Sleep β / SE	(3) Sleep β / SE	(4) Sleep β / SE	(5) Sleep β / SE
Sunset Time (Hours)	-0.44***	-0.45***	-0.44***	-0.50*	-0.58**
	(0.14)	(0.14)	(0.17)	(0.27)	(0.29)
Sunset Time*Worker	-0.11**	-0.11**	-0.11**	-0.11*	-0.11**
	(0.06)	(0.05)	(0.06)	(0.06)	(0.05)
p-value	0.00	0.00	0.00	0.02	0.02
Mean	9.07	9.07	9.07	9.07	9.07
Observations	13964	13964	13964	13964	13964
R^2	0.091	0.248	0.092	0.096	0.141
	(6) Study β / SE	(7) Study β / SE	(8) Study β / SE	(9) Study β / SE	(10) Study β / SE
Sunset Time (Hours)	-0.88***	-0.87***	-0.99***	-0.68	-0.98**
	(0.24)	(0.24)	(0.25)	(0.48)	(0.48)
Sunset Time*Worker	0.82***	0.79***	0.82***	0.86***	0.85***
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
p-value	0.82	0.75	0.53	0.70	0.78
Mean	1.50	1.50	1.50	1.50	1.50
Observations	13964	13964	13964	13964	13964
R^2	0.342	0.376	0.343	0.354	0.387
	(11) Leisure β / SE	(12) Leisure β / SE	(13) Leisure β / SE	(14) Leisure β / SE	(15) Leisure β / SE
Sunset Time (Hours)	2.03***	1.95***	2.42***	1.15*	1.57***
	(0.41)	(0.40)	(0.45)	(0.60)	(0.59)
Sunset Time*Worker	-1.36***	-1.40***	-1.36***	-1.47***	-1.51***
	(0.20)	(0.19)	(0.19)	(0.20)	(0.19)
p-value	0.13	0.20	0.03	0.60	0.92
Mean	7.60	7.60	7.60	7.60	7.60
Observations	13964	13964	13964	13964	13964
R^2	0.321	0.360	0.322	0.341	0.375
	(16) Work β / SE	(17) Work β / SE	(18) Work β / SE	(19) Work β / SE	(20) Work β / SE
Sunset Time (Hours)	0.21	0.22	0.45	-0.09	-0.12
	(0.26)	(0.26)	(0.29)	(0.47)	(0.43)
Sunset Time*Worker	-0.69***	-0.59***	-0.69***	-0.69***	-0.58***
	(0.17)	(0.15)	(0.17)	(0.17)	(0.17)
p-value	0.11	0.19	0.46	0.11	0.13
Mean	2.05	2.05	2.05	2.05	2.05
Observations	13964	13964	13964	13964	13964
R^2	0.477	0.556	0.477	0.481	0.502
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes
HH and Individual Attributes	No	Yes	No	No	No
Weather Controls	No	No	Yes	No	No
State-by-Season FE	No	No	No	Yes	No
District-by-Season FE	No	No	No	No	Yes

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure and work (in hours) for children between 6 and 16 years of age on weekdays. The interaction term captures the effect of an hour delay in daily sunset time for child laborer compared to a student. 'p-value' denotes the p-value for '$SunsetTime(Hours)$' + '$SunsetTime * Worker$' = 0. Columns 1, 6, 11, and 16 include district and week-of-year fixed effects. Columns 2, 7, 12, and 17 include district and week-of-year fixed effects and household- and individual level controls. Columns 3, 8, 13, and 18 include district and week-of-year fixed effects and weather controls. Columns 4, 9, 14, and 19 include state-by-season, district, and week-of-year fixed effects. Columns 5, 10, 15, and 20 include district-by-season and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

modest marginal gains for labor productivity. Conversely, for child laborers the increase in marginal product of labor from an extra hour of sleep is larger than the increase in marginal product of an extra hour of study effort. Overall, these results are in line with the predictions of the analytical model presented in Appendix A.

5 Effect of Later Sunset on Children's Learning Outcomes

In this section, I examine the effects of sunset-induced sleep deficits on children's learning outcomes in the short- and long run.

5.1 Effect of Later Sunset on Children's Learning Outcomes in the Short Run

Here, I use individual level longitudinal panel from Andhra Pradesh, India, the 2002-2014 Young Lives Survey (YLS), to evaluate short-run effects of sunset-induced sleep deficits on children's test scores.[25] The study follows two cohorts of children, born in 1994/95 and 2001/02, respectively, across 7 districts, for more than 10 years. Children between the ages 5 and 19 were administered low-stakes tests math tests at regular intervals between 2002-2014. I leverage seasonal variation in daily sunset time at the district level after absorbing seasonal confounders common across all districts in the sample (e.g., school or agricultural calendars) via week-of-the-year fixed effects to estimate the effects of short-term sleep deprivation on math test scores. That is, I compare scores of two children who took the math test in the same week, where one child resides in a district where the sun sets later (west) and the other in a district where the sun sets earlier (east). Because the same child is tested at different days of the year across survey rounds, to test robustness, I control for fixed child-specific characteristics via lagged test scores and child fixed effects.

I find an hour delay in sunset time reduces children's math scores by 0.6 standard deviation (Table 5, Column 1). This estimate reflects the direct effect of sunset-induced

[25] I briefly describe the YLS data in Appendix B.

Table 5: Effect of Later Sunset on Children's Learning Outcomes in the Short Run

	(1) Math (SD) β / SE	(2) Math (SD) β / SE	(3) Math (SD) β / SE
Daily Sunset Time (Hours)	-0.627***	-0.570***	-0.529
	(0.088)	(0.062)	(0.415)
L.Math		0.645***	
		(0.011)	
Age Dummies	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes
Child FE	No	No	Yes
Weather Controls	No	No	Yes
Observations	7511	4589	7511
R^2	0.045	0.439	0.778

Notes: This table presents the effect of an hour delay in sunset time on math scores in the short run for school-age children. Column 1 includes age and week-of-year fixed effects. Column 2 includes age and week-of-year fixed effects and controls for lagged test scores. Column 3 includes child, age, and week-of-year fixed effects and weather controls. Standard errors are in parentheses, clustered at the child level. Source: YLS.

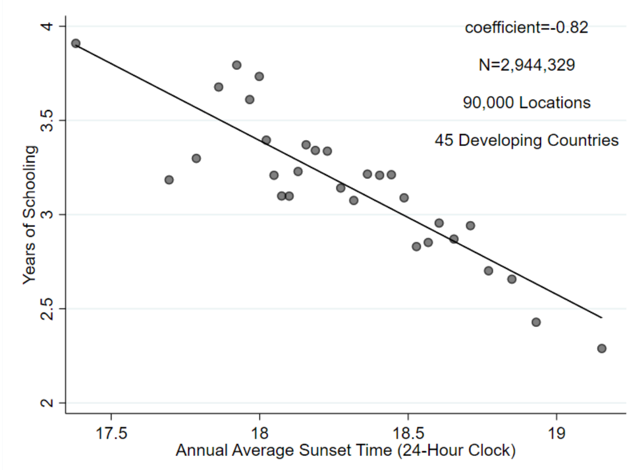
sleep deficits net of any avoidance in short run as well as the indirect effect of sunset-induced sleep deficits through decrease in study time in the short run (Appendix F).

The magnitude of this effect is similar to the short-run impact of a personalized technology-aided after-school instruction program on math scores in India (Muralidharan, Singh and Ganimian, 2019). However, the estimated effect is much larger than the effect of early school start time on test scores. For instance, Carrell, Maghakian and West (2011) find that a start time of 7 am reduces test scores for a course taught in the first period class by 0.15 standard deviation, and for subsequent classes by 0.1 standard deviations, while a 7.50 am start time has no effect on test scores. It is not straightforward to compare the short-run impact of sunset-induced sleep deficits on test scores to the effect of early school start time on test scores because (a) the school-start-time literature does not observe the qualitative or quantitative effect of school start times on children's sleep or associated trade-offs with other time uses, which would have facilitated an informed comparison – e.g., my short-run estimate incorporates the effect of decrease in study time on education production; Stinebrickner and Stinebrickner (2008) estimate an elasticity of academic performance with respect to study time of approximately 0.4 – (b) the reduced form effect of early school start time on sleep incorporates the positive effect of rearranging school schedules as children learn more in the morning than later in the school day (Pope, 2016), and (c) there exist no prior estimates of the effects of early school start times on children's test scores in a developing country.[26] In fact, to my knowledge, my paper provides the first well-identified estimates of the short-run effects of sleep deprivation on children's test scores.

To test robustness, I control for time-invariant location- and child-specific unobservables using lagged test scores (Table 5, Column 2) and child fixed effects (Table 5, Column 3). It is reassuring that controlling for lagged test scores and child fixed effects explains meaningful variation in math scores, but does not affect the point estimate. Note, under the child fixed effect specification, the coefficient is underpowered.[27] Nevertheless, the roughly linear short-run effect of sunset-induced sleep deficits on math scores is quite clear (Figure D.2). Finally, to provide evidence that the estimated relationship is not spurious, I show math scores are not affected by sunset time associated with test date for the previous survey round and sunset time associated with the test date for the subsequent survey round (Table D.1).

These results stand in contrast to findings from a new field experiment that examines the short-run consequences of sleep deprivation among low-income adults in India. Bessone et al. (2019) find increasing sleep duration has no impact on adults' earnings. They identify highly fragmented and inefficient nature of baseline sleep as a key reason for why increases in sleep duration does not translated into productivity gains for low-income adults. Therefore, one plausible explanation for differences in short-run estimates observed in this paper compared to those observed in Bessone et al. (2019) may be that compared to adults in lower-income countries, children's sleep is less fragmented and less inefficient.[28]

Figure 2: Annual Average Sunset Time and Children's Education in the Developing World



Notes: This figure presents a binned scatterplot and linear fitted values for the raw relationship (correlation) between years of schooling and annual average sunset time for children between 6 and 16 years of age across the developing world. Data on years of schooling is obtained from nationally representative surveys conducted by the Demographic and Health Survey (DHS). I assembled and harmonized all DHS datasets collected through 2016 for which latitude and longitude of the primary sampling unit (PSU) or cluster was recorded allowing me to generate annual average sunset time at the PSU level. That is, I use the universe of DHS data with geolocation information from Latin America, Africa, South Asia, and Southeast Asia: 90,000 locations in 45 countries. The 45 countries include Angola, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Cameroon, Chad, Colombia, Comoros, Democratic Republic of the Congo, Dominican Republic, East Timor, Egypt, Ethiopia, Ghana, Guatemala, Guinea, Haiti, Honduras, India, Indonesia, Ivory Coast, Kenya, Lesotho, Liberia, Malawi, Mali, Morocco, Mozambique, Myanmar, Namibia, Nepal, Niger, Nigeria, Pakistan, Peru, Philippines, Rwanda, Senegal, Sierra Leone, Uganda, United Republic of Tanzania, Zambia and Zimbabwe.

5.2 Effect of Later Sunset on Children's Learning Outcomes in the Long Run

Next, using nationally-representative DHS data from 45 countries across the developing world, Figure 2 documents a strong negative correlation between annual average sunset time associated with a geographic location and years of schooling among school-age children. However, simple cross-country comparison of children's academic outcomes may be confounded by systematic differences in salient features that co-vary with both annual average sunset time and children's education. To overcome this identification problem, and because my core time use data are from India, I use the geocoded 2015 India DHS to investigate the

[26]Another explanation for the magnitude of short-run effects observed in this paper compared to effect sizes observed in the school-start time literature may be the fact that tests administered in the YLS are low-stakes; deleterious effects of sleep deprivation may be smaller if stakes are higher.

[27]The leftover variation in sunset time is quite limited: It pertains to differences in sunset time associated with two (or three) test dates across survey rounds for the same child after absorbing seasonal variation in daily sunset time common across all districts in Andhra Pradesh.

[28]On average, children in the ITUS sample sleep one hour more compared to adults, which may suggest that children's sleep is of higher quality. While I do not observe adults' wages in the short-run, I fail to find conclusive evidence that sleep deprived adults, unlike children, decrease productive effort in the short-run which may suggest sleep is not productivity-enhancing for low-income adults in developing countries in the short-run, consistent with their findings.

effects of chronic sunset-induced sleep deficits on children's learning outcomes in the long run, exploiting cross-sectional variation in annual average sunset time across eastern and western locations within small administrative divisions, districts.

5.2.1 Empirical Model

I estimate the following econometric model:

$$y_{iavd} = \beta Sunset_{vd} + \mu_d + \mu_a + \epsilon_{iavd} \tag{2}$$

where y_{iavd} is the outcome of interest for child i of age a in PSU v in district d; outcomes of interest include years of schooling, primary school completion, middle school completion, and enrollment status. Both primary and middle school completion are binary variables that take the value '1' if the child has completed primary and middle school, respectively, 0 otherwise. Similarly, enrollment status is a binary variable that takes the value '1' if the child is enrolled in school, 0 otherwise. μ_d are district fixed effects, while μ_a are age fixed effects. District fixed effects control for plausible time invariant omitted variables at the district level. I include age fixed effects to control for differences in grade progression between children of different age groups. That is, I compare the outcomes of children of the same age residing in PSUs with different annual average sunset times (eastern vs. western PSUs) within a district. Therefore, the identification assumption underlying this research design is that there exist no omitted variables at the PSU level that co-vary with both annual average sunset times and children's educational outcomes within a district. A battery of robustness tests suggest that this assumption is reasonable. β is the average effect of an hour delay in *annual average sunset time*, i.e., β is the long-run effect of an hour delay in sunset time. I cluster standard errors at the PSU level as variation in annual average sunset time is at the PSU level and not at the household level (Abadie et al., 2018).

It is important to note annual average sunset time is orthogonal to latitude, but perfectly correlated with longitude; therefore, if economic activity is also correlated with longitude (Stein and Daude, 2007), it may bias my estimates. In Appendix D, I eliminate such an explanation: I exploit time zone boundaries that break the link between annual average

Table 6: Effect of Later Sunset on Children's Learning Outcomes in the Long Run

	(1) Years of Schooling β / SE	(2) Primary (0/1) β / SE	(3) Middle (0/1) β / SE	(4) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-0.86***	-0.13***	-0.08**	-0.11**
	(0.31)	(0.04)	(0.03)	(0.05)
Age FE	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	4.44	0.48	0.21	0.90
Observations	638682	638682	638682	638682
R^2	0.732	0.643	0.561	0.093

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling, likelihood of completing primary (0/1) and middle school (0/1), and enrollment status (0/1) for children between 6 and 16 years of age. All columns include district and age fixed effects. Standard errors are in parentheses, clustered at the PSU level. Source: 2015 India DHS.

sunset time and longitude, and take advantage of a sharp one-hour discontinuity in annual average sunset time at the time zone border in Kalimantan, Indonesia. I find quantitatively similar effects of annual average sunset time on children's learning outcomes in the long run.

5.2.2 Results

I find an hour delay in annual average sunset time reduces schooling by about 0.8 years (Table 6, Column 1). This result translates into lower educational attainment at primary and middle school level (Table 6, Column 2 and 3). That is, an hour delay in annual average sunset time decreases primary school completion by over 10 percentage points, and middle school completion by 8 percentage points. Lastly, an hour delay in annual average sunset time decreases enrollment rates by roughly 11% (Table 6, Column 4). These estimates reflect long-run impacts. They capture the direct and indirect accumulative effects of chronic sunset-induced sleep deficits net of both ex ante avoidance behavior and ex post compensatory responses (e.g., daytime naps) (Appendix F).

These effect sizes are comparable to impacts of larger policy interventions designed to increase schooling in developing countries. For example, in Mexico, childhood exposure to conditional cash transfers through PROGRESA increases schooling by 1.5 years (Parker and Vogl, 2018). A meta-analysis of 94 studies from 47 conditional cash transfer programs in low- and middle-income countries worldwide finds that the average conditional cash transfer program increases school enrollment by roughly 7% (Garcia and Saavedra, 2017).

Robustness Checks: In robustness checks, I show these point estimates are robust to the inclusion of other observables like elevation, latitude, and socioeconomic status (Table D.2, Columns 4, 8, 12, and 16). Table D.3 shows attainment results are robust to restricting estimation for each tier of education – primary and middle – to the corresponding age-appropriate sample. In Table D.4, I show my results are robust to the use of an alternative indicator for educational attainment: if a child is in primary (secondary) school or has completed primary (secondary) school. I find that an hour delay in annual average sunset reduces the likelihood that school-age children are in primary (secondary) school or have completed primary (secondary) school by roughly 11% (25%). In Table D.5, I cluster standard errors at the district level to allow errors to be spatially correlated across PSUs within a district: except for the estimate of the effect of annual average sunset on enrollment status, all my point estimates remain precisely estimated. Lastly, if younger children (with mechanically fewer years of schooling) are sampled in locations with later annual average sunset, my estimates for years of schooling and educational attainment may be biased. However, I fail to find evidence for such a hypothesis (Table D.6).[29]

Identifying Variation and Spuriousness: These estimates are identified by exploiting small variation (up to 10 minutes) in annual average sunset time across the east-west gradient within a district (Figure D.1). Two immediate concerns arise due to such a research design:

One, it is legitimate to ask how small differences in annual average sunset time, and consequently sleep deficits, could translate into deleterious effects on children's learning outcomes in the long run. To alleviate the concern that these estimates might be spurious, I estimate the effect of an hour delay in annual average sunset time on children's learning outcomes in the long run under a less robust, state fixed effects specification, where I exploit cross-sectional variation in annual average sunset time within a state. Here, I exploit greater

[29]Residential sorting could bias my estimates if such sorting was correlated with annual average sunset time and characteristics that affect children's education outcomes. This is relatively unlikely as internal migration is very low in India, both in absolute terms as well as relative to other countries of comparable size and level or economic development (Munshi and Rosenzweig, 2016). In addition, I fail to find evidence for out-migration (in-migration) in locations that observe later (earlier) sunsets (Appendix D).

variation (up to 45 minutes) in annual average sunset time. I find the point estimates are negative and precisely estimated (Table D.2, Columns 1, 5, 9, and 13). However, these coefficients are much smaller, likely due to downward bias induced from omitted variables: point estimates become larger once geographic and socioeconomic controls are introduced (Table D.2, Columns 2, 6, 10, and 14). I also show the DHS results are not driven by a few wide districts: In Tables D.7 and D.8, I show my point estimates are largely unaffected when I drop or restrict the sample to wider districts in India, respectively. Furthermore, I replicate these findings using a nationally representative rural sample of Indian households, the 2006 Rural Economic and Demographic Survey (REDS) (Appendix D). I find qualitatively and quantitatively similar results. Lastly, sleep research has shown that just 3 minutes of even light NREM (stage 2) sleep improves task performance (Hayashi, Motoyoshi and Hori, 2005).[30]

Two, the underlying assumption when extrapolating the identifying variation to calculate the long-run effect of an hour delay in annual average sunset time is that the relationship between sunset-induced sleep deficits and academic outcomes is roughly linear, at least within the support of the effect of an hour delay in sunset time on children's sleep: 30 minutes. Such an assumption is consistent with results from the longest laboratory-controlled study on the relationship between sleep and cognitive performance that shows cognition declines linearly with sleep deprivation (Van Dongen et al., 2003). I also provide empirical support for this assumption.

Indonesia: In Appendix D, I exploit a sharp, one-hour discontinuity in average annual sunset time across locations on either side of the time zone boundary on Kalimantan, Indonesia. Using the 2003 Indonesia DHS, I show the regression discontinuity estimate of the effect of a one-hour delay in annual average sunset on children's years of schooling in Indonesia is similar to the estimate obtained by scaling smaller (within-district) variation in annual average sunset time in India. I find an hour delay in annual average sunset time reduces children's years of schooling by 0.7 years. In addition, because Kalimantan, Indonesia

[30] We sleep in 90-minute cycles that contain both NREM and REM (rapid eye movement) sleep. First half of the night is dominated by NREM sleep: light NREM (stage 2) sleep is important for memory refreshment while deep NREM (stages 3 and 4) sleep is important for memory consolidation. The second half of the night is dominated by REM (stage 5) sleep, which is important for problem-solving and creativity. Within each cycle, each stage lasts anywhere between 5-15 minutes.

followed the same time zone until 1988, I use older cohorts or individuals who completed their education before 1988 as a placebo sample. I fail to find evidence for a statistically significant discontinuity in years of schooling at the time zone border for individuals who completed their education before 1988.

