Sunset Time and the Health Effects of Social Jetlag Evidence from US Time Zone Borders

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Draft

August 25, 2016

Abstract

This paper uses a spatial regression discontinuity design to identify the health effects of the misalignment between social and biological time induced by different sunset times and the fact that social schedules are not responsive to solar cues. Exploiting the discontinuity in the timing of natural light provided by the existence of time zones, we find that being exposed to more light in the evening has negative effects on sleep duration, increases obesity and diabetes prevalence, and the likelihood of reporting any cognitive impairment. Our results suggest that sleep is the main mechanisms explaining the effects on health and cognitive outcomes.

Keywords: Health, Sleep Deprivation, Time Use, Obesity, Regression Discontinuity
JEL Classification: I12; J22; C31

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1 Introduction

Working schedules, school start times, and generally the organization of social time are subject to growing economic incentives for coordination and synchronization. Recent research suggests that this can lead to misalignment of social and biological time, with detrimental consequences for overall health. Chronobiologists refer to this discrepancy between biological and social time as "social jetlag" (Roenneberg et al., 2012). Social schedules can conflict with individual circadian rhythms, the physiological processes (physical, mental and behavioral) characterized by a 24-hour cycle affecting sleep-wake-cycles and other physiological functions (e.g., hormone release, body temperature). Circadian rhythms disruptions have been associated with negative health outcomes (e.g., Vitaterna et al., 2001).

Time zone borders provide a natural setting to study the discrepancy arising between social time and the most important factor influencing our biological clock: light. Environmental light has a direct effect on the sleep-wake cycle. The human body reacts to environmental light, producing more melatonin when it becomes darker governing the timing of sleep.[1] Medical studies provide evidence of important associations of exposure to artificial and natural light at night with sleep loss, weight gain, cognitive impairment and chronic diseases such as diabetes (Roenneberg, 2013; Shi et al., 2013; Schmidt et al., 2007). However, most of the evidence is based on observational studies or laboratory experiments. Observational studies do not shed light on the mechanisms underlying these associations, while laboratory experiments provide a limited understanding of the effects of circadian rhythms disruptions in the real-world (Roenneberg, 2013). Furthermore, they do not allow us to understand the role of social constructs such as work schedules, school start times, and other forms of "forced synchronization". The goal of this paper is to study the health effects of the misalignment between biological and social time that arises at a time-zone border analyzing the discontinuity in sleep and health outcomes that are typically associated with circadian rhythms disruptions.

Sleep is a commodity we all demand. Yet, statistics suggest many of us sleep less than the recommended 7-8 hours.[2] A survey conducted in 2013 by the U.S. National Sleep Foundation found that Americans are more sleep-starved than their peers abroad, and the Institute of Medicine (2006) estimates that 50-70 million US adults have sleep or wakefulness disorder (Altevogt et al., 2006). Estimates suggest that in many countries, individuals are sleeping as much as two hours less per night than did their ancestors one hundred years ago (Roenneberg, 2013). Figure 1 illustrates the dramatic shift in the share of individuals reporting less than 6 hours of sleep between 1942 and 1990. During the workweek, individuals tend to sleep significantly

[1]There is voluminous scientific evidence on the relationship between environmental light and sleep timing (see Roenneberg et al., 2007, for a review). Circadian rhythms are governed by the suprachiasmatic nucleus (SCN), or internal pacemaker also known as the body's master clock. The SCN synchronizes biological rhythms with environmental light, a process known as "entrainment". When there is less light, the SCN stimulates the production of melatonin, also known as "the hormone of darkness", which in turn promotes sleep in diurnal animals, including humans.

[2]See the recent sleep guidelines from the National Heart, Lung, and Blood Institute: `http://www.cdc.gov/sleep/about_sleep/how_much_sleep.html`.

less than the recommended 8 hours but with important heterogeneity with respect to education and work schedules (see Figure 2). Consistent with previous studies analyzing the relationship between wages, socio-economic status and sleeping time (Ásgeirsdóttir and Ólafsson, 2015; Biddle and Hamermesh, 1990), we find evidence that education is negatively correlated with sleep duration, suggesting a trade-off between sleeping and income. Furthermore, regardless of the educational group considered, individuals who begin to work later in the morning tend to sleep longer. Insufficient sleep is associated with a higher incidence of chronic diseases (i.e. hypertension, diabetes), cancer, depression, and early mortality and sleep duration is an important regulator of body weight and metabolism (see Cappuccio et al., 2010, for a systematic review).

Despite the large heterogeneity in sleep duration in the population and the growing medical evidence on the risks associated with short sleep duration and poor sleep quality, the economic literature has largely ignored the analysis of both the economic causes and consequences of sleep deprivation.[3]

Given the direct biological link between the dark-light and the sleep-wake cycle, sleep is our primary outcome of interest. However, we also analyze the effects on weight, diabetes, cognitive impairment, and self-reported health status. All these outcomes have been shown to be associated with circadian rhythms disruptions and insufficient sleep and to have important effects on individuals' productivity, economic performance, and health care costs (Cawley, 2015, 2004; Leese, 1992; Banks and Oldfield, 2007).[4]

Time zones allow us to identify an exogenous variation in sunset times and, thus, to study the health effects of the discrepancy arising between social and biological time because of the conflict between local clock time and sunlight. In counties lying on the eastern (right) side of a time zone boundary, sunset time occurs an hour later than in nearby counties on the opposite side of the boundary (see Figure 3). Henceforth, we will refer to these counties as counties on the late sunset side of the border. Because sunset occurs at a later hour, individuals on the late sunset side of a time zone boundary will tend to