Children's Wages: Consistent with empirical evidence presented in Section 4 that suggests sleep is relatively more labor-productivity enhancing than study-productivity enhancing for child laborers, I provide evidence for a statistically significant negative association between annual average sunset time and children's daily wage rate. Using the 2006 REDS, I find an hour delay in annual average sunset time reduces daily wage rate paid to child laborers by roughly INR 17 (Table D.14).

Effect Size: Unsurprisingly, the magnitudes of the observed effects on children's learning outcomes are large: The point estimates capture long run impacts of chronic sunset-induced sleep deficits on learning and cognition.

In Section 4, I find that an hour delay in sunset time reduces children's sleep by roughly 30 minutes. If one were to extrapolate, my results suggest 30 minutes decrease in *daily* sleep decreases children's years of schooling by approximately 0.8 years. Expressed as an elasticity with respect to sleep duration, my long-run education estimate is 3.5. Quantitatively these estimates are consistent with Gibson and Shrader (2018), who show an hour delay in annual average sunset reduces weekly sleep (daily sleep) by roughly one hour (9 minutes) and decreases long-run earnings by 4%. Expressed as an elasticity with respect to sleep duration, their long-run earnings estimate is 2.6.

These estimates capture all location-level general equilibrium effects. Every child and parent in a location experiences the same, permanent sunset-induced sleep deficits. Thus, the estimated β includes any spillover and peer effects from decreasing the mean sleep in a location. Carrell, Fullerton and West (2009) estimate an elasticity of academic achievement with respect to peer quality of roughly 0.9. In Appendix E, I show sunset-induced sleep deficits decrease adults' wages in the long run: an hour delay in annual average sunset time reduces adult wage rate by 8%. Dahl and Lochner (2012) estimate an elasticity of family income with respect to child achievement of approximately 0.6. Similarly, sunset-induced sleep deficits may also decrease teacher value-added. This discussion implies that a child would not see a 0.8 year increase from an additional hour of daily sleep, but instead something potentially smaller.[31]

Short- vs. Long-Run Effect of Later Sunset on Children's Learning Outcomes: In Section 4, I provide evidence that children in engage in ex post compensatory behavior: daytime naps. To shed light on whether afternoon naps and other unobserved compensatory behavior mitigates the accumulative effects of chronic sunset-induced sleep deficits on learning outcomes in the long-run, I convert the short-run effect, decrease in test score standard deviations, to more concrete measures following the methodology and parameter estimates from Evans and Yuan (2019), and compare it to the long-run effect. The difference between short- and long-run estimates will reflect the accumulated impacts of chronic sunset-induced sleep deficits on learning plus the impacts of any ex post compensatory behaviors (Appendix F). Evans and Yuan (2019) find a one standard deviation gain in literacy skill is associated with between 4.7 and 6.8 additional years of schooling.[32] Using this metric, the decrease of 0.6 standard deviations in math scores is equivalent to reducing the effective years of schooling by 3.5 years (5.75*0.6 standard deviations). This effect is significantly larger than my long-run estimate, suggesting individual adaptation mitigates roughly 75% of the accumulative effects of chronic sunset-induced sleep deficits on children's learning outcomes in the long run. This result is consistent with papers in environmental economics that finds evidence on the impacts of adaptation on the relationship between temperature extremes and mortality as well as temperature extremes and human capital accumulation (Barreca et al., 2016; Zivin, Hsiang and Neidell, 2018).

[31] Even future field experiments that evaluate effects of sleep deprivation on children's learning outcomes in long run, by randomly assigning students to schools with early vs. late start times, for example, would generate point estimates that include these spillover and peer effects.

[32] These estimates are based on the World Bank's STEP Skills Measurement Program, which is a test designed to test proficiency in literacy with respect to word meaning, sentence processing and basic passage comprehension, in the language of the resident country (World Bank, 2018). I use 5.75 years of equivalent schooling as the conversion factor, which is the midpoint of the range of the estimates of 4.7 to 6.8.

6 Conclusion

During the past two decades advances in collection of new data have allowed researchers to make significant progress in our understanding of how individuals allocate their time, and examine the effects of time use (Aguiar, Hurst and Karabarbounis, 2012). Yet, we know little about how children allocate their time or the effects of children's time use. In this study, I use a unique 24-hour time use data from India, and exogenous variation provided by sunset time, to examine how children trade off sleep – the most common time use – against other time uses as well as the impact of lower sleep on learning outcomes. I establish two new sets of results:

First, an hour delay in sunset time reduces children's sleep by 30 minutes: when the sun sets later, children go to bed later; however, children fail to compensate by waking-up later. Sleep-deprived children decrease productive effort – sleep-deprived students (child laborers) decrease time allocated to self-study or homework (formal and informal work) – and increase time allocated to sedentary (e.g., talking) and compensatory leisure activities (e.g., daytime naps). These results suggest sleep is relatively more study-productivity enhancing than labor-productivity enhancing for students, and relatively more labor-productivity enhancing than study-productivity enhancing for child laborers. I use time-of-day activity data to provide evidence for a causal chain linking sleep and productivity and rule out alternative explanations.

Second, sunset-induced sleep deficits have significant negative effects on children's learning outcomes. In the short-run, sunset-induced sleep deficits decrease math scores by 0.6 standard deviations. In the long-run, sustained sunset-induced sleep deficits translate into 0.8 fewer years of education: school-age children are less likely to complete primary and middle school completion rates, and less likely to be enrolled in school. The difference between short- and long-run estimates reflects the accumulated impacts of chronic sunset-induced sleep deficits on learning plus the impacts of any ex post compensatory behaviors. To shed light on which effect dominates, I convert the short-run estimate, captured via decrease in test score standard deviations, to equivalent years of schooling (-3.5 years), and compare it to the long-run effect (-0.8 years). Difference between the two estimates suggests individiduals' adaptation (e.g., daytime naps) is partially successful in mitigating the accumulative effects of chronic sunset-induced sleep deficits. Yet, the unmitigated effects are quantitatively significant.

Living conditions in developing countries are associated with noise, heat, mosquitoes, overcrowding, and overall uncomfortable physical conditions, that may inhibit sleep. If sleep is associated with cognitive performance, sleep deprivation among the poor could deepen poverty. However, thus far, studies that investigate the short- or long-run effects of sleep deprivation on cognition, productivity, or health, have exclusively focused on the developed world. In the context of a core outcome of interest to long-term poverty alleviation and economic growth, this paper provides the first estimates of the effect of chronic sleep deficits on children's learning outcomes in the long run. The magnitude of these effects must serve as a call to arms to evaluate policy levers – e.g., school start times – that may help improve sleep among children in lower-income countries.

References

Abadie, Alberto, Susan Athey, Guido Imbens, and Jeffrey Wooldridge. 2018. "When Should You Adjust Standard Errors for Clustering?" *Mimeo.*

Aguiar, Mark, Erik Hurst, and Loukas Karabarbounis. 2012. "Recent Developments in the Economics of Time Use." *Annual Review of Economics*, 4(1): 373–397.

Aguiar, Mark, Mark Bils, Kerwin Charles, and Erik Hurst. 2016. "Leisure Luxuries and the Labor Supply of Young Men." *Mimeo.*

Antonenko, Daria, Susanne Diekelmann, Cathrin Olsen, Jan Born, and Matthias Mölle. 2013. "Napping to renew learning capacity: Enhanced encoding after stimulation of sleep slow oscillations." *European Journal of Neuroscience*, 37(7): 1142–1151.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. 2016. "Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the Twentieth Century." *Journal of Political Economy*, 124(1): 105–159.

Barro, Robert J. 2001. "Human Capital and Growth." *American Economic Review Papers and Proceedings*, 91(2): 12–17.

Basner, Mathias, Hengyi Rao, Namni Goel, and David F. Dinges. 2013. "Sleep deprivation and neurobehavioral dynamics." *Current Opinion in Neurobiology*, 23(5): 854–863.

Becker, Gary S. 1965. "A Theory of the Allocation of Time." *Economic Journal*, 75(299): 493–517.

Becker, Gary S. 1974. "A Theory of Social Interactions." *Journal of Political Economy*, 82(6): 1063–1093.

Bessone, Pedro, Gautam Rao, Frank Schilbach, Heather Schofield, and Mattie Toma. 2019. "Sleepless in Chennai: The Consequences of Sleep Deprivation Among the Urban Poor." *Mimeo.*

Biddle, Jeff E., and Daniel S. Hamermesh. 1990. "Sleep and the Allocation of Time." *Journal of Political Economy*, 98(5): 922–943.

Calonico, Sebastian, Matias D. Cattaneo, and Rocio Titiunik. 2014. "Robust Nonparametric Confidence Intervals for Regression-Discontinuity Designs." *Econometrica*, 82(6): 2295–2326.

Calonico, Sebastian, Matias D. Cattaneo, Max H. Farrell, and Rocío Titiunik. 2017. "Rdrobust: Software for regression-discontinuity designs." *Stata Journal*, 17(2): 372–404.

Cappuccio, Francesco P., Lanfranco D'Elia, Pasquale Strazzullo, and Michelle A. Miller. 2010. "Sleep duration and all-cause mortality: A systematic review and meta-analysis of prospective studies." *Sleep*, 33(5): 585–592.

Carrell, Scott E., Richard L. Fullerton, and James E. West. 2009. "Does Your Cohort Matter? Measuring Peer Effects in College Achievement." *Journal of Labor Economics*, 27(3): 439–464.

Carrell, Scott E, Teny Maghakian, and James E West. 2011. "A's from Zzzz's? The Causal Effect of School Start Time on the Academic Achievement of Adolescents." *American Economic Journal: Economic Policy*, 3(3): 62–81.

Carskadon, Mary A., Katelyn Harvey, and William C. Dement. 1981*a*. "Sleep loss in young adolescents." *Sleep*, 4(3): 299–312.

Carskadon, Mary A., Kim Harvey, and William C. Dement. 1981*b*. "Acute Restriction of Nocturnal Sleep in Children." *Perceptual and Motor Skills*, 53(1): 103–112.

Census. 2011. "The Census of India." *Office of the Registrar General and Census Commissioner.*

Conley, T.G. 1999. "GMM Estimation with Cross-sectional Dependence." *Journal of Econometrics*, 92(1): 1–45.

Dahl, By Gordon B, and Lance Lochner. 2012. "The Impact of Family Income on Child Achievement : Evidence from the Earned Income Tax Credit." *American Economic Review*, 102(5): 1927–1956.

Das, Jishnu, Stefan Dercon, James Habyarimana, Pramila Krishnan, Karthik Muralidharan, and Venkatesh Sundararaman. 2013. "School Inputs, Household Substitution, and Test Scores." *American Economic Journal: Applied Economics*, 5(2): 29–57.

Deaton, Angus. 1997. *The Analysis of Household Surveys: A Microeconometric Approach to Development Policy.*

Edwards, Finley. 2012. "Early to rise? The effect of daily start times on academic performance." *Economics of Education Review*, 31(6): 970–983.

Evans, David K, and Fei Yuan. 2019. "Equivalent Years of Schooling A Metric to Communicate Learning Gains in Concrete Terms." *World Bank Policy Research Working Paper.*

Fallone, Gahah, Christine Acebo, J. Todd Arnedt, Ronald Seifer, and Mary A. Carskadon. 2001. "Effects of Acute Sleep Restriction on Behavior, Sustained Attention, and Response Inhibition in Children." *Perceptual and Motor Skills*, 93: 213–229.

Fogel, Robert William. 2004. *The Escape from Hunger and Premature Death, 1700–2100.* Cambridge, UK: Cambridge Univ. Press.

Garcia, Sandra, and Juan Saavedra. 2017. "Educational Impacts and Cost-Effectiveness of Conditional Cash Transfer Programs in Developing Countries: A Meta-Analysis." *Review of Educational Research*, 87(5): 921–965.

Gaski, John F., and Jeff Sagarin. 2011. "Detrimental effects of daylight-saving time on SAT scores." *Journal of Neuroscience, Psychology, and Economics*, 4(1): 44–53.

Gibson, Matthew, and Jeffrey Shrader. 2018. "Time Use and Productivity: The Wage Returns to Sleep." *Review of Economics and Statistics*, Forthcoming.

Giuntella, Osea, and Fabrizio Mazzonna. 2018. "Sunset Time and the Health Effects of Social Jetlag: Evidence from US Time Zone Borders." *Mimeo.*

Gronau, Reuben. 1977. "Leisure, Home Production, and Work–the Theory of the Allocation of Time Revisited." *Journal of Political Economy*, 85(6): 1099–1123.

Gupta, Ravi, Sunil Dutt Kandpa, Deepak Goel, Nidhi Mittal, Mohan Dhyani, and Manish Mittalc. 2016. "Sleep-patterns, co-sleeping and parent's perception of sleep among school children: Comparison of domicile and gender." *Sleep Science*, 9(3): 192–197.

Hamermesh, Daniel S., Caitlin Knowles Myers, and Mark L. Pocock. 2008. "Cues for Timing and Coordination: Latitude, Letterman, and Longitude." *Journal of Labor Economics*, 26(2): 223–246.

Hayashi, Mitsuo, Naoko Motoyoshi, and Tadao Hori. 2005. "Recuperative Power of a Short Daytime Nap With or Without Stage 2 Sleep." *Sleep*, 28(7): 829–836.

Heissel, Jennifer, and Samuel Norris. 2017. "Rise and Shine: The Effect of School Start Times on Academic Performance from Childhood through Puberty." *Journal of Human Resources*, Forthcoming.

Herber, Stefanie P., Johanna Sophie Quis, and Guido Heineck. 2017. "Does the transition into daylight saving time affect students' performance?" *Economics of Education Review*, 61: 130–139.

Hinrichs, Peter. 2011. "When the Bell Tolls: The Effects of School Starting Times on Academic Achievement." *Education Finance and Policy*, 6(4): 486–507.

Hirshkowitz, Max, Kaitlyn Whiton, Steven M. Albert, Cathy Alessi, Oliviero Bruni, Lydia DonCarlos, Nancy Hazen, John Herman, Eliot S. Katz, Leila Kheirandish-Gozal, David N. Neubauer, Anne E. O'Donnell, Maurice Ohayon, John Peever, Robert Rawding, Ramesh C. Sachdeva, Belinda Setters, Michael V. Vitiello, J. Catesby Ware, and Paula J. Adams Hillard. 2015. "National sleep foundation's sleep time duration recommendations: Methodology and results summary." *Sleep Health*, 1(1): 40–43.

Hsiang, S. M. 2010. "Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America." *Proceedings of the National Academy of Sciences*, 107(35): 15367–15372.

Imbens, Gguido, and Karthik Kalyanaraman. 2012. "Optimal bandwidth choice for the regression discontinuity estimator." *Review of Economic Studies*, 79(3): 933–959.

Jae Lo, Ming. 2016. "Relationship between Sleep Habits and Daytime Sleepiness, Inattention, and Aggressive Behavior among Taiwanese Kindergarten Children." *Clinics in Mother and Child Health*, 13(3): 1–7.

Killgore, William D S. 2010. "Effects of sleep deprivation on cognition." *Progress in Brain Research*, 185: 105–129.

Lam, Janet C., E. Mark Mahone, Thornton B.A. Mason, and Steven M. Scharf. 2011. "The Effects of Napping on Cognitive Function in Preschoolers." *Journal of Developmental Behavioral Pediatrics*, 32(2): 90–97.

Lam, Janet C, Taylor A Koriakin, Steven M Scharf, Thornton B A Mason, and E Mark Mahone. 2015. "Does Increased Consolidated Nighttime Sleep Facilitate Attentional Control? A Pilot Study of Nap Restriction in Preschoolers." *Journal of Attention Disorders*, 1–8.

Lauderdale, DS, KL Knutson, L. L Yan, Kiang Liu, and P.J. Rathouz. 2008. "Sleep duration: how well do self-reports reflect objective measures? The CARDIA Sleep Study." *Epidemiology*, 19(6): 838–45.

Lim, Julian, and David F. Dinges. 2010. "A Meta-Analysis of the Impact of Short-Term Sleep Deprivation on Cognitive Variables." *Psychological Bulletin*, 136(3): 375–389.

Li, Shenghui, Xingming Jin, Chonghuai Yan, Shenghu Wu, Fan Jiang, and Xiaoming Shen. 2008. "Bed- and room-sharing in Chinese school-aged children: prevalence and association with sleep behaviors." *Sleep Medicine*, 9(5): 555–563.

Lochner, Lance. 2011. "Non-Production Benefits of Education: Crime, Health, and Good Citizenship." *NBER Working Paper Series.*

Matricciani, Lisa, Sarah Blunden, Gabrielle Rigney, Marie T. Williams, and Tim S. Olds. 2013. "Children's Sleep Needs: Is There Sufficient Evidence to Recommend Optimal Sleep for Children?" *Sleep*, 36(4): 527–534.

Mincer, Jacob. 1962. *Labor Force Participation of Married Women: A Study of Labor Supply.* Princeton University Press.

Munshi, Kaivan, and Mark Rosenzweig. 2016. "Networks and Misallocation: Insurance, Migration, and the Rural-Urban Wage Gap." *American Economic Review*, 106(1): 46–98.

Muralidharan, K. 2017. *Field Experiments in Education in Developing Countries.* Vol. 2.

Muralidharan, Karthik, Abhijeet Singh, and Alejandro J. Ganimian. 2019. "Disrupting education? Experimental evidence on technology-aided instruction in India." *American Economic Review*, 109(4): 1426–1460.

Nelson, Richard R., and Edmund S. Phelps. 1966. "Investment in Humans, Technological Diffusion, and Economic Growth." *American Economic Review*, 56(1): 69–75.

Ohayon, Maurice, Mary A Carskadon, and Christian Guilleminault. 2004. "Meta-Analysis of Quantitative Sleep Parameters From Childhood to Old Age in Healthy Individuals: Developing Normative Sleep Values Across the Human Lifespan." *Sleep*, 27(2): 20–23.

Oreopoulos, Philip, and Uros Petronijevic. 2019. "The Remarkable Unresponsiveness of College Students to Nudging and What Can We Learn From It." *NBER Working Paper Series.*

Oreopoulos, Philip, Richard Patterson, Uros Petronijevic, and Nolan Pope. 2018. "Lack of Study Time is the Problem, But What is the Solution? Unsuccessful Attempts to Help Traditional and Online College Students." *NBER Working Paper Series.*

Owens, Judith A, Katherine Belon, and Patricia Moss. 2010. "Impact of Delaying School Start Time on Adolescent Sleep, Mood, and Behavior." *Archives of Pediatrics & Adolescent Medicine*, 164(7): 608–614.

Pandey, R. N. 1999. "Operational Issues in Conducting the Pilot Time Use Survey in India." *Central Statistical Organisation - Ministry of Statistics and Programme Implementation, New Delhi*, 1–7.

Parker, Susan W, and Tom S Vogl. 2018. "Do Conditional Cash Transfers Improve Economic Outcomes in the Next Generation? Evidence from Mexico." *NBER Working Paper*, 1–51.

Paruthi, Shalini, Lee J. Brooks, Carolyn D'Ambrosio, Wendy A. Hall, Suresh Kotagal, Robin M. Lloyd, Beth A. Malow, Kiran Maski, Cynthia Nichols, Stuart F. Quan, Carol L. Rosen, Matthew M. Troester, and Merrill S. Wise. 2016. "Recommended amount of sleep for pediatric populations: A consensus statement of the American Academy of Sleep Medicine." *Journal of Clinical Sleep Medicine*, 12(6): 785–786.

Pope, Nolan G. 2016. "How the time of day affects productivity: Evidence from school schedules." *The Review of Economics and Statistics*, 98(1): 1–11.

Roenneberg, Till. 2013. "Chronobiology: The Human Sleep Project." *Nature*, 498(7455): 427–428.

Roenneberg, Till, and Martha Merrow. 2007. "Entrainment of the Human Circadian Clock." *Cold Spring Harbor Symposia on Quantitative Biology: Clocks and rhythms*, 72: 293–299.

Romer, Paul M. 1986. "Increasing Returns and Long-Run Growth." *Journal of Political Economy*, 94(5): 1002–1037.

Sadeh, Avi, Reut Gruber, and Amiram Raviv. 2003. "The Effects of Sleep Restriction and Extension on School-Age Children: What a Difference an Hour Makes." *Child Development*, 74(2): 444–455.

Samuelson, Paul A. 1947. *Foundations of Economic Analysis.* Cambridge: Harvard University Press.

Spaeth, Andrea M., David F. Dinges, and Namni Goel. 2013. "Effects of Experimental Sleep Restriction on Weight Gain, Caloric Intake, and Meal Timing in Healthy Adults." *Sleep*, 36(7): 981–990.

Stein, Ernesto, and Christian Daude. 2007. "Longitude Matters: Time Zones and the Location of Foreign Direct Investment." *Journal of International Economics*, 71(1): 96–112.

Stewart, Jay. 2009. "Tobit or Not Tobit?" *BLS Working Paper.*

Stinebrickner, R., and T. R Stinebrickner. 2008. "the Causal Effect of Studying on Academic Performance." *BE Journal of Economic Analysis & Policy*, 8(1): 14.

Van Der Werf, Ysbrand D., Ellemarije Altena, Menno M. Schoonheim, Ernesto J. Sanz-Arigita, José C. Vis, Wim De Rijke, and Eus J.W. Van Someren. 2009. "Sleep benefits subsequent hippocampal functioning." *Nature Neuroscience*, 12(2): 122–123.

Van Dongen, Hans P.A., Greg Maislin, Janet M. Mullington, and David F. Dinges. 2003. "The Cumulative Cost of Additional Wakefulness: Dose-Response Effects on Neurobehavioral Functions and Sleep Physiology From Chronic Sleep Restriction and Total Sleep Deprivation." *Sleep*, 26(2): 117–126.

Wahlstrom, Kyla. 2002. "Changing Times: Findings From the First Longitudinal Study of Later High School Start Times." *NASSP Bulletin*, 86(633): 3–21.

Walker, Matthew P. 2017. *Why We Sleep: Unlocking the Power of Sleep and Dreams.* Scribner.

Walker, M. P. 2010. "Sleep-Dependent Memory Processing." *Encyclopedia of Neuroscience*, 1055–1065.

World Bank. 2018. "The STEP Skills Measurement Program."

Yoo, Seung Schik, Peter T. Hu, Ninad Gujar, Ferenc A. Jolesz, and Matthew P. Walker. 2007. "A deficit in the ability to form new human memories without sleep." *Nature Neuroscience*, 10(3): 385–392.

Zivin, Joshua Graff, Solomon M. Hsiang, and Matthew Neidell. 2018. "Temperature and human capital in the short and long run." *Journal of the Association of Environmental and Resource Economists*, 5(1): 77–105.

Supplementary Appendices

A A Model of Children's Time Use

To formally examine how children trade-off sunset-induced reduction in sleep with other time uses, I extend the productive sleep model from Gibson and Shrader (2018) – an extension of the time use model of Gronau (1977) – to children. The child's problem is to maximize a utility function $u(x, L)$ where x are consumables, and L is leisure time. u is weakly increasing in each argument and is quasi-concave. I assume that parents induce children's investment in schooling through parental transfers (Becker, 1974). Thus, the child's consumables depend on earnings through own labor, x_O, earned by working for parents, and reward, r, set by parents for educational achievement.

Work time is denoted as N, thus the child can gain output, $x_O = NW(S)$, where $W(S)$, is wage received from parents, and is a function of children's sleep, S. Price is normalized to 1. Similarly, the child can also gain goods, $x_H = rh(H, S)$, where reward, r, can be thought of as a parent's present discounted value of the returns to child's achievement in the current period, and $h(H, S)$ is the education production function, with inputs H, denoting time spent on schooling, including self investment in study effort. Thus, total consumables are given by $x = x_O + x_H$. I assume that the parent has full information and can fully commit to this contract. I model sleep as productivity-enhancing, more sleep will, *ceteris paribus*, increase labor productivity ($\frac{\partial W(S)}{\partial S} > 0$) and educational achievement ($\frac{\partial h(H,S)}{\partial S} > 0$). However, the total effect of sleep on earnings and achievement, and hence parental transfers, also depends on how children trade-off sleep with work ($\frac{\partial N}{\partial S}$), study time ($\frac{\partial H}{\partial S}$), and leisure time ($\frac{\partial L}{\partial S}$).

Putting all time uses together, the total time constraint is $T = L + H + N + S$. Substituting the time budget into the goods budget, the combined budget constraint is

$$x_H = rh(T - L - S - N, S) \tag{3}$$

and the optimization problem is

$$\max_{L,N,S} \tag{4}$$

$$u(NW(S) + x_H, L) + \lambda_1(rh(T - L - S - N, S) - x_H) + \lambda_2 N + \lambda_3 S$$

Consider a child who is a student, but also works at home or in the market. Also, assume sleep is positive, so $N > 0$, $S > 0$, and $\lambda_2 = \lambda_3 = 0$, by complementary slackness. Further, $h'_1 > 0$, $h'_2 > 0$, $h''_{11} < 0$, and $h''_{22} < 0$. First order conditions can be written as

$$\frac{u'_2}{u'_1} = rh'_1 \tag{5}$$

$$W(S) = rh'_1 \tag{6}$$

$$NW'(S) + rh'_2 = rh'_1 \tag{7}$$

Taking the total derivative of Equation (6), I get

$$\frac{dH}{dS} = \frac{W'(S) - rh''_{12}(H^*, S^*)}{h''_{11}(H^*, S^*)} \tag{8}$$

Thus, $\frac{dH}{dS} > 0$ if $W'(S) < rh''_{12}(H^*, S^*)$. Sleep will induce study effort if marginal increase in study productivity with respect to sleep is larger than the marginal increase in wages (labor productivity) with respect to sleep. However, if the opposite condition holds, $W'(S) > rh''_{12}(H^*, S^*)$, then increase in sleep will reduce self-investment in study effort $\frac{dH}{dS} < 0$. Taking the total derivative of Equation (7),

$$\frac{dN}{dS} = \frac{[rh''_{11}(H^*, S^*) - rh''_{21}(H^*, S^*)]\frac{dH}{dS} + rh''_{12}(H^*, S^*) - rh''_{22}(H^*, S^*) - NW''(S)}{W'(S)} \tag{9}$$

Assume $W''(S) \leq 0$, and sleep is productive: $h''_{21}(H^*, S^*) > 0$ and $W'(S) > 0$, if $\frac{dH}{dS} < 0$, then $\frac{dN}{dS} > 0$.[33] Therefore, sleep and work effort will be complements if sleep and study effort are substitutes and vice-a-versa.[34]

To summarize, the model predicts sleep increases study effort but decreases work effort, if sleep is more achievement-enhancing than work-productivity enhancing. On the other hand, if sleep is more work-productivity enhancing than achievement-enhancing, then sleep will increase work time, instead decreasing study time.

[33] Medical studies often find a nonlinear relationship between sleep and health that suggests $W''(S) < 0$ (Cappuccio et al., 2010). Van Dongen et al. (2003) find that cognition declines linearly with sleep deprivation.

[34] An increase in duration of productive sleep induces an increase in 'wages', so income and substitution effects make the sign of the net effect on leisure time ambiguous.

B Appendix: Data

Young Lives Survey (YLS)

Young Lives Survey (YLS) is a study of childhood poverty coordinated by the University of Oxford.[35] The study has collected data on two cohorts of children in the state of Andhra Pradesh, in India: 1,008 children born between January 1994 and June 1995, and 2,011 children born between January 2001 and June 2002.[36] Data were collected from children and their families using household visits in 2002, 2006, 2009, and in 2013. Children were tested in math across these survey rounds. The tests were related to the formal school curriculum in Andhra Pradesh. Different tests were administered to children across rounds in order to ensure that they were appropriate for the children's age and current stage of education. These tests were quite comprehensive, with the math questionnaire containing 30 questions.

Rural Economic and Demographic Survey (REDS)

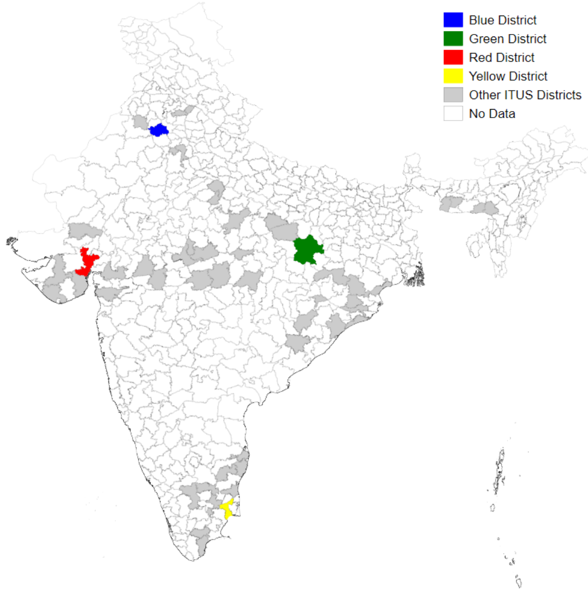
I use village- and household-level surveys from the 2006 round of REDS, administered by the National Council of Applied Economic Research (NCAER). It is a nationally representative survey of rural households in India spanning over 200 villages across 100 districts in 17 major states.[37] The REDS data provide village identifiers. Therefore, I compute sunset times at the village level. Like ITUS and DHS, I restrict the REDS sample to children between 6 and 16 years of age. Roughly 90% school-age children are enrolled in school; 52% have completed primary school and 23% have completed middle school. In the previous 50 years, the average village observed 7 episodes of in-migration and 2 episodes of out-migration. In the average village 40% households have an electricity connection, and roughly 20% households have access to running water. The REDS data also include record of the prevailing village-level daily wage rate for children and gender-specific daily wage rate for adults.

[35]Young Lives is funded by UK aid from the Department for International Development (DFID). The views expressed here are those of the author(s). They are not necessarily those of Young Lives, the University of Oxford, DFID, or other funders. For more information of YLS, see: www.younglives.org.uk

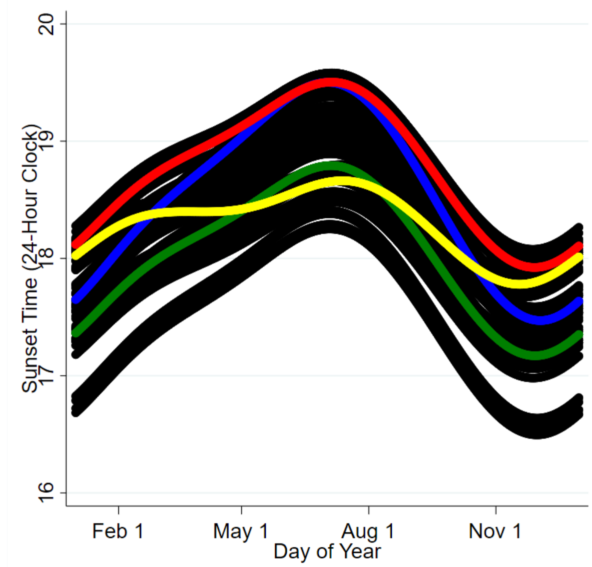
[36]The districts included in the sample are presented in Figure B.18. Figure B.19 presents the distribution of annual average sunset time for all 7 districts in the YLS data as well as the distribution of sunset time at the district-test-date level.

[37]REDS villages are mapped in Figure B.17.

Figure B.1: Seasonal Variation in Daily Sunset Time in ITUS Districts

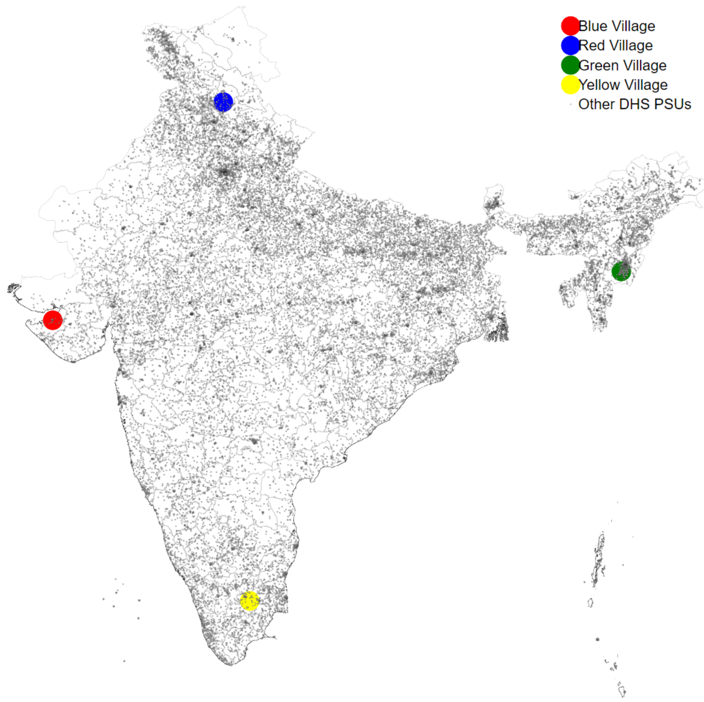


(a) ITUS districts

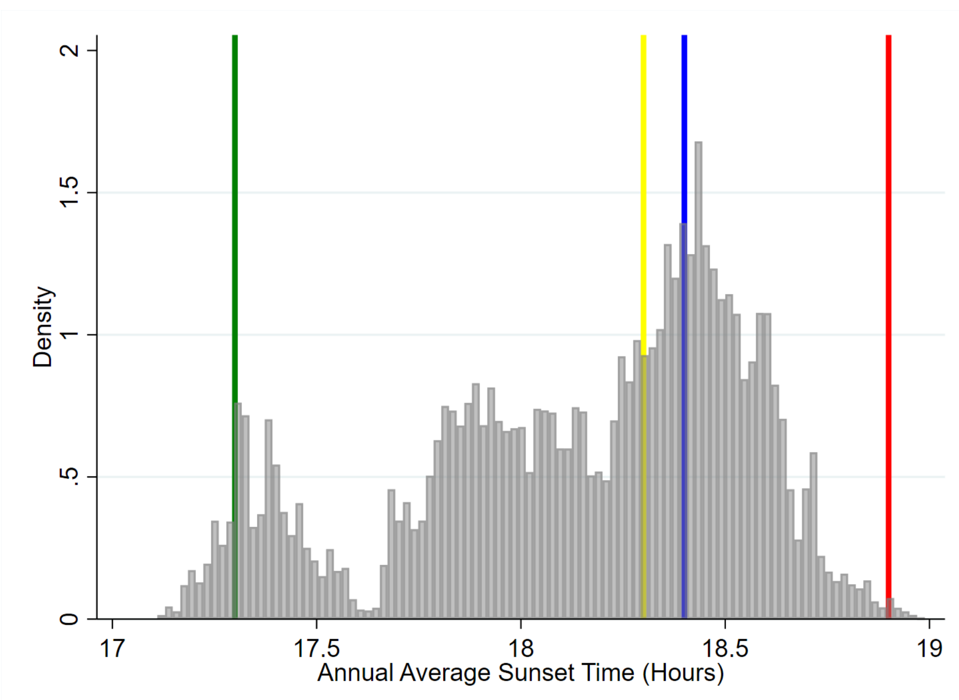


(b) Daily sunset time in ITUS districts

Figure B.2: Geographic Variation in Annual Average Sunset Time in DHS Villages



(a) DHS villages



(b) Annual average sunset time associated with DHS villages

Figure B.3: Districts in the India Time Use Survey (ITUS)

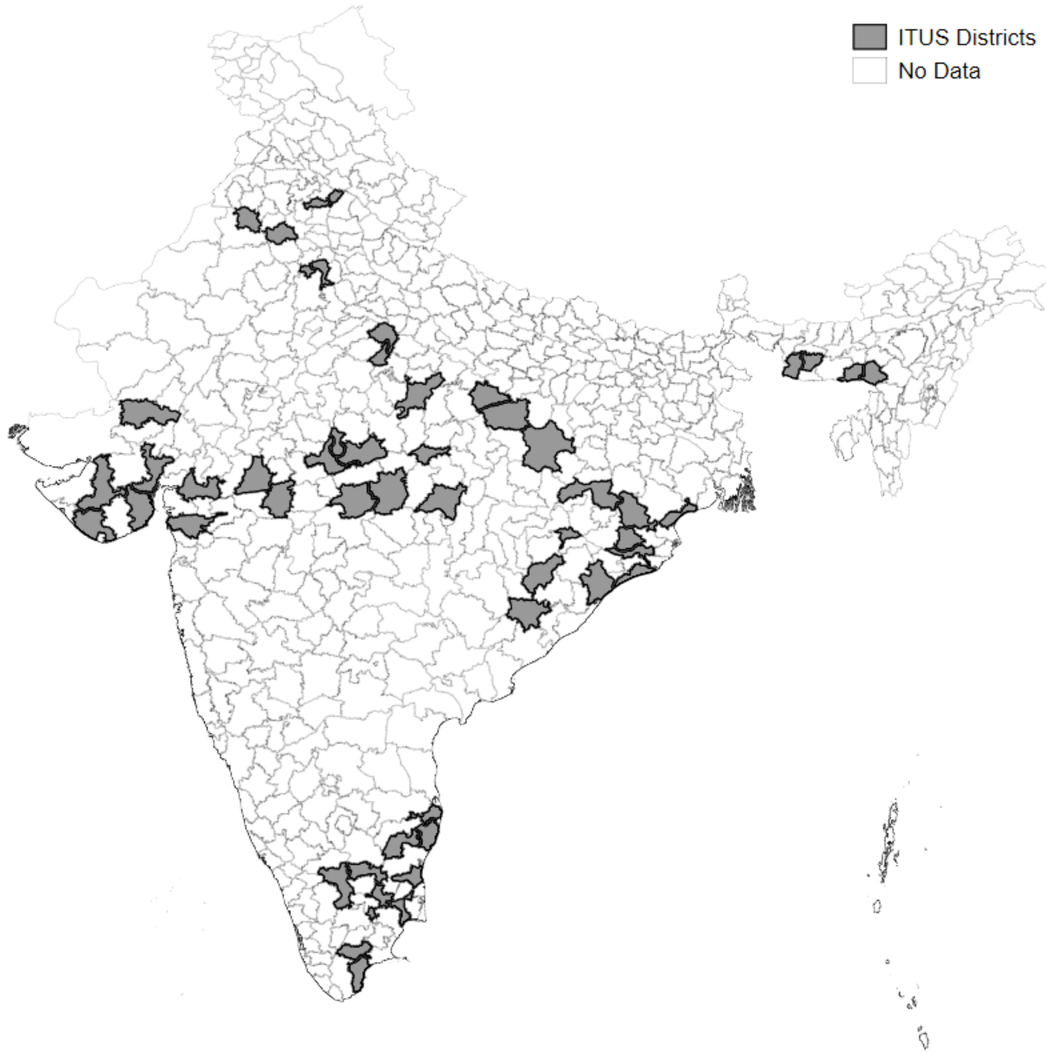
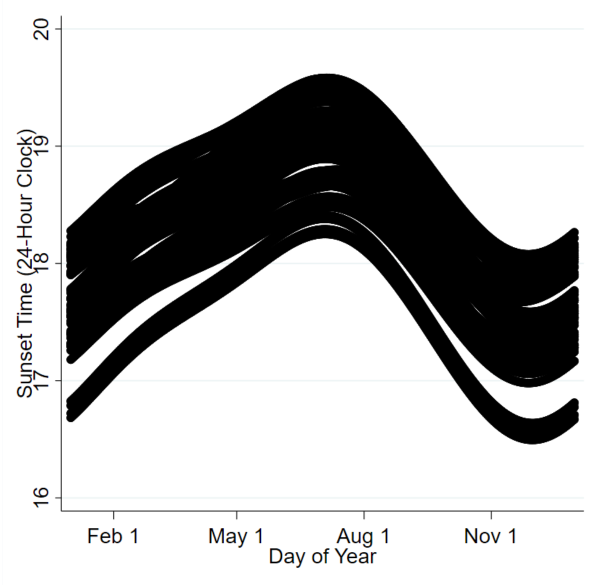
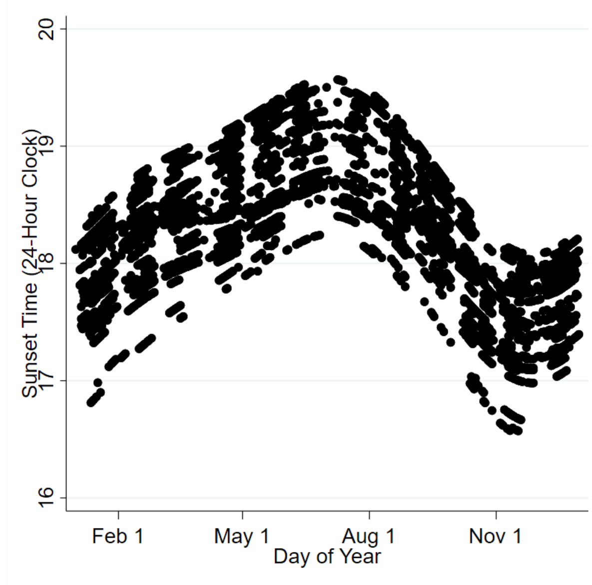


Figure B.4: Summary Statistics: Distribution of Daily Sunset Time in ITUS Districts



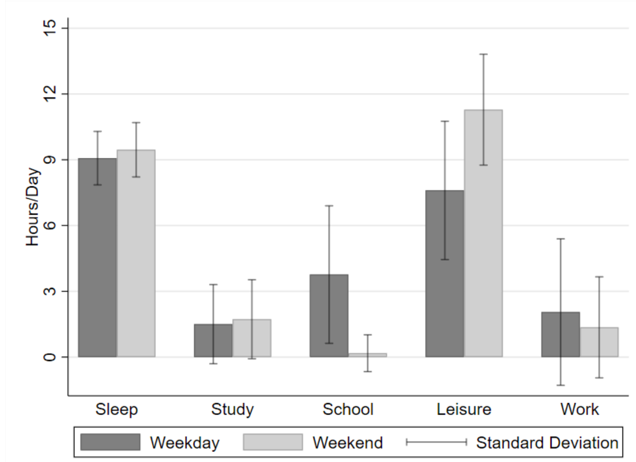
(a) Daily sunset time in ITUS districts



(b) Daily sunset time for sampled dates in ITUS districts

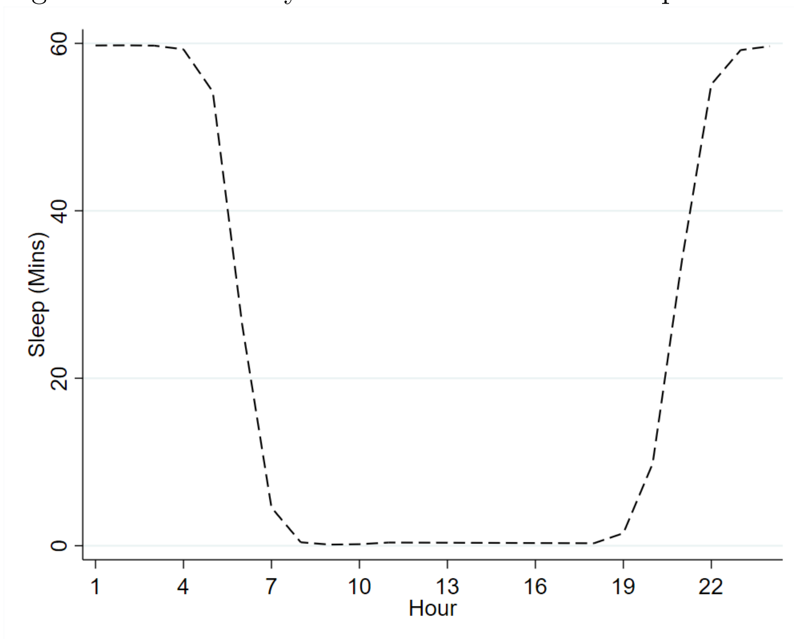
Notes: This figure presents distribution of daily sunset time in ITUS districts. Panel (a) presents daily sunset time for every day in a year for all districts in ITUS. Panel (b) presents daily sunset time for dates for which time use data was collected in ITUS districts.

Figure B.5: Summary Statistics: Children's Time Use



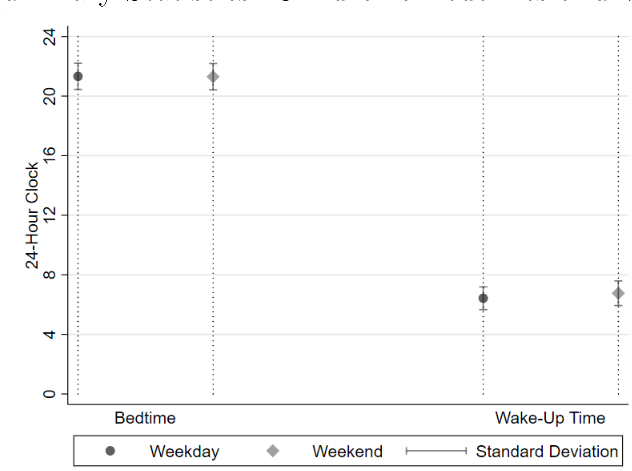
Notes: This figure presents the average time allocated by children between 6 and 16 years of age to sleep, study, school, leisure and work on weekdays and weekends. Source: ITUS.

Figure B.6: Summary Statistics: Children's Sleep Patterns



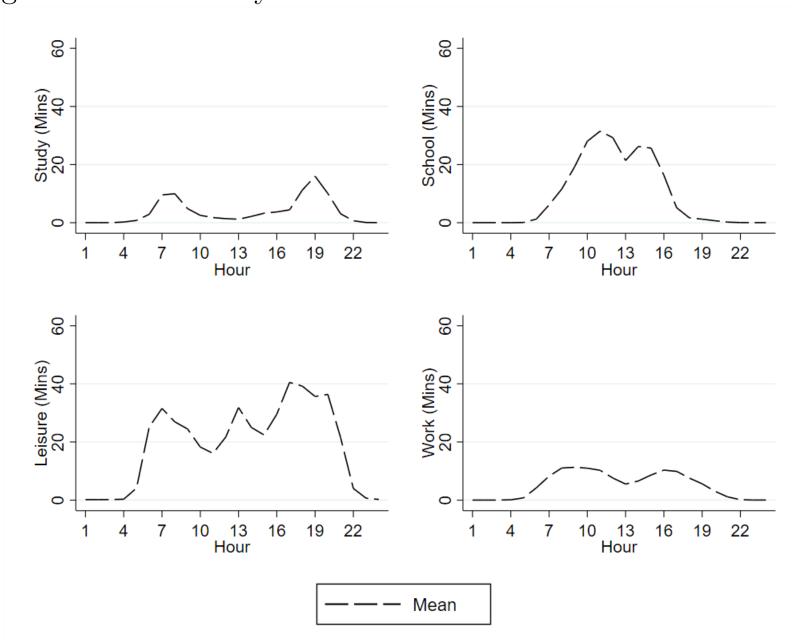
Notes: This figure presents the average time spent on sleep by children between 6 and 16 years of age for each hour of the 24-hour day cycle on a weekday. Source: ITUS.

Figure B.7: Summary Statistics: Children's Bedtimes and Wake-up Times



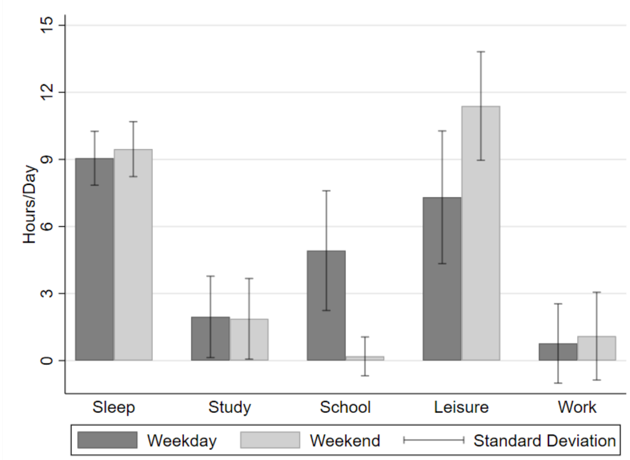
Notes: This figure presents the average bedtimes and wake-up times for children between 6 and 16 years of age on weekdays and weekends. Source: ITUS.

Figure B.8: Summary Statistics: Children's Time Use Patterns



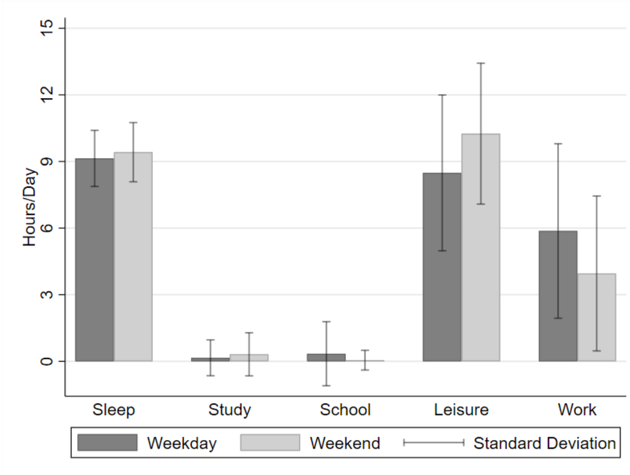
Notes: This figure presents the average time spent on study, school, leisure and work by children between 6 and 16 years of age for each hour of the 24-hour day cycle on a weekday. Source: ITUS.

Figure B.9: Summary Statistics: Students' Time Use



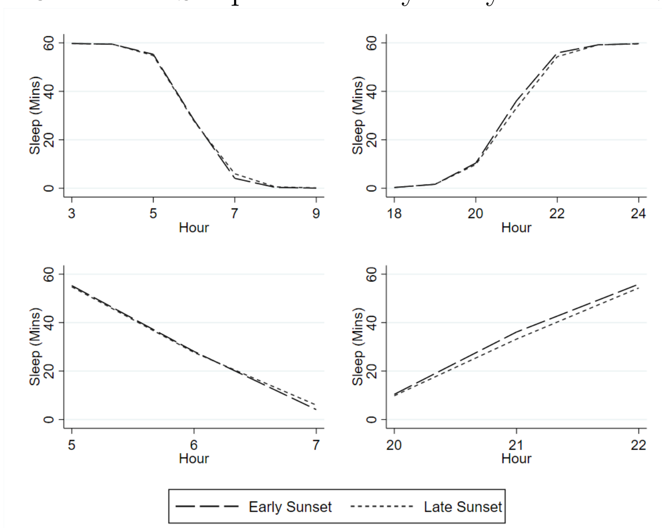
Notes: This figure presents the average time spent on sleep, study, school, leisure and work by students (or children whose primary activity is school) between 6 and 16 years of age on weekdays and weekends. Source: ITUS.

Figure B.10: Summary Statistics: Child Laborers' Time Use



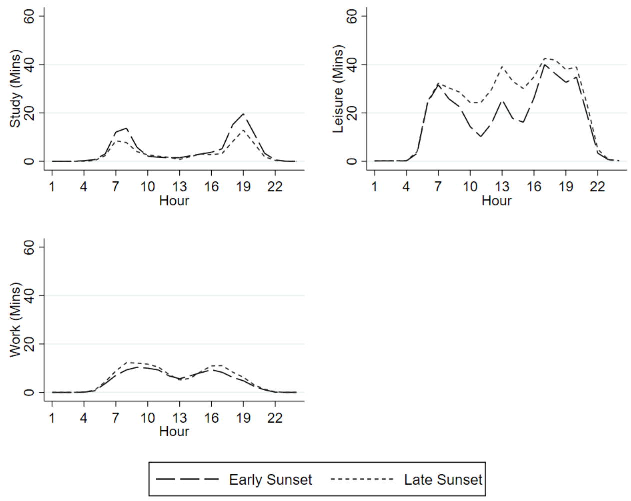
Notes: This figure presents the average time spent on sleep, study, school, leisure and work by child laborers (or children whose primary activity is work) between 6 and 16 years of age on weekdays and weekends. Source: ITUS.

Figure B.11: Children's Sleep Patterns by Early and Later Sunset Time



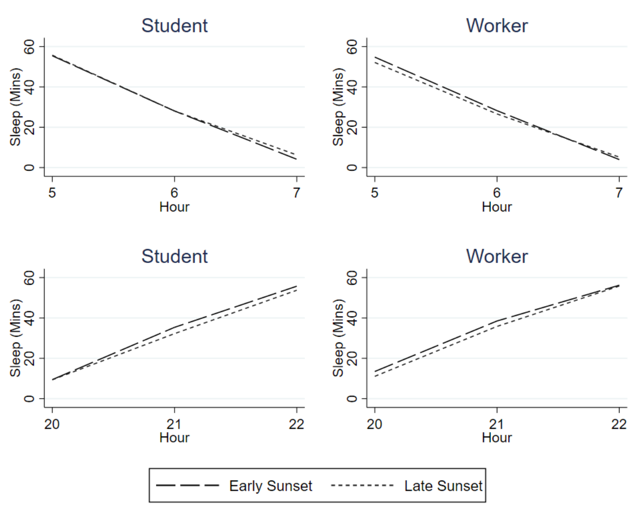
Notes: This figure compares the average time spent on sleep by children between 6 and 16 years of age for each hour across the 24-hour day cycle between early and late sunset days on a weekday. Within each district, early sunset observations include children interviewed when seasonal sunsets were below 25th percentile, while late sunset observations include children interviewed when seasonal sunsets were above 75th percentile. Source: ITUS.

Figure B.12: Children's Time Use Patterns by Early and Later Sunset Time



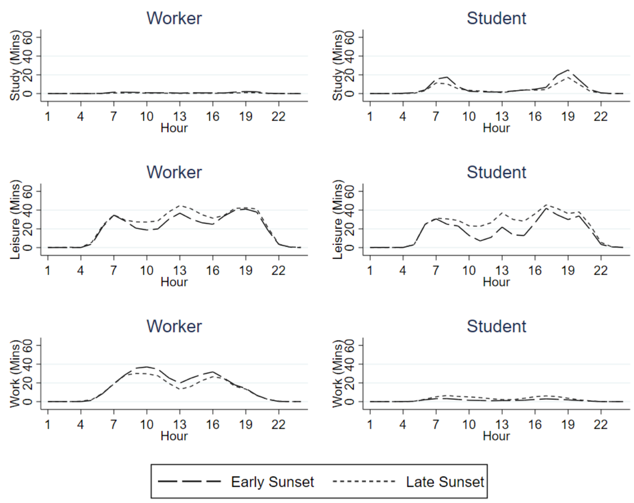
Notes: This figure compares the average time spent on study, school, leisure and work by children between 6 and 16 years of age for each hour across the 24-hour day cycle between early and late sunset days on a weekday. Within each district, early sunset observations include children interviewed when seasonal sunsets were below 25th percentile, while late sunset observations include children interviewed when seasonal sunsets were above 75th percentile. Source: ITUS.

Figure B.13: Children's Sleep Patterns by Early and Later Sunset Time by Primary Activity



Notes: This figure compares the average time spent on sleep by children between 6 and 16 years of age for each hour across the 24-hour day cycle between early and late sunset days on a weekday. Within each district, early sunset observations include children interviewed when seasonal sunsets were below 25th percentile, while late sunset observations include children interviewed when seasonal sunsets were above 75th percentile. Source: ITUS.

Figure B.14: Children's Time Use Patterns by Early and Later Sunset Time by Primary Activity



Notes: This figure compares the average time spent on study, leisure and work by children between 6 and 16 years of age for each hour across the 24-hour day cycle between early and late sunset days on a weekday. Within each district, early sunset observations include children interviewed when seasonal sunsets were below 25th percentile, while late sunset observations include children interviewed when seasonal sunsets were above 75th percentile. Source: ITUS.

Figure B.15: Primary Sampling Units (Villages/City Blocks) in the 2015 Indian DHS

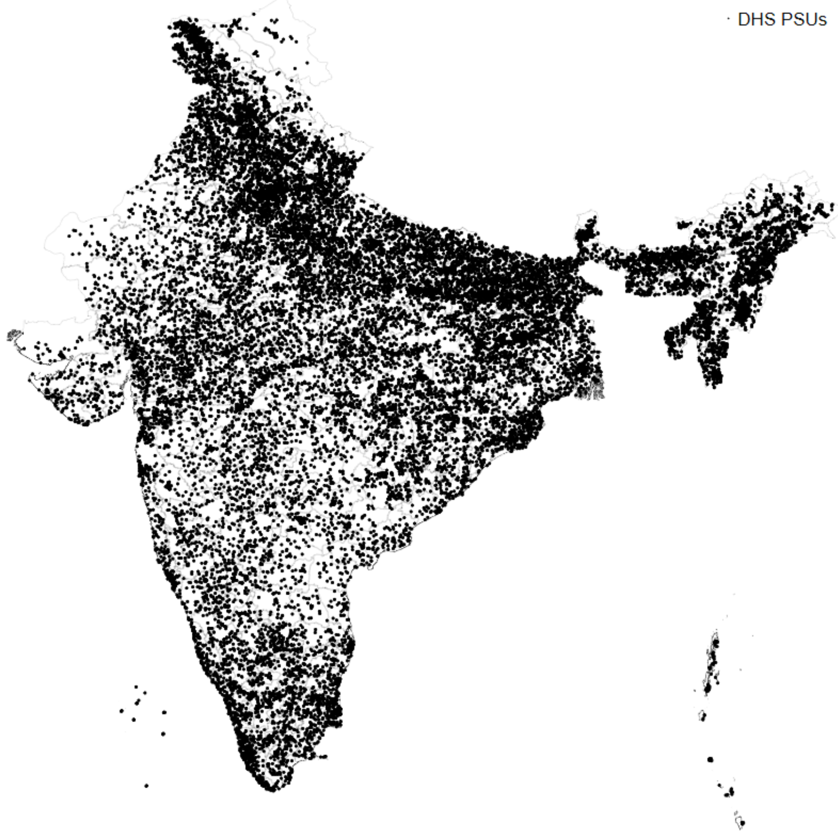


Figure B.16: Summary Statistics: Distribution of Annual Average Sunset Time at the Sampling Unit Level (Villages/City Blocks) in the 2015 Indian DHS

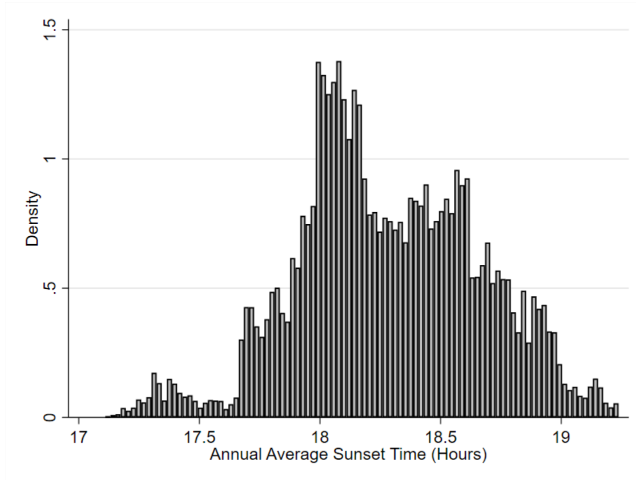


Figure B.17: Villages in Rural Economic and Demographic Survey (REDS)

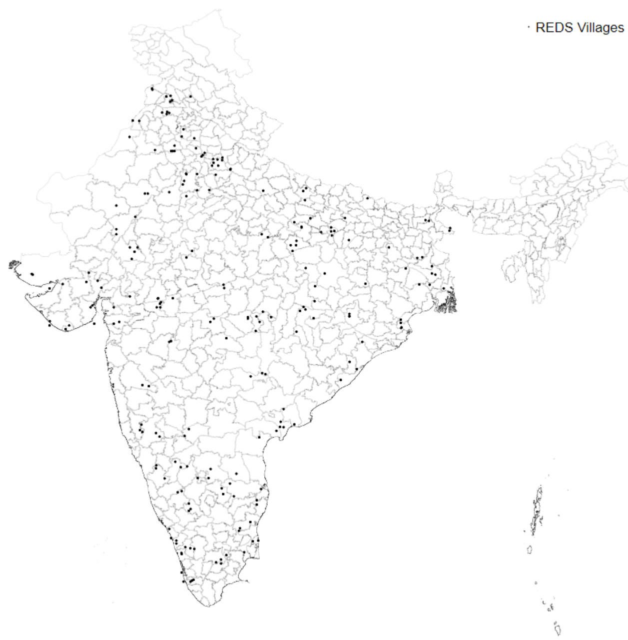


Figure B.18: Districts in the Young Lives Study (YLS)

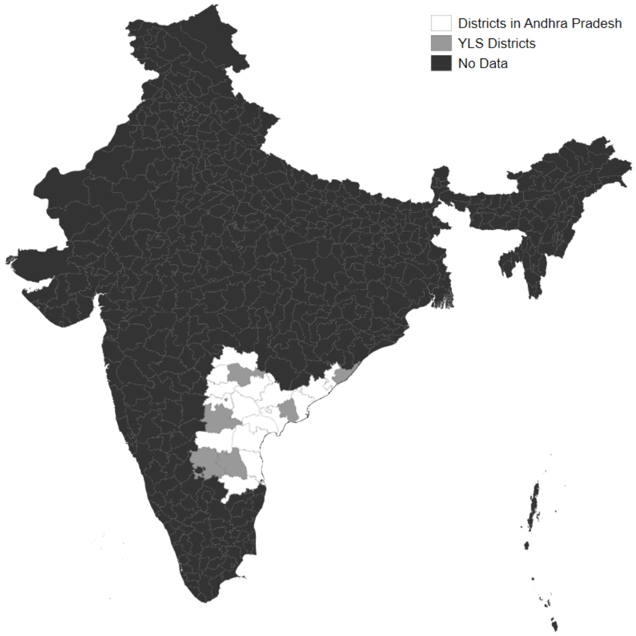
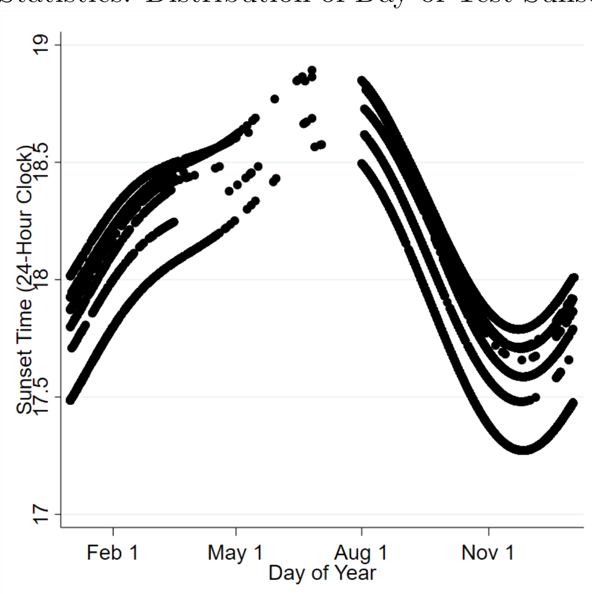


Figure B.19: Summary Statistics: Distribution of Day-of-Test Sunset Time in YLS Districts



Notes: This figure presents distribution daily sunset time for dates on which children were tested in math in YLS districts across survey rounds.

Table B.1: Summary Statistics: Monthly Distribution of Interview Dates in ITUS by State

	Haryana	Madhya Pradesh	Gujarat	Orissa	Tamil Nadu	Meghalaya
January	0.12	0.09	0.10	0.10	0.04	0.05
	(0.33)	(0.29)	(0.30)	(0.31)	(0.19)	(0.22)
Febuary	0.10	0.11	0.11	0.12	0.05	0.09
	(0.30)	(0.31)	(0.31)	(0.33)	(0.23)	(0.28)
March	0.05	0.10	0.07	0.05	0.15	0.12
	(0.22)	(0.30)	(0.26)	(0.22)	(0.36)	(0.33)
April	0.12	0.05	0.06	0.13	0.03	0.12
	(0.33)	(0.21)	(0.24)	(0.33)	(0.17)	(0.32)
May	0.09	0.06	0.07	0.06	0.04	0.09
	(0.28)	(0.23)	(0.26)	(0.24)	(0.21)	(0.29)
June	0.01	0.07	0.04	0.01	0.15	0.05
	(0.12)	(0.26)	(0.19)	(0.07)	(0.35)	(0.22)
July	0.08	0.07	0.03	0.11	0.01	0.06
	(0.28)	(0.26)	(0.17)	(0.31)	(0.10)	(0.24)
August	0.08	0.09	0.09	0.12	0.03	0.13
	(0.27)	(0.28)	(0.29)	(0.32)	(0.18)	(0.33)
September	0.09	0.08	0.14	0.03	0.17	0.04
	(0.29)	(0.28)	(0.35)	(0.17)	(0.37)	(0.19)
October	0.09	0.08	0.10	0.12	0.08	0.06
	(0.29)	(0.27)	(0.30)	(0.33)	(0.26)	(0.24)
November	0.12	0.07	0.08	0.11	0.07	0.20
	(0.33)	(0.26)	(0.27)	(0.32)	(0.25)	(0.40)
December	0.04	0.14	0.10	0.04	0.19	0.00
	(0.19)	(0.34)	(0.29)	(0.20)	(0.39)	(0.00)
Observations	2089	6395	4277	4057	5022	739

Notes: This table presents the monthly distribution (in proportions) of ITUS interview dates of children between 6 and 16 years of age. Standard deviations in parentheses. Source: ITUS.

Table B.2: Effect of Later Sunset on Interview Date

	(1) Survey Date (0/1) β / SE	(2) Survey Date (0/1) β / SE
Sunset Time (Hours)	-0.002	-0.004
	(0.003)	(0.005)
Mean	0.12	0.24
Observations	37960	18980
R^2	0.000	0.000

Notes: This table presents the relationship between daily sunset time and interview dates. Column 1 includes all months in years 1998 and 1999, however, because ITUS was mainly conducted between July 1998 and June 1999, Column 2 only includes July 1998 - June 1999. Homoskedastic standard errors presented in parentheses. Source: ITUS.

Table B.3: Summary Statistics: ITUS Sample Description by Type of Day

	Entire Sample (Age 6-16)	Normal Day Sample	Weekly Variant Sample
Age	11.19	11.33	10.97
	(2.95)	(2.97)	(2.89)
Years of Education	4.38	4.27	4.57
	(3.42)	(3.46)	(3.35)
Sex (0/1)	0.55	0.54	0.56
	(0.50)	(0.50)	(0.50)
Rural (0/1)	0.69	0.70	0.68
	(0.46)	(0.46)	(0.47)
Homestead (0/1)	0.65	0.65	0.64
	(0.48)	(0.48)	(0.48)
Land Owned (0/1)	0.46	0.47	0.45
	(0.50)	(0.50)	(0.50)
Land Possessed (0/1)	0.46	0.46	0.45
	(0.50)	(0.50)	(0.50)
Monthly HH Exp (INR)	2731.22	2700.74	2780.62
	(1634.11)	(1624.54)	(1648.40)
Temporary House (0/1)	0.38	0.38	0.37
	(0.48)	(0.49)	(0.48)
Semi-Temporary House (0/1)	0.23	0.23	0.22
	(0.42)	(0.42)	(0.42)
Permanent House (0/1)	0.39	0.38	0.41
	(0.49)	(0.49)	(0.49)
Primary Activity: Not a Student (0/1)	0.19	0.25	0.09
	(0.39)	(0.43)	(0.29)
Normal Days/Week	6.10	6.25	5.84
	(0.60)	(0.63)	(0.44)
Weekly Variant Days/Week	0.88	0.72	1.13
	(0.57)	(0.60)	(0.40)
Abnormal Days/Week	0.03	0.03	0.03
	(0.17)	(0.17)	(0.18)
Household Size	5.52	5.54	5.48
	(1.98)	(1.96)	(2.00)
Hinduism (0/1)	0.88	0.88	0.88
	(0.33)	(0.33)	(0.33)
Sunday (0/1)	0.28	0.04	0.66
	(0.45)	(0.19)	(0.47)
Observations	22579	13964	8615

Notes: This table presents summary statistics on both individual and household characteristics for children between 6 and 16 years of age on weekdays and weekends. Standard deviations in parentheses. Source: ITUS.

Table B.4: Summary Statistics: Educational Outcomes

	India
Years of Schooling	4.44
	(3.16)
	[638682]
Primary (0/1)	0.48
	(0.50)
	[638682]
Middle (0/1)	0.21
	(0.41)
	[638682]
Age (Years)	10.99
	(3.15)
	[638682]
Rural (0/1)	0.74
	(0.44)
	[638682]

Notes: This table presents summary statistics on years of schooling, educational attainment, age, and rural-urban status for children between 6 and 16 years of age across India (2015). Standard deviations in parentheses, and number of observations in brackets. Source: DHS.

C Appendix: Children's Time Use

Table C.1: Balance Table: Daily Sunset Time and Household- and Individual-Level Observables

	(1) Years of Education β / SE	(2) Worker (0/1) β / SE	(3) Sex (0/1) β / SE	(4) Rural (0/1) β / SE	(5) Household Size β / SE
Sunset Time (Hours)	0.01	0.02	-0.00	-0.00	-0.07
	(0.32)	(0.04)	(0.04)	(0.08)	(0.19)
Mean	4.27	0.25	0.54	0.70	5.54
Observations	13964	13964	13964	13964	13964
R^2	0.139	0.076	0.013	0.228	0.106
	(6) Hinduism (0/1) β / SE	(7) Age (Years) β / SE	(8) Homestead (0/1) β / SE	(9) Land Owned (0/1) β / SE	(10) Log Mnth HH Exp β / SE
Sunset Time (Hours)	0.04	-0.27	-0.08	-0.05	0.01
	(0.05)	(0.24)	(0.06)	(0.07)	(0.07)
Mean	0.88	11.33	0.65	0.47	7.74
Observations	13964	13964	13964	13964	13964
R^2	0.255	0.023	0.448	0.159	0.217
	(11) Temporary House (0/1) β / SE	(12) Semi-Temporary House (0/1) β / SE	(13) Permanent House (0/1) β / SE		
Sunset Time (Hours)	-0.06	0.01	0.05		
	(0.05)	(0.05)	(0.06)		
Mean	0.38	0.23	0.38		
Observations	13964	13964	13964		
R^2	0.325	0.115	0.286		
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes

Notes: This table presents the effect of an hour delay in sunset time on time invariant individual- and household-level observables for children between 6 and 16 years of age on weekdays. All columns include district and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table C.2: Sunset Time, Sunrise Time, Daylight Duration and Children's Sleep (Hours)

	(1) Sleep β / SE	(2) Sleep β / SE	(3) Sleep β / SE
Sunset Time (Hours)	-0.47***		
	(0.14)		
Sunrise Time (Hours)		0.43***	
		(0.14)	
Daylight Duration (Hours)			-0.23***
			(0.07)
Mean	9.07	9.07	9.07
Observations	13964	13964	13964
R^2	0.091	0.090	0.090
	(4) Bedtime β / SE	(5) Bedtime β / SE	(6) Bedtime β / SE
Sunset Time (Hours)	0.36***		
	(0.10)		
Sunrise Time (Hours)		-0.35***	
		(0.10)	
Daylight Duration (Hours)			0.18***
			(0.05)
Mean	21.33	21.33	21.33
Observations	13863	13863	13863
R^2	0.178	0.178	0.178
	(7) Wake-up Time β / SE	(8) Wake-up Time β / SE	(9) Wake-up Time β / SE
Sunset Time (Hours)	-0.13		
	(0.08)		
Sunrise Time (Hours)		0.11	
		(0.09)	
Daylight Duration (Hours)			-0.06
			(0.04)
Mean	6.43	6.43	6.43
Observations	13911	13911	13911
R^2	0.250	0.250	0.250
District FE	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes

Notes: This table presents the effect of an hour delay in sunset time, sunrise time, and daylight duration on time allocated to sleep, bedtime, and wake-up time (in hours) for children between 6 and 16 years of age on weekdays. All columns include district and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table C.3: Effect of Later Sunset on Non-Linear Metrics of Sleep Duration for School-Age Children

	(1) Sleep>9h β / SE	(2) Sleep>9h β / SE	(3) Sleep>9h β / SE	(4) Sleep>9h β / SE	(5) Sleep>9h β / SE
Sunset Time (Hours)	-0.14***	-0.14***	-0.18***	-0.31***	-0.31***
	(0.05)	(0.05)	(0.06)	(0.10)	(0.10)
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes
HH and Individual Attributes	No	Yes	No	No	No
Weather Controls	No	No	Yes	No	No
State-by-Season FE	No	No	No	Yes	No
District-by-Season FE	No	No	No	No	Yes
Mean	0.63	0.63	0.63	0.63	0.63
Observations	13964	13964	13964	13964	13964
R^2	0.100	0.218	0.101	0.104	0.140

Notes: This table presents the effect of an hour delay in sunset time on non-linear metrics of sleep duration for children between 6 and 16 years of age on weekdays. Column 1 include district and week-of-year fixed effects. Column 2 include district and week-of-year fixed effects and household- and individual level controls. Column 3 include district and week-of-year fixed effects and weather controls. Column 4 include state-by-season, district, and week-of-year fixed effects. Column 5 include district-by-season and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table C.4: Tobit Estimates: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Sleep β / SE	(2) Study β / SE	(3) Leisure β / SE	(4) Work β / SE
Sunset Time (Hours)	-0.47***	-1.31***	1.65***	-0.15
	(0.14)	(0.42)	(0.41)	(0.69)
District FE	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes
Mean	9.07	1.50	7.60	2.05
Observations	13964	13964	13964	13964

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure and work by children between 6 and 16 years of age on weekdays. All columns include district and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table C.5: Conley Standard Errors: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Sleep β / SE	(2) Study β / SE	(3) Leisure β / SE	(4) Work β / SE
Sunset Time (Hours)	-0.47***	-0.67**	1.65***	0.10
	(0.13)	(0.26)	(0.53)	(0.35)
Mean	9.07	1.50	7.60	2.05
Observations	13964	13964	13964	13964
R^2	0.002	0.002	0.005	0.000

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure and work by children between 6 and 16 years of age on weekdays. All columns include district and week-of-year fixed effects. Standard errors are adjusted to reflect spatial dependence as modeled in Conley (1999). Spatial autocorrelation is assumed to linearly decrease in distance up to a cutoff of 500 km. Source: ITUS.

Table C.6: Standard Errors Clustered at the District Level: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Sleep β / SE	(2) Study β / SE	(3) Leisure β / SE	(4) Work β / SE
Sunset Time (Hours)	-0.47***	-0.67**	1.65**	0.10
	(0.17)	(0.33)	(0.65)	(0.35)
District FE	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes
Mean	9.07	1.50	7.60	2.05
Observations	13964	13964	13964	13964
R^2	0.091	0.169	0.294	0.070

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure and work by children between 6 and 16 years of age on weekdays. All columns include district and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district level. Source: ITUS.

Table C.7: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Nap β / SE	(2) Nap β / SE	(3) Nap β / SE	(4) Nap β / SE	(5) Nap β / SE
Sunset Time (Hours)	0.27**	0.25**	0.24**	0.45***	0.34**
	(0.11)	(0.11)	(0.12)	(0.17)	(0.15)
Mean	0.36	0.36	0.36	0.36	0.36
Observations	13964	13964	13964	13964	13964
R^2	0.246	0.276	0.247	0.272	0.336

	(6) Mass Media β / SE	(7) Mass Media β / SE	(8) Mass Media β / SE	(9) Mass Media β / SE	(10) Mass Media β / SE
Sunset Time (Hours)	0.03	-0.01	0.29	0.31	0.14
	(0.22)	(0.19)	(0.23)	(0.37)	(0.38)
Mean	1.06	1.06	1.06	1.06	1.06
Observations	13964	13964	13964	13964	13964
R^2	0.157	0.236	0.159	0.165	0.214

	(11) Eating β / SE	(12) Eating β / SE	(13) Eating β / SE	(14) Eating β / SE	(15) Eating β / SE
Sunset Time (Hours)	-0.12	-0.14	-0.07	-0.12	-0.09
	(0.10)	(0.10)	(0.11)	(0.20)	(0.20)
Mean	2.40	2.40	2.40	2.40	2.40
Observations	13964	13964	13964	13964	13964
R^2	0.237	0.245	0.237	0.244	0.283

	(16) Doing Nothing β / SE	(17) Doing Nothing β / SE	(18) Doing Nothing β / SE	(19) Doing Nothing β / SE	(20) Doing Nothing β / SE
Sunset Time (Hours)	0.79***	0.78***	0.81***	0.14	0.02
	(0.14)	(0.13)	(0.15)	(0.24)	(0.27)
Mean	1.03	1.03	1.03	1.03	1.03
Observations	13964	13964	13964	13964	13964
R^2	0.185	0.266	0.185	0.205	0.260

	(21) Talking β / SE	(22) Talking β / SE	(23) Talking β / SE	(24) Talking β / SE	(25) Talking β / SE
Sunset Time (Hours)	0.19*	0.20*	0.11	0.12	0.37*
	(0.10)	(0.10)	(0.12)	(0.21)	(0.22)
Mean	0.69	0.69	0.69	0.69	0.69
Observations	13964	13964	13964	13964	13964
R^2	0.176	0.253	0.177	0.190	0.226

	(26) Pastime β / SE	(27) Pastime β / SE	(28) Pastime β / SE	(29) Pastime β / SE	(30) Pastime β / SE
Sunset Time (Hours)	0.32	0.26	0.57**	0.01	0.51
	(0.20)	(0.19)	(0.24)	(0.34)	(0.31)
Mean	1.46	1.46	1.46	1.46	1.46
Observations	13964	13964	13964	13964	13964
R^2	0.154	0.312	0.154	0.168	0.219

	(31) Other Sedentary β / SE	(32) Other Sedentary β / SE	(33) Other Sedentary β / SE	(34) Other Sedentary β / SE	(35) Other Sedentary β / SE
Sunset Time (Hours)	0.03	0.03	0.02	0.05	0.02
	(0.07)	(0.07)	(0.08)	(0.16)	(0.16)
Mean	0.19	0.19	0.19	0.19	0.19
Observations	13964	13964	13964	13964	13964
R^2	0.057	0.079	0.058	0.061	0.100
	(36) Exercise β / SE	(37) Exercise β / SE	(38) Exercise β / SE	(39) Exercise β / SE	(40) Exercise β / SE
Sunset Time (Hours)	0.10	0.11	0.03	0.02	0.14
	(0.07)	(0.07)	(0.09)	(0.13)	(0.13)
Mean	0.21	0.21	0.21	0.21	0.21
Observations	13964	13964	13964	13964	13964
R^2	0.100	0.114	0.102	0.109	0.157
	(41) Travel for Leisure β / SE	(42) Travel for Leisure β / SE	(43) Travel for Leisure β / SE	(44) Travel for Leisure β / SE	(45) Travel for Leisure β / SE
Sunset Time (Hours)	0.04	0.04	0.00	0.02	-0.04
	(0.04)	(0.04)	(0.05)	(0.08)	(0.07)
Mean	0.12	0.12	0.12	0.12	0.12
Observations	13964	13964	13964	13964	13964
R^2	0.175	0.187	0.176	0.184	0.297
	(46) Other Active β / SE	(47) Other Active β / SE	(48) Other Active β / SE	(49) Other Active β / SE	(50) Other Active β / SE
Sunset Time (Hours)	0.01	0.01	-0.02	-0.18**	-0.31***
	(0.05)	(0.05)	(0.06)	(0.09)	(0.08)
Mean	0.08	0.08	0.08	0.08	0.08
Observations	13964	13964	13964	13964	13964
R^2	0.063	0.070	0.064	0.068	0.128
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes
HH/Individual Controls	No	Yes	No	No	No
Weather Controls	No	No	Yes	No	No
State-by-Season FE	No	No	No	Yes	No
District-by-Season FE	No	No	No	No	Yes

Notes: This table presents the effect of an hour delay in sunset time on time allocated to daytime naps, mass media, eating, doing nothing, talking, pastime, other sedentary leisure, exercise, travel for leisure, and other active leisure (in hours) for children between 6 and 16 years of age on weekdays. Columns 1, 6, 11, 16, 21, 26, 31, 36, 41, and 46 include district and week-of-year fixed effects. Columns 2, 7, 12, 17, 22, 27, 32, 37, 42, and 47 include district and week-of-year fixed effects and household- and individual level controls. Columns 3, 8, 13, 18, 23, 28, 33, 38, 43, and 48 include district and week-of-year fixed effects and weather controls. Columns 4, 9, 14, 19, 24, 29, 34, 39, 44, and 49 include state-by-season, district, and week-of-year fixed effects. Columns 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 include district-by-season and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table C.8: Dropping 'Nappers': Effect of Later Sunset on Children's Time Use (Hours)

	(1) Sleep β / SE	(2) Study β / SE	(3) Leisure β / SE	(4) Work β / SE
Sunset Time (Hours)	-0.39***	-0.97***	2.08***	0.23
	(0.14)	(0.28)	(0.39)	(0.40)
District FE	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes
Mean	9.07	1.66	6.93	2.04
Observations	11350	11350	11350	11350
R^2	0.098	0.190	0.234	0.099

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure and work by children between 6 and 16 years of age on weekdays. All columns include district and week-of-year fixed effects. I only include children who did spend time on daytime naps. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table C.9: Effect of Later Sunset on Children's Study Effort (0/1)

	(1) Study (0/1) β / SE	(2) Study (0/1) β / SE
Sunset Time (Hours)	-0.10	-0.14**
	(0.06)	(0.06)
Sunset Time*Worker		0.19***
		(0.02)
District FE	Yes	Yes
Week-of-Year FE	Yes	Yes
p-value		0.37
Mean	0.57	0.57
Observations	13964	13964
R^2	0.177	0.497

Notes: This table presents the effect of an hour delay in sunset time on study effort (0/1) for children 6 and 16 years of age on weekdays. The interaction term captures the effect of an hour delay in daily sunset time for child laborer compared to a student. 'p-value' denotes the p-value for '$SunsetTime(Hours)' + 'SunsetTime * Worker' = 0$. All columns include district and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table C.10: Heterogeneity by Night Lights: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Sleep β / SE	(2) Study β / SE	(3) Leisure β / SE	(4) Work β / SE
Sunset Time (Hours)	-0.38**	-0.54**	1.66***	0.05
	(0.15)	(0.23)	(0.40)	(0.33)
Sunset Time*Night Lights∈(0p,50p)	-0.15**	-0.23**	-0.01	0.09
	(0.07)	(0.11)	(0.16)	(0.17)
District FE	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes
Mean	9.07	1.50	7.60	2.05
Observations	13964	13964	13964	13964
R^2	0.091	0.169	0.294	0.070

Notes: This table presents the heterogeneous effects of an hour delay in sunset time on time allocated to sleep, study, leisure, and work by children between 6 and 16 years of age by value of lights at night. To construct "Night Lights∈(0p,50p)", I use the mean values of night lights as measured from space in 2001, at the district level; "Night Lights∈(0p,50p)" is an indicator variable equal to 1 if the mean value of night lights in 2001 for a given district is less than the mean value of night lights in 2001 for the median district in the sample, 0 otherwise. All columns include district and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table C.11: Dropping Children Spending Time on Outdoor Leisure Late Afternoon: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Sleep β / SE	(2) Study β / SE	(3) Leisure β / SE	(4) Work β / SE
Sunset Time (Hours)	-0.59***	-0.97***	1.03**	0.51
	(0.18)	(0.32)	(0.47)	(0.47)
District FE	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes
Mean	9.01	1.45	7.03	2.86
Observations	6018	6018	6018	6018
R^2	0.098	0.174	0.224	0.132

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure and work by children between 6 and 16 years of age on weekdays. All columns include district and week-of-year fixed effects. I only include children who did not spend time on outdoor leisure between 5 pm and 7 pm. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

China

China Health and Nutrition Survey (CHNS)

The CHNS is collected by the Carolina Population Center at the University of North Carolina at Chapel Hill and the National Institute for Nutrition and Health (NINH). This survey includes subjects from a sample of about 7,200 households with over 30,000 individuals in 15 provinces and municipal cities in China from 1989 to 2011.[38] Although the CHNS sample is not representative of the Chinese population, one-third of the Chinese population (approximately 450 million people in 1989) lives in these provinces. The CHNS has released eight waves of data so far (1989, 1991, 1993, 1997, 2000, 2004, 2006, and 2009). I use the 2004-2009 data waves of the survey because the earlier waves did not collect children's time use data. Following ITUS, I restricted analyses to school-age children, individuals over 5 but less than 17 years of age. Unlike ITUS, CHNS did not collect time use data for a particular date. Children were asked about the time spent on sleep on a 'usual' or 'typical' day. Similarly, children were asked about time spent on leisure activities, both physical (running, soccer, etc.) and sedentary (TV, video games, etc.) in nature, as well as on homework. Data on leisure and homework was collected for both weekdays and weekends. Although measures for leisure and study are not comparable to ITUS, the direction of the estimates would still be useful as corroborative evidence.

Results

I use the 2004-2009 China Health and Nutrition Survey (CHNS) to examine the effects of later sunset on children's time use in China. Unlike ITUS, CHNS includes information on children's time allocation for a 'typical' or 'usual' day of the year, and not for a particular date. And, although CHNS only provides data on sleep, leisure and homework time, it allows me to investigate the effect of *annual average* sunset time on children's time allocation.[39] In this setting, I abstract away from seasonal variation in sunset time, instead exploiting cross-sectional variation in annual average sunset time. I estimate the following econometric model:

$$y_{idst} = \beta Sunset_{ds} + \mu_t + \mu_s + \epsilon_{idst} \tag{10}$$

Time allocated to sleep, leisure or homework (y), by child i, in district (or county) d, in state (or province) s, in year t, is regressed on annual average sunset time observed in district d in state s to estimate the average effect of an hour's increase in annual average sunset time (β). μ_t are year fixed effects, and μ_s are state fixed effects. Thus, I exploit district-level variation (east to west) in annual average sunset time within a state. Therefore, I control for time invariant state-level unobservables that are correlated with children's time allocation and annual average sunset time.

An hour delay in annual average sunset time reduces sleep by 0.43 hours (Table C.12). This estimate is remarkably similar to the effect of late sunset on sleep in India, where I exploit district-specific seasonal variation in daily sunset time. Furthermore, in line with

[38]Figure C.1 presents the provinces in CHNS. A detailed description of the CHNS design can be found at www.cpc.unc.edu/projects/china.

[39]There exist substantial differences in the definition of leisure between ITUS and CHNS. Furthermore, as a measure of self-investment in study effort, CHNS only provides homework time.

the ITUS results, I find positive effects on leisure and negative effects on time spent on homework, although these estimates are noisier.

Because I exploit cross-sectional variation in annual average sunset time within a state, county level attributes that are correlated with annual average sunset time as well as children's time use could potentially bias my estimates. For instance, if compared to eastern districts (early sunset), western districts (late sunset) are warmer or poorer, then the coefficients might be upwardly biased. In Columns 2, 4, and 6, I control for weather and other observables like income, urban status, household size and nutritional intake, that may co-vary with children's time allocation and annual average sunset time across the east-west gradient within a province. However, my point estimates remain unaffected.

Figure C.1: Provinces in the China Health an Nutrition Survey (CHNS)

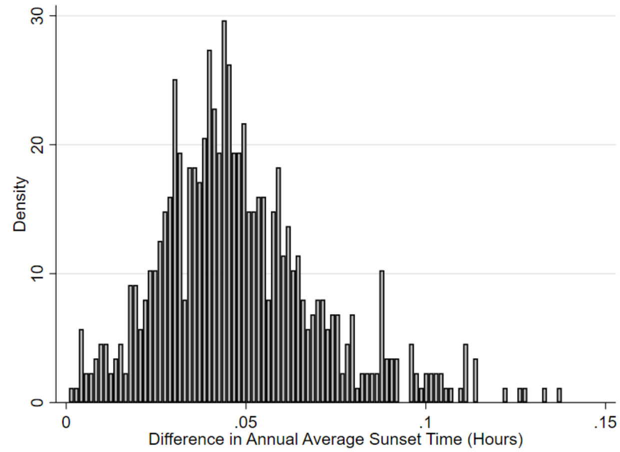
Table C.12: China: Effect of Later Sunset on Children's Time Use (Hours)

	(1) Sleep β / SE	(2) Sleep β / SE	(3) Study β / SE	(4) Study β / SE	(5) Leisure β / SE	(6) Leisure β / SE
Annual Average Sunset Time (Hours)	-0.43**	-0.44**	-0.36	-0.30	0.59	0.58
	(0.21)	(0.21)	(0.26)	(0.24)	(0.56)	(0.59)
Age		-0.15***		0.09***		0.01
		(0.01)		(0.01)		(0.01)
Rural		0.16***		-0.05		-0.31***
		(0.05)		(0.05)		(0.11)
Log HH Income		-0.00		0.01		0.04*
		(0.01)		(0.01)		(0.02)
Log HH Expense		0.01		-0.00		0.00
		(0.01)		(0.01)		(0.01)
HH Size		-0.01		-0.03**		-0.03
		(0.01)		(0.01)		(0.03)
Energy(kcal)		-0.00		-0.01**		-0.01
		(0.00)		(0.00)		(0.01)
Carbohydrates(g)		0.00		0.03**		0.03
		(0.01)		(0.01)		(0.03)
Fat(g)		0.01		0.06**		0.08
		(0.02)		(0.03)		(0.07)
Protein(g)		0.00		0.03**		0.04
		(0.01)		(0.01)		(0.03)
Urbanization Index		-0.01		-0.00		0.04*
		(0.01)		(0.01)		(0.02)
Communications Component Score		0.02		-0.01		-0.04
		(0.02)		(0.03)		(0.05)
Community Population Density Category		0.03		0.01		-0.04
		(0.02)		(0.02)		(0.05)
Diversity Score		0.02		0.01		0.03
		(0.02)		(0.03)		(0.05)
Economic Component Score		0.02		0.02		-0.04
		(0.02)		(0.02)		(0.03)
Quality of Health Score		0.00		0.01		-0.04
		(0.01)		(0.02)		(0.03)
Housing Component Score		0.02		0.03		-0.08
		(0.03)		(0.03)		(0.06)
Market Component Score		0.02		-0.00		-0.04
		(0.01)		(0.01)		(0.03)
Social Services Score		0.01		0.00		-0.06*
		(0.01)		(0.01)		(0.03)
Transportation Component Score		-0.00		0.01		-0.06*
		(0.01)		(0.02)		(0.03)
Community Education Category		0.00		0.05*		-0.10*
		(0.02)		(0.02)		(0.05)
Modern Markets Component Score		0.00		-0.00		-0.04
		(0.01)		(0.02)		(0.03)
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	No	Yes	No	Yes
Mean	9.03	9.04	1.25	1.26	3.18	3.19
Observations	5794	5471	5794	5471	5794	5471
R^2	0.029	0.231	0.066	0.147	0.033	0.052

Notes: This table presents the effect of an hour delay in annual average sunset time on time allocated to sleep, leisure and homework by children between 6 and 16 years of age. Standard errors are in parentheses, clustered at the county-year level. Source: CHNS.

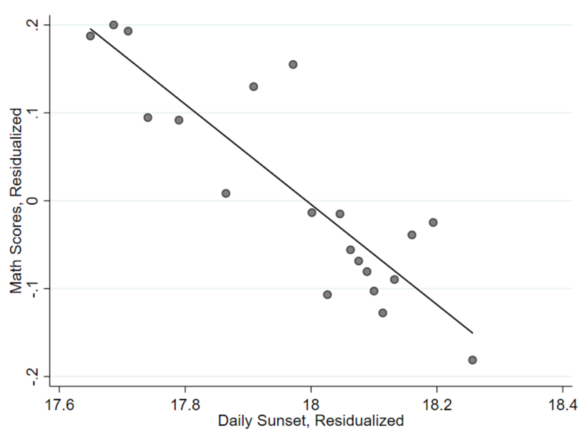
D Appendix: Children's Academic Outcomes

Figure D.1: Within-District Variation in Annual Average Sunset Time

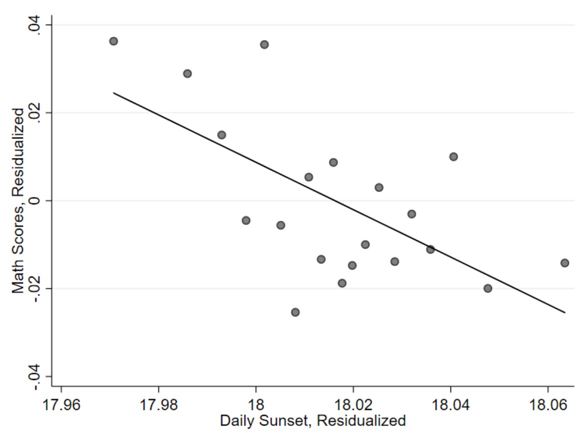


Notes: This figure presents within-district variation in annual average sunset time or the distribution of difference in annual average sunset time between the easternmost and westernmost PSUs within a district. Source: DHS.

Figure D.2: Effects of Later Sunset on Children's Math Scores in the Short Run



(a) Math Test Scores (Table 5, Column 1)



(b) Math Test Scores (Table 5, Column 3)

Notes: This figure presents binned scatterplots for the relationship between day-of-the-test sunset time on the day of the test (24-hour clock) and children's math test scores in India. Panel (a) plots residuals for day-of-the-test sunset time and math scores after absorbing week-of-year and age fixed effects. Panel (b) plots residuals for day-of-the-test sunset time and math scores after absorbing week-of-year, age, child fixed effects, and controlling for weather. Source: YLS.

Table D.1: Falsification Test: Effects of Past and Future Day-of-Test Sunset Time on Current Survey Round Math Test Scores in the Short Run

	(1) Math (SD) β / SE
Daily Sunset Time (Hours)	-0.692***
	(0.136)
L.Daily Sunset Time (Hours)	0.134
	(0.098)
F.Daily Sunset Time (Hours)	0.010
	(0.090)
L.Math	0.637***
	(0.018)
Age Dummies	Yes
Week-of-Year FE	Yes
Observations	1834
R^2	0.412

Notes: This table presents the effect of sunset time on the previous survey round test date and sunset time on the next survey round test date on math scores in the current survey round for school-age children. All columns include age and week-of-year fixed effects and controls for lagged math scores. Standard errors are in parentheses, clustered at the child level. Source: YLS.

Table D.2: Effect of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment Status

	(1) Years of Schooling β / SE	(2) Years of Schooling β / SE	(3) Years of Schooling β / SE	(4) Years of Schooling β / SE
Annual Average Sunset Time (Hours)	-0.25***	-0.50***	-0.86***	-0.95***
	(0.06)	(0.05)	(0.31)	(0.29)
Mean	4.44	4.44	4.44	4.44
Observations	638682	638682	638682	638682
R^2	0.719	0.727	0.732	0.738
	(5) Primary (0/1) β / SE	(6) Primary (0/1) β / SE	(7) Primary (0/1) β / SE	(8) Primary (0/1) β / SE
Annual Average Sunset Time (Hours)	-0.03***	-0.06***	-0.13***	-0.13***
	(0.01)	(0.01)	(0.04)	(0.04)
Mean	0.48	0.48	0.48	0.48
Observations	638682	638682	638682	638682
R^2	0.636	0.640	0.643	0.646
	(9) Middle (0/1) β / SE	(10) Middle (0/1) β / SE	(11) Middle (0/1) β / SE	(12) Middle (0/1) β / SE
Annual Average Sunset Time (Hours)	-0.02***	-0.05***	-0.08**	-0.09***
	(0.01)	(0.01)	(0.03)	(0.03)
Mean	0.21	0.21	0.21	0.21
Observations	638682	638682	638682	638682
R^2	0.555	0.560	0.561	0.565
	(13) Enrolled (0/1) β / SE	(14) Enrolled (0/1) β / SE	(15) Enrolled (0/1) β / SE	(16) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-0.13***	-0.18***	-0.11**	-0.12**
	(0.01)	(0.01)	(0.05)	(0.05)
Mean	0.90	0.90	0.90	0.90
Observations	638682	638682	638682	638682
R^2	0.065	0.091	0.093	0.112
Age FE	Yes	Yes	Yes	Yes
State FE	Yes	Yes	No	No
Geographic Controls	No	Yes	No	Yes
Socioeconomic Indicators	No	Yes	No	Yes
District FE	No	No	Yes	Yes

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling, likelihood of completing primary (0/1) and middle school (0/1), and enrollment status (0/1) for children between 6 and 16 years of age. Columns 1, 5, 9, and 13 include age and state fixed effects. Columns 2, 6, 10, and 14 include age and state fixed effects, and geographic and socioeconomic controls: latitude, altitude, urban status (0/1) and wealth index (1-5). Columns 3, 7, 11, and 15 include age and district fixed effects. Columns 4, 8, 12, and 16 include age and district fixed effects, and geographic and socioeconomic controls: latitude, altitude, urban status (0/1) and wealth index (1-5). Standard errors are in parentheses, clustered at the PSU level. Source: 2015 India DHS.

Table D.3: Age-Appropriate Sample: Effect of Later Sunset on Years of Schooling and Educational Attainment

	(1) Years of Schooling Age>8 β / SE	(2) Primary (0/1) Age>8 β / SE	(3) Years of Schooling Age>11 β / SE	(4) Middle (0/1) Age>11 β / SE
Annual Average Sunset Time (Hours)	-1.10***	-0.17***	-1.38***	-0.15**
	(0.39)	(0.06)	(0.49)	(0.07)
Age FE	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	5.72	0.66	6.94	0.46
Observations	461850	461850	294088	294088
R^2	0.546	0.463	0.308	0.384

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling and likelihood of completing primary and middle school for children between 6 and 16 years of age. Columns 1 and 2 include children over 8 years of age. Columns 3 and 4 include children over 11 years of age. All columns include age and district fixed effects. Standard errors are in parentheses, clustered at the PSU level. Source: 2015 India DHS.

Table D.4: Alternative Measure of Educational Attainment: Effect of Later Sunset on Educational Attainment

	(1) In/Completed Primary (0/1) Age>5 β / SE	(2) In/Completed Secondary (0/1) Age>5 β / SE	(3) In/Completed Primary (0/1) Age>8 β / SE	(4) In/Completed Secondary (0/1) Age>11 β / SE
Annual Average Sunset Time (Hours)	-0.11**	-0.12***	-0.10***	-0.21***
	(0.04)	(0.04)	(0.04)	(0.08)
Age FE	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	0.95	0.38	0.96	0.77
Observations	638682	638682	461850	294088
R^2	0.063	0.622	0.045	0.178

Notes: This table presents the effect of an hour delay in annual average sunset time on the likelihood that a child is in primary (secondary or post-primary) school or has completed primary (secondary or post-primary) school for children between 6 and 16 years of age. All columns include age and district fixed effects. Standard errors are in parentheses, clustered at the PSU level. Source: 2015 India DHS.

Table D.5: Standard Errors Clustered at the District Level: Effect of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment Status

	(1) Years of Schooling β / SE	(2) Primary (0/1) β / SE	(3) Middle (0/1) β / SE	(4) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-0.86*	-0.13**	-0.08*	-0.11
	(0.45)	(0.06)	(0.04)	(0.07)
Age FE	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	4.44	0.48	0.21	0.90
Observations	638682	638682	638682	638682
R^2	0.732	0.643	0.561	0.093

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling, likelihood of completing primary and middle school, and enrollment status for children between 6 and 16 years of age. All columns include age and district fixed effects. Standard errors are in parentheses, clustered at the district level. Source: 2015 India DHS.

Table D.6: Did Surveyors Sample Younger Children in Places with Later Annual Average Sunset Times?

	(1) Age β / SE
Annual Average Sunset Time (Hours)	0.34
	(0.33)
District FE	Yes
Mean	10.99
Observations	638682
R^2	0.004

Notes: This table presents the effect of an hour delay in annual average sunset time on age for children between 6 and 16 years of age. All columns include district fixed effects. Standard errors are in parentheses, clustered at the PSU level. Source: 2015 India DHS.

Table D.7: Dropping Wider Districts: Effect of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment Status

	(1) Years of Schooling β / SE	(2) Primary (0/1) β / SE	(3) Middle (0/1) β / SE	(4) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-0.80**	-0.13***	-0.05	-0.10*
	(0.38)	(0.05)	(0.04)	(0.06)
Age FE	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	4.42	0.48	0.21	0.90
Observations	568519	568519	568519	568519
R^2	0.731	0.642	0.560	0.093

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling, likelihood of completing primary and middle school, and enrollment status for children between 6 and 16 years of age. I drop wider districts or districts where the difference in annual average sunset time between the easternmost and westernmost PSUs within a district is over the 90th percentile of the distribution presented in Figure D.1. All columns include age and district fixed effects. Standard errors are in parentheses, clustered at the PSU level. Source: 2015 India DHS.

Table D.8: Only Wider Districts: Effect of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment Status

	(1) Years of Schooling β / SE	(2) Primary (0/1) β / SE	(3) Middle (0/1) β / SE	(4) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-0.96*	-0.11	-0.13**	-0.11
	(0.53)	(0.07)	(0.06)	(0.09)
Age FE	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	4.57	0.50	0.22	0.90
Observations	70163	70163	70163	70163
R^2	0.735	0.658	0.573	0.093

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling, likelihood of completing primary and middle school, and enrollment status for children between 6 and 16 years of age. I only include wider districts or districts where the difference in annual average sunset time between the easternmost and westernmost PSUs within a district is over the 90th percentile of the distribution presented in Figure D.1. All columns include age and district fixed effects. Standard errors are in parentheses, clustered at the PSU level. Source: 2015 India DHS.

2006 REDS: Effect of Later Sunset on Children's Learning Outcomes in the Long Run

In this section, I use a nationally representative survey of rural households in India, the 2006 Rural Economic and Demographic Survey or REDS, to investigate the effects of sunset-induced sleep deficits on children's learning outcomes in the long run.[40] Analogous to the 2015 Indian DHS specification, I exploit plausibly exogenous within-district cross-sectional variation in annual average sunset time at the village level. I find that an hour delay in annual average sunset time reduces years of schooling by roughly 1 year, translating into decreases in educational attainment at the primary and middle school level (Table D.9). Although the point estimates for years of schooling and primary school completion are underpowered, the magnitude of these effects should increase confidence in the 2015 India DHS estimates discussed above.

If wealthier households sort themselves into villages with earlier annual average sunset, my baseline estimates may be confounded by residential sorting. However, if sorting were occurring, one might expect villages that observe later sunset to have low in-migration and more out-migration. I examine the relationship between later sunset and episodes of in- and out-migration at the village level (Table D.10). I fail to find evidence that villages that observe later sunset have more episodes of out-migration or fewer episodes of in-migration. Moreover, I fail to find evidence for a negative relationship between sunset time and instances of non-residents migrating to work to villages.

In Tables D.11 and D.12, I control for village level geographic characteristics like elevation, latitude, temperature and rainfall as well as child level biological characteristics like height, weight and sex. I also control for episodes of in- and out-migration experienced at the village level in the last 50 years, access to water and electricity as well as other street level attributes such as availability of street lighting or proportion of households with an indoor toilet. My baseline estimates remain relatively unaffected.[41]

These tests imply that any unobservable omitted variable that generates bias in my estimates must be orthogonal to these observables, but co-vary systematically with both annual average sunset time and educational outcomes across the east-west gradient within a district. Given the richness of the observables, the existence of such unobservable omitted variables seems implausible.

[40] Appendix B describes the REDS data.

[41] In Table D.13 I adjust standard errors to reflect spatial dependence as modeled in Conley (1999), and implemented by Hsiang (2010). I allow errors to be spatially auto-correlated within a distance of 500 km. The point estimates remain precisely estimated.

Table D.9: Effect of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment

	(1) Years of Schooling β / SE	(2) Primary (0/1) β / SE	(3) Middle (0/1) β / SE	(4) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-1.06	-0.13	-0.17**	-0.17**
	(0.71)	(0.09)	(0.07)	(0.08)
Age Dummies	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	4.79	0.52	0.23	0.91
Observations	10006	10006	10006	9192
R^2	0.663	0.650	0.574	0.117

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling, educational attainment and enrollment status for children between 6 and 16 years of age. All columns include age and district fixed effects. Standard errors are in parentheses, clustered at the village level. Source: REDS.

Table D.10: Effect of Later Sunset on Migration

	(1) No. Times In-Migration: 50 yrs β / SE	(2) No. Times Out-Migration: 50 yrs β / SE	(3) Non-Residents In-Migrate for Work 10 years: (0/1) β / SE
Annual Average Sunset Time (Hours)	10.93	-5.00	0.06
	(13.23)	(3.54)	(0.67)
District FE	Yes	Yes	Yes
Mean	7.27	2.01	0.71
Observations	190	158	204
R^2	0.813	0.912	0.709

Notes: This table presents the effect of an hour delay in annual average sunset time on episodes of in-migration and out-migration in the last 50 years as well as on the likelihood of in-migration for work in the last 10 years, both at the village level. All columns include district fixed effects. Heteroskedasticity robust standard errors are in parentheses. Source: REDS.

Table D.11: Controlling for Geographic and Individual Level Observables: Effect of Later Sunset on Years of Schooling, Educational Attainment and Enrollment

	(1) Years of Schooling β / SE	(2) Primary (0/1) β / SE	(3) Middle (0/1) β / SE	(4) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-0.87	-0.13	-0.14*	-0.14*
	(0.78)	(0.10)	(0.07)	(0.08)
Latitude	-0.10	-0.00	-0.01	0.00
	(0.08)	(0.01)	(0.01)	(0.01)
Elevation	-0.00**	-0.00	-0.00**	-0.00***
	(0.00)	(0.00)	(0.00)	(0.00)
Rain	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Temperature	-0.15**	-0.01	-0.01**	-0.02***
	(0.07)	(0.01)	(0.01)	(0.01)
Log Height	0.29**	0.03*	0.02	-0.04**
	(0.13)	(0.02)	(0.02)	(0.02)
Log Weight	0.20*	0.00	0.02	0.04**
	(0.11)	(0.02)	(0.01)	(0.02)
Male (0/1)	0.30***	0.02***	0.03***	0.03***
	(0.05)	(0.01)	(0.01)	(0.01)
Age Dummies	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	4.79	0.52	0.23	0.91
Observations	10006	10006	10006	9192
R^2	0.666	0.651	0.575	0.122

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling, educational attainment and enrollment status for children between 6 and 16 years of age. All columns include age and district fixed effects, and controls for geographic and individual attributes. Standard errors are in parentheses, clustered at the village level. Source: REDS.

Table D.12: Controlling for Household and Village Level Observables: Effect of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment

	(1) Years of Schooling β / SE	(2) Primary (0/1) β / SE	(3) Middle (0/1) β / SE	(4) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-1.44**	-0.18**	-0.25***	-0.32***
	(0.69)	(0.07)	(0.08)	(0.08)
No. Times In-Migration 50 yrs	-0.00	-0.00	-0.00	-0.00**
	(0.01)	(0.00)	(0.00)	(0.00)
No. Times Out-Migration 50 yrs	0.02	0.00	0.00	-0.00
	(0.02)	(0.00)	(0.00)	(0.00)
In-Migration for Work in 10 years (0/1)	0.55***	0.06***	0.04*	0.03**
	(0.15)	(0.02)	(0.02)	(0.01)
Permanent Road (0/1)	-0.03	-0.01	-0.01	0.00
	(0.08)	(0.01)	(0.01)	(0.01)
Brick Houses (Prop.)	-0.05	0.01	-0.04	0.07
	(0.47)	(0.07)	(0.06)	(0.06)
Huts (Prop.)	-1.69*	-0.16	-0.09	-0.11
	(0.95)	(0.15)	(0.11)	(0.12)
Mud Houses (Prop.)	-0.29	-0.03	-0.03	0.01
	(0.36)	(0.05)	(0.04)	(0.04)
Multi-Storeyed Houses (Prop.)	0.02	-0.07	0.16	0.09
	(0.92)	(0.11)	(0.15)	(0.14)
Public Tap (0/1)	0.05	-0.01	0.02	-0.00
	(0.08)	(0.01)	(0.01)	(0.01)
Wells (0/1)	-0.27**	-0.02	-0.04***	-0.02
	(0.11)	(0.01)	(0.01)	(0.01)
HHs Running Water (Prop.)	0.50	0.04	0.01	0.03
	(0.54)	(0.07)	(0.06)	(0.04)
Street Lights (0/1)	0.27*	0.04**	-0.00	-0.02
	(0.14)	(0.02)	(0.02)	(0.02)
HHs Electricity (Prop.)	0.09	0.05	0.02	-0.04
	(0.46)	(0.06)	(0.06)	(0.05)
Public Toilet (0/1)	-0.22	-0.01	-0.04***	-0.00
	(0.17)	(0.03)	(0.01)	(0.02)
HHs Indoor Toilet (Prop.)	-0.15	0.02	-0.12**	-0.10*
	(0.52)	(0.07)	(0.05)	(0.05)
HHs Landline (Prop.)	0.56	0.04	0.01	-0.03
	(1.12)	(0.14)	(0.18)	(0.13)
HHs Large Livestock (Prop.)	-0.58***	-0.07***	0.01	-0.04
	(0.19)	(0.02)	(0.02)	(0.03)
HHs Bicycle (Prop.)	1.04***	0.12***	0.06**	-0.01
	(0.29)	(0.04)	(0.03)	(0.03)
HHs Mobile (Prop.)	0.12	-0.04	-0.12**	0.00
	(0.44)	(0.08)	(0.05)	(0.05)
HHs Motorcycle (Prop.)	-0.20	-0.02	0.11*	0.09
	(0.55)	(0.06)	(0.06)	(0.06)
HHs Car (Prop.)	2.48**	0.21	0.32*	0.33***
	(1.07)	(0.15)	(0.17)	(0.12)
Age Dummies	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Mean	4.63	0.50	0.22	0.91
Observations	7601	7601	7601	6914
R^2	0.650	0.641	0.555	0.111

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling for children between 6 and 16 years of age. All columns include age and district fixed effects, and controls for household- and village level observables. Standard errors are in parentheses, clustered at the village level. Source: REDS.

Table D.13: Conley Standard Errors: Effect of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment

	(1) Years of Schooling β / SE	(2) Primary (0/1) β / SE	(3) Middle (0/1) β / SE	(4) Enrolled (0/1) β / SE
Annual Average Sunset Time (Hours)	-1.06*	-0.13*	-0.17**	-0.17**
	(0.55)	(0.08)	(0.07)	(0.07)
Age Dummies	Yes	Yes	Yes	Yes
Observations	10006	10006	10006	9192
R^2	0.634	0.629	0.554	0.085

Notes: This table presents the effect of an hour delay in annual average sunset time on years of schooling, educational attainment and enrollment status for children between 6 and 16 years of age. All columns include age and district fixed effects. Standard errors are adjusted to reflect spatial dependence as modeled in Conley (1999). Spatial autocorrelation is assumed to linearly decrease in distance up to a cutoff of 500 km. Source: REDS.

Table D.14: Effect of Later Sunset on Children's Daily Wage Rate

	(1) Wage Casual Child (INR) β / SE	(2) Ag. Wage Child (INR) β / SE
Annual Average Sunset Time (Hours)	-17.72**	-16.81
	(8.27)	(14.00)
District FE	Yes	Yes
Industry FE	Yes	Yes
Place FE	Yes	Yes
Geographic Controls	Yes	Yes
Mean	34.41	39.55
Observations	1663	771
R^2	0.570	0.741

Notes: This table presents the effect of an hour delay in annual average sunset time on children's daily wage rate by industry at the village level. All regressions include district, industry, and place (inside or outside the village) fixed effects, and geographic controls: latitude, rainfall, temperature and elevation. Daily wage rates are winsorized at the 1% level. Standard errors are in parentheses, clustered at the village level. Source: REDS.

Indonesia: Regression Discontinuity Estimates

2003 Indonesia DHS

In addition to the 2015 DHS, I use the 2003 Indonesia DHS because it allows me to leverage a sharp, one-hour discontinuity in annual average sunset time at the time zone border in Kalimantan, Indonesia: Kalimantan is the Indonesian portion of the island of Borneo with two time zones: UTC+7 and UTC+8.[42] I restrict the sample to household members between 6 and 16 years of age.[43] In the 2003 Indonesian DHS, the average school-age child has completed roughly 4 years of schooling. 34% have completed primary school and 10% have completed middle school.

Results

I use the 2003 Indonesian DHS I exploit time zone boundaries in Kalimantan to generate plausibly exogenous variation in annual average sunset time and examine the effects on schooling outcomes for children between 6 and 16 years of age. Kalimantan is the Indonesian portion of the island of Borneo with two time zones: UTC+7 and UTC+8 (Figure D.3). In PSUs lying on the eastern (right) side of the time zone boundary, sunset time occurs an hour later than in nearby PSUs on the western (left) side of the time zone boundary. Thus, school-age children on the later sunset side of the border are more likely to be sleep deprived and have worse educational outcomes.

The first stage is presented in Figure D.4. By construction, I observe a clear discontinuity in annual average sunset time at the border. To estimate the effects on schooling I include age fixed effects to control for differences in grade progression between children of different age groups. My identification strategy rests on the assumption that there are no discontinuities in observable or unobservable variables potentially correlated with outcomes of children of the same age. Indeed, I find that school-age children living in PSUs on the later sunset side are less likely to be enrolled in school, have fewer years of schooling, and relatedly, are less likely to complete primary and middle school. Figure D.5 presents these discontinuities graphically, while Table D.15 presents the formal results. Specifically, school-age children living close to the time zone boundary but on the later sunset side have years of education by 0.74 years fewer years of schooling. This point estimate is remarkably similar to the effects of annual average sunset time on years of schooling for school-age children in India. Next, I control for geographic and household level socioeconomic indicators: latitude, elevation, urban status and wealth index. If wealthier households were sorting across the time zone border one would expect these controls to correct the bias emanating from such omitted variables. I show my point estimates remain unaffected (Table D.16).

The time zone boundary perfectly overlaps with provincial administrative boundaries on Kalimantan, Indonesia. That is, the regression discontinuity design examines differences in children's education outcomes for PSUs closest to the administrative border between West and Central Kalimantan (UTC+7) and South and East Kalimantan (UTC+8). If

[42]Although Indonesia has multiple islands on different time zones, Kalimantan is the only contiguous Indonesian island with an internal time zone border.

[43]In Indonesia, the levels of the education system are as follows: primary school ranges from grade 1 to grade 6 and middle school ranges from grade 7 to grade 9.

administrative boundaries are drawn to ensure that economically developed locations fall on a certain side of the time zone boundary then my point estimates may be biased. However, all four provinces followed the Central Indonesian Time or UTC+8 until 1987. West and Central Kalimantan only switched to UTC+7 in 1988.[44] Importantly, to my knowledge, administrative boundaries were not altered during or after this switch. In addition, this means that I can use older cohorts or individuals who completed their education before 1988 (>40 year-olds), under UTC+8, as a placebo sample. As one might expect, I fail to find evidence for a statistically significant discontinuity in years of schooling at the time zone border for individuals over 40 years of age (Figure D.6 and Table D.17).

[44]West Kalimantan followed UTC+7.5 between 1945 and 1963, with the exception of a brief period between 1948 and 1950 when the province followed UTC+8. West Kalimantan switched to UTC+8 in 1964.

Figure D.3: DHS Clusters in Indonesia and Time Zone Boundary on the Kalimantan Island

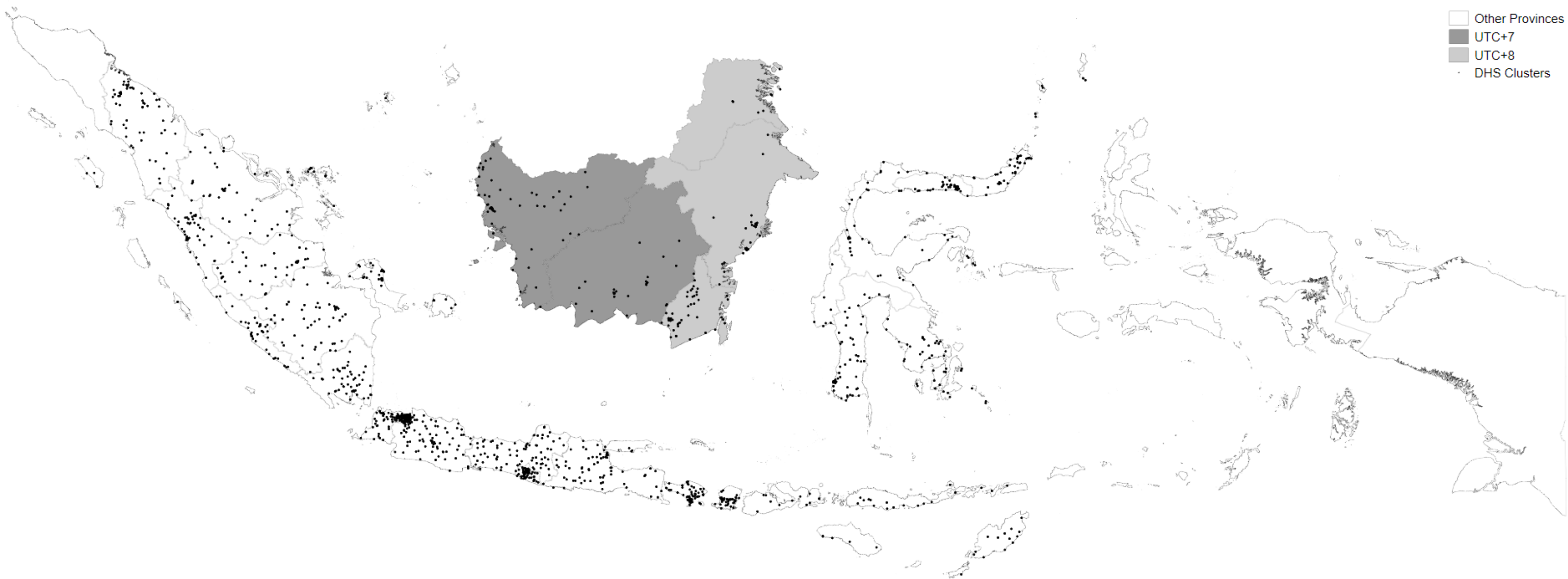
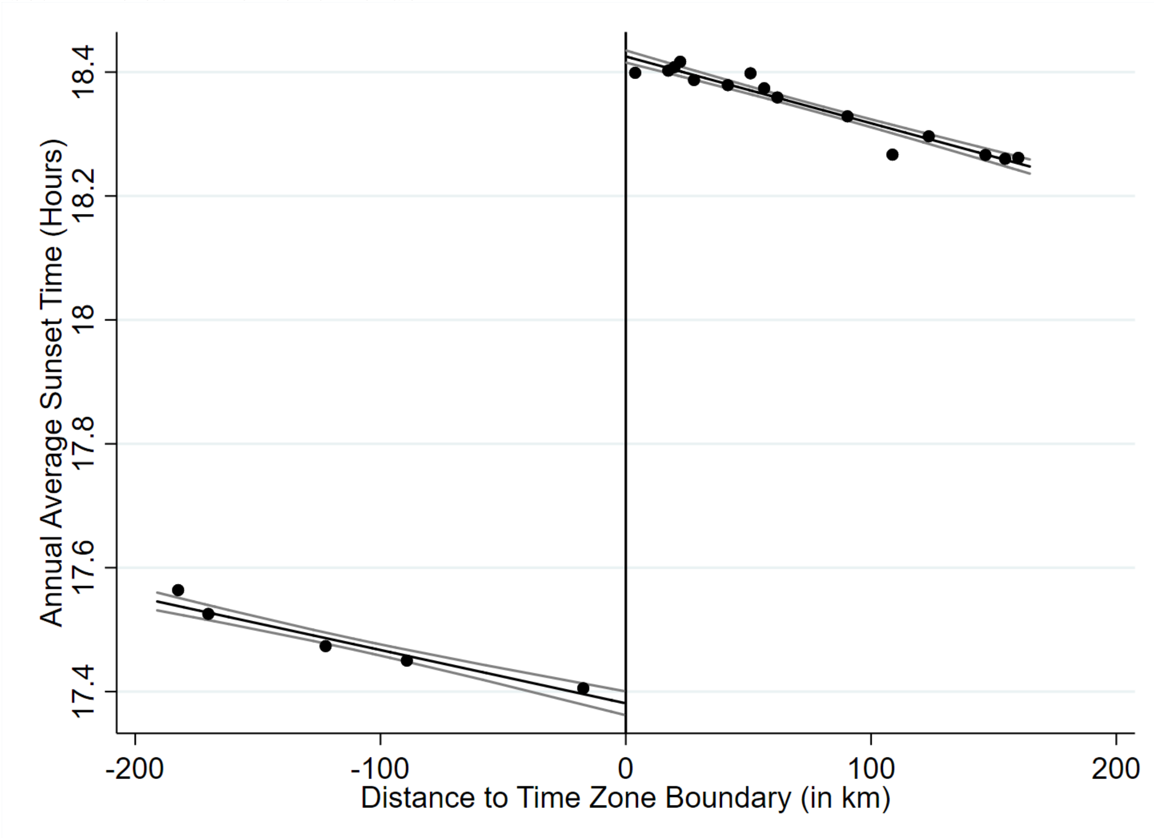
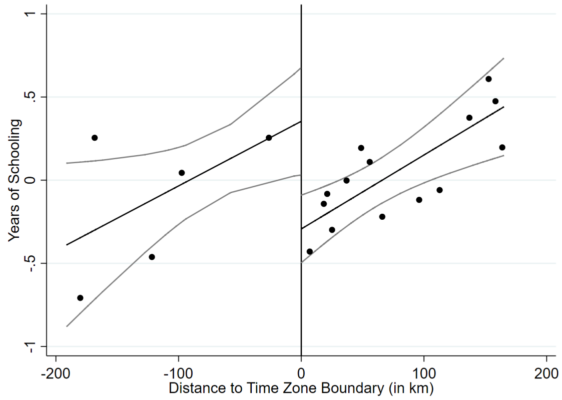


Figure D.4: Indonesia Regression Discontinuity Estimates: Discontinuity in Average Annual Sunset Time at Time Zone Border

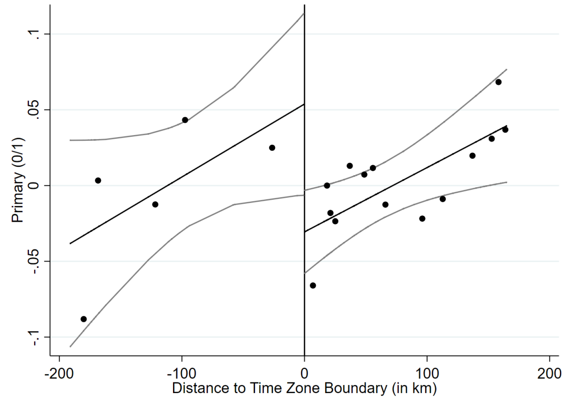


Notes: This figure presents the sharp one-hour discontinuity in annual average sunset time for DHS PSUs on either side of the time zone border (as depicted in Figure D.3) on Kalimantan, Indonesia. Standard errors are clustered at the PSU level. Source: DHS.

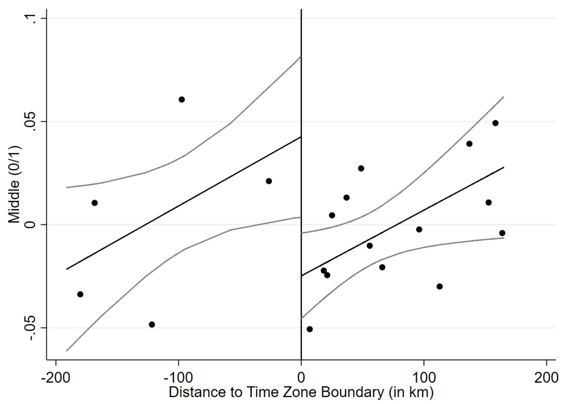
Figure D.5: Indonesia Regression Discontinuity Estimates: Effects of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment



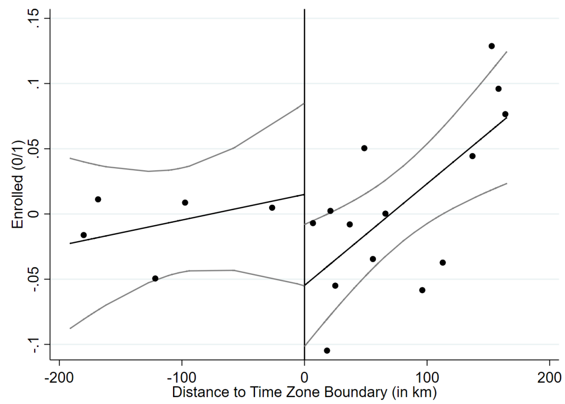
(a) Years of Schooling



(b) Primary School (0/1)



(c) Middle School (0/1)



(d) Enrollment Status (0/1)

Notes: This figure presents the effects of annual average sunset time on years of schooling, educational attainment and enrollment for children between 6 and 16 years of age in Indonesia. I leverage discontinuity in annual average sunset time (Figure D.4) for DHS PSUs on either side of the time zone border (as depicted in Figure D.3) on Kalimantan, Indonesia. Standard errors are clustered at the PSU level. All regressions include controls for age. Source: DHS.

Figure D.6: Placebo Test: Effects of Later Sunset on Years of Schooling for Individuals Over 40 Years of Age

Notes: This figure presents the effects of annual average sunset time on years of schooling for adults over 40 years of age. I leverage discontinuity in annual average sunset time (Figure D.4) for DHS PSUs on either side of the time zone border (as depicted in Figure D.3) on Kalimantan, Indonesia. All regressions include controls for age. Standard errors are clustered at the PSU level. Source: DHS.

Table D.15: Indonesia Regression Discontinuity Estimates: Effects of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment

	(1) Years of Schooling	(2) Primary (0/1)	(3) Middle (0/1)	(4) Enrolled (0/1)
Conventional	-0.740	-0.0406	-0.0690	-0.0561
Bias-corrected	-0.719	-0.0324	-0.0689	-0.0527
Robust	-0.719	-0.0324	-0.0689	-0.0527
Robust 95% CI	[-1.186 -.251]	[-.11 .045]	[-.121 -.017]	[-.183 .078]
Observations	3722	3722	3722	3722
Conventional p-value	0.000	0.251	0.003	0.321
Robust p-value	0.003	0.414	0.010	0.429
Order Loc. Poly. (p)	1.000	1.000	1.000	1.000
Order Bias (q)	2.000	2.000	2.000	2.000

Notes: This figure presents the effects of annual average sunset time on years of schooling, educational attainment and enrollment for children between 6 and 16 years of age. All regressions include controls for age. The RD estimates are constructed using the epanechnikov kernel. The bandwidth choice mserd is an upgraded version of both the IK and the CCT implementations of the MSE-optimal bandwidth selectors discussed in Imbens and Kalyanaraman (2012) and Calonico, Cattaneo and Titiunik (2014), respectively. I use the code written by Calonico et al. (2017) for robust bias-corrected inference. Standard errors are clustered at the PSU level. Source: 2003 Indonesia DHS.

Table D.16: Indonesia Regression Discontinuity Estimates (Other Controls): Effects of Later Sunset on Years of Schooling, Educational Attainment, and Enrollment

	(1) Years of Schooling	(2) Primary (0/1)	(3) Middle (0/1)	(4) Enrolled (0/1)
Conventional	-0.834	-0.107	-0.103	-0.121
Bias-corrected	-0.853	-0.123	-0.106	-0.127
Robust	-0.853	-0.123	-0.106	-0.127
Robust 95% CI	[-1.252 -.453]	[-.192 -.055]	[-.153 -.06]	[-.239 -.014]
Geographic Controls	Yes	Yes	Yes	Yes
Socioeconomic Controls	Yes	Yes	Yes	Yes
Observations	3722	3722	3722	3722
Conventional p-value	0.000	0.000	0.000	0.018
Robust p-value	0.000	0.000	0.000	0.028
Order Loc. Poly. (p)	1.000	1.000	1.000	1.000
Order Bias (q)	2.000	2.000	2.000	2.000

Notes: This figure presents the effects of annual average sunset time on years of schooling, educational attainment and enrollment for children between 6 and 16 years of age. All regressions include controls for age as well as socioeconomic and geographic indicators: latitude, altitude, urban status (0/1) and wealth index (1-5). The RD estimates are constructed using the epanechnikov kernel. The bandwidth choice mserd is an upgraded version of both the IK and the CCT implementations of the MSE-optimal bandwidth selectors discussed in Imbens and Kalyanaraman (2012) and Calonico, Cattaneo and Titiunik (2014), respectively. I use the code written by Calonico et al. (2017) for robust bias-corrected inference. Standard errors are clustered at the PSU level. Source: 2003 Indonesia DHS.

Table D.17: Placebo Test: Effects of Later Sunset on Years of Schooling for Individuals Over 40 Years of Age

	(1) Years of Schooling
Conventional	-0.0111
Bias-corrected	-0.0928
Robust	-0.0928
Robust 95% CI	[-1.857 1.672]
Observations	3266
Conventional p-value	0.989
Robust p-value	0.918
Order Loc. Poly. (p)	1.000
Order Bias (q)	2.000

Notes: This figure presents the effects of annual average sunset time on years of schooling for adults over 40 years of age. All regressions include controls for age. The RD estimates are constructed using the epanechnikov kernel. The bandwidth choice mserd is an upgraded version of both the IK and the CCT implementations of the MSE-optimal bandwidth selectors discussed in Imbens and Kalyanaraman (2012) and Calonico, Cattaneo and Titiunik (2014), respectively. I use the code written by Calonico et al. (2017) for robust bias-corrected inference. Standard errors are clustered at the PSU level. Source: 2003 Indonesia DHS.

E Effects of Later Sunset on Adults' Time Use and Wages

Later sunset may also affect adults' sleep duration. Moreover, depending on how adults trade-off sleep with work and home production, sunset-induced sleep deficits may affect monetary and time investments in children's education. If labor markets are competitive, workers are paid their marginal revenue product, and sleep is more work-productivity-enhancing than home-productivity-enhancing, adults may decrease labor productivity, disincentivizing work effort, but increase time allocated to home production. In this case, later sunset may decrease household expenditure on children's education but increase parental time investment in children. On the other hand, if sleep is more home-productivity-enhancing than work-productivity-enhancing, adults may decrease time allocated to home production but increase time allocated to formal work.

To test these hypotheses, I use ITUS to examine the effect of later sunset on adults' time use (Table E.1). I find that an hour delay in daily sunset time reduces adults' sleep by roughly 30 minutes. The statistically significant negative (positive) effect of later sunset on time allocated to formal work (home production) is not robust to controlling for state- or district-by-season fixed effects. I also fail to find a robust negative effect of later sunset on time spent with children (Table E.2).

Next, I use the 2006 REDS to evaluate the effect of sustained sunset-induced sleep deficits on adults' daily wage rate in the long run. That is, I compare the prevailing wage rate among adult daily wage laborers who reside in villages with different annual average sunset time within a district. I show an hour delay in annual average sunset reduces adult wage rate by INR 8. Although the point estimate both males and females is negative, the effect on male wage rate noisier (Table E.3). Overall, an hour delay in sunset is associated with a decrease of roughly INR 2,500 (INR 8 x 312 working days) or USD 40 in annual earnings of a rural daily wage worker.[45]

[45] By inducing school dropouts, sunset-induced sleep deficits may increase the supply of child labor at the village level, in turn reducing adults' wage rate. Because my estimates are at the village level I cannot rule out such a general equilibrium effect.

Table E.1: Effect of Later Sunset on Adults' Time Use (Hours)

	(1) Sleep β / SE	(2) Sleep β / SE	(3) Sleep β / SE	(4) Sleep β / SE	(5) Sleep β / SE
Sunset Time (Hours)	-0.50***	-0.45***	-0.45***	-0.66***	-0.44**
	(0.10)	(0.09)	(0.12)	(0.19)	(0.19)
Mean	8.11	8.11	8.11	8.11	8.11
Observations	48804	48802	48804	48804	48804
R^2	0.078	0.155	0.079	0.081	0.110
	(6) Study β / SE	(7) Study β / SE	(8) Study β / SE	(9) Study β / SE	(10) Study β / SE
Sunset Time (Hours)	-0.03	-0.04	-0.00	0.04	0.05
	(0.03)	(0.03)	(0.04)	(0.07)	(0.08)
Mean	0.11	0.11	0.11	0.11	0.11
Observations	48804	48802	48804	48804	48804
R^2	0.012	0.185	0.013	0.014	0.019
	(11) Leisure β / SE	(12) Leisure β / SE	(13) Leisure β / SE	(14) Leisure β / SE	(15) Leisure β / SE
Sunset Time (Hours)	0.90***	0.79***	0.93***	0.79*	0.36
	(0.21)	(0.18)	(0.24)	(0.43)	(0.48)
Mean	7.06	7.06	7.06	7.06	7.06
Observations	48804	48802	48804	48804	48804
R^2	0.044	0.263	0.044	0.046	0.061
	(16) Work β / SE	(17) Work β / SE	(18) Work β / SE	(19) Work β / SE	(20) Work β / SE
Sunset Time (Hours)	-0.56***	-0.41**	-0.74***	0.01	0.22
	(0.21)	(0.17)	(0.25)	(0.45)	(0.50)
Mean	5.40	5.40	5.40	5.40	5.40
Observations	48804	48802	48804	48804	48804
R^2	0.026	0.563	0.026	0.028	0.036
	(21) HH Chores β / SE	(22) HH Chores β / SE	(23) HH Chores β / SE	(24) HH Chores β / SE	(25) HH Chores β / SE
Sunset Time (Hours)	0.21*	0.18	0.23*	-0.13	-0.18
	(0.12)	(0.12)	(0.13)	(0.24)	(0.25)
Mean	2.72	2.72	2.72	2.72	2.72
Observations	48804	48802	48804	48804	48804
R^2	0.018	0.645	0.018	0.019	0.023
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes
HH/Individual Controls	No	Yes	No	No	No
Weather Controls	No	No	Yes	No	No
State-by-Season FE	No	No	No	Yes	No
District-by-Season FE	No	No	No	No	Yes

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure, work, home production and time spent with children by individuals (in hours) over the age 16 on weekdays. Columns 1, 6, 11, 16, and 21 include district and week-of-year fixed effects. Columns 2, 7, 12, 17, and 22 include district and week-of-year fixed effects and household- and individual level controls. Columns 3, 8, 13, 18, and 23 include district and week-of-year fixed effects and weather controls. Columns 4, 9, 14, 19, and 24 include state-by-season, district, and week-of-year fixed effects. Columns 5, 10, 15, 20, and 25 include district-by-season and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table E.2: Effect of Later Sunset on Adults' Time Use (Hours)

	(1) Time With Kids β / SE	(2) Time With Kids β / SE	(3) Time With Kids β / SE	(4) Time With Kids β / SE	(5) Time With Kids β / SE
Sunset Time (Hours)	0.08	0.04	0.11*	-0.03	-0.04
	(0.05)	(0.05)	(0.06)	(0.09)	(0.10)
District FE	Yes	Yes	Yes	Yes	Yes
Week-of-Year FE	Yes	Yes	Yes	Yes	Yes
HH/ Individual Controls	No	Yes	No	No	No
Weather Controls	No	No	Yes	No	No
State-by-Season FE	No	No	No	Yes	No
District-by-Season FE	No	No	No	No	Yes
Mean	0.43	0.43	0.43	0.43	0.43
Observations	48804	48802	48804	48804	48804
R^2	0.022	0.193	0.023	0.023	0.030

Notes: This table presents the effect of an hour delay in sunset time on time allocated to sleep, study, leisure, work, home production and time spent with children by individuals (in hours) over the age 16 on weekdays. Column 1 include district and week-of-year fixed effects. Column 2 include district and week-of-year fixed effects and household- and individual level controls. Column 3 include district and week-of-year fixed effects and weather controls. Column 4 include state-by-season, district, and week-of-year fixed effects. Column 5 include district-by-season and week-of-year fixed effects. Standard errors are in parentheses, clustered at the district-week level. Source: ITUS.

Table E.3: Effect of Later Sunset on Adults' Daily Wage Rate

	(1) Adult Wage (INR) β / SE	(2) Male Wage (INR) β / SE	(3) Female Wage (INR) β / SE
Annual Average Sunset Time (Hours)	-8.03**	-3.92	-13.98**
	(3.69)	(3.91)	(5.81)
District FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Place FE	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes
Mean	63.97	67.49	49.66
Observations	6055	5952	2491
R^2	0.592	0.612	0.550

Notes: This table presents the effect of an hour delay in annual average sunset time on adult's daily wage rate by industry at the village level. All regressions include district, industry and place (inside or outside the village) fixed effects, and geographic controls: latitude, rainfall, temperature and elevation. Daily wage rates are winsorized at the 1% level. Standard errors are in parentheses, clustered at the village level. Source: REDS.

F A Model of Human Capital Accumulation

Given the dynamic nature of human capital production, sunset-induced sleep deficits may accumulate, leading to decreases in educational attainment levels. As noted in the introduction, if one were to compare short-run effects of sleep deprivation to long-run effects of sleep deprivation at issue in this paper, two differences have offsetting effects. First, effects of sleep deprivation on education production could accumulate (Basner et al., 2013; Van Dongen et al., 2003). Second, short-run impacts may be mitigated in the long-run by individuals' adjustments (Barreca et al., 2016; Samuelson, 1947; Zivin, Hsiang and Neidell, 2018). In this section, I outline a framework for conceptual framework for conceptualizing these offsetting effects.

Following Zivin, Hsiang and Neidell (2018), I begin with a simple two-period model of human capital accumulation. In the first period, academic performance y is defined as follows:

$$y_1 = h(K_1, H_1, S_1(\theta_1, A_1(\theta_1))) \tag{11}$$

where K_1 represents human capital endowments at birth, H_1 denotes time spent on schooling, including self investment in study effort in period 1, S_1 is time allocated to sleep in period 1, θ_1 is sunset time in period 1, and A_1 is avoidance behavior in period 1. Avoidance behavior in the short-run may include actions such as staying indoors in the evening and using sleep-inducing goods like window shades or indoor beds, which depend on sunset time. As such, the third argument in the human capital production function ($S_1(\theta, A_1(\theta))$) can be viewed as a measure of sleep resulting from changes in sunset time and consequent ex ante behavioral responses to such a change.

Performance in the second period is defined similarly to first-period performance with two key distinctions. Human capital accumulates from earlier periods and individuals now have the opportunity to respond to feedback embodied in their first-period performance through compensatory behaviors. As such, second-period performance is expressed as follows:

$$y_2 = h(K_2, H_2, S_2(\theta_2, A_2(\theta_2)), b(y_1)) \tag{12}$$

As with the initial period, performance will depend of human capital levels, time spent on schooling, and time allocated to sleep, which depends on sunset time and avoidance behavior. For simplicity, I assume that $K_2 = K_1 + g(y_1)$ to reflect human capital accumulation between periods, where the function g reflects the growth in human capital, which depends on prior period learning as reflected by test performance. Compensatory behaviors b are an ex post response to performance in period 1. They could include actions such as daytime naps or monetary investments in education. It is possible that a child understands that her performance depends on sleep, and engages in compensatory behavior like daytime naps. However, it is not necessary that children understand that their performance depends on sleep to engage in ex post compensatory behavior. For e.g., if a child learns less material due to sunset-induced sleep deficits, parents may invest additional monetary resources in the following days, potentially offsetting the effect of lost learning.

My short-run analysis focuses on the impact of sunset-induced sleep deficits on the day of the assessment on cognitive performance. The short-run estimate reflects the total derivative of y_t with respect to θ_t, as follows:

$$\frac{dy_t}{d\theta_t} = \frac{\partial h}{\partial H_t} * \frac{\partial H_t}{\partial \theta_t} + \frac{\partial h}{\partial S(.)_t} * \frac{\partial S(.)_t}{\partial \theta_t} + \frac{\partial h}{\partial S(.)_t} * \frac{\partial S(.)_t}{\partial A_t} * \frac{\partial A_t}{\partial \theta_t} \tag{13}$$

The first term represents the effect of time allocated to self-studying or homework. The second term represents the effect of sunset-induced sleep deficits on performance. Because sleep is productivity-enhancing for students, $\frac{\partial H_t}{\partial \theta_t} < 0$ (Appendix A). The third term represents the ex-ante behavioral effect of sunset time, which depends upon the effectiveness of that avoidance behavior in diminishing the impacts on cognitive performance and the extent of that avoidance behavior. Therefore, my empirical estimate of short-run impacts will capture the direct effect of sunset-induced sleep deficits net of any avoidance, and the indirect effect of sunset-induced sleep deficits through decrease in study time.

The effects of sunset-induced sleep deficits on learning outcomes in the long run can be interpreted as the sum of impacts of sunset time from period 1 and period 2, plus any component of the ex post response to observed first-period performance $b(y_1)$ that is affected by first-period sunset-induced sleep deficits and the dynamic accumulation of human capital. Thus, my long-run estimate reflects the total derivative of y_2 with respect to both θ_1 and θ_2, which can be expressed as follows:

$$\begin{aligned}\frac{dy_2}{d\theta_1} + \frac{dy_2}{d\theta_2} = \frac{\partial h}{\partial H_2} * \frac{\partial H_2}{\partial \theta_2} + \frac{\partial h}{\partial S(.)_2} * \frac{\partial S(.)_2}{\partial \theta_t} &+ \frac{\partial h}{\partial S(.)_2} * \frac{\partial S(.)_2}{\partial A_2} * \frac{\partial A_2}{\partial \theta_2} \\ &+ \frac{\partial h}{\partial g(y)_1} * \frac{\partial g(y)_1}{\partial y_1} * \frac{\partial y_1}{\partial \theta_1} \\ &+ \frac{\partial h}{\partial b(y)_1} * \frac{\partial b(y)_1}{\partial y_1} * \frac{\partial y_1}{\partial \theta_1}\end{aligned} \tag{14}$$

The first three terms are identical to those in Equation (12) and reflect the contemporaneous effect of sunset-induced sleep deficits on second-period performance. The fourth term ($\frac{\partial h}{\partial g(y)_1} * \frac{\partial g(y)_1}{\partial y_1} * \frac{\partial y_1}{\partial \theta_1}$) captures the impacts of first-period sunset-induced sleep deficits on learning and thus human capital accumulation by period 2. The fifth term ($\frac{\partial h}{\partial b(y)_1} * \frac{\partial b(y)_1}{\partial y_1} * \frac{\partial y_1}{\partial \theta_1}$) captures the impacts of ex post behavioral responses. It appears in this analysis precisely because compensatory behavior responds to prior period performance. Thus, the difference between the short-run estimates characterized in Equation (13) and the long-run estimates described by Equation (14) will reflect the accumulated impacts of sunset-induced sleep deficits on learning plus the impacts of any ex post compensatory behaviors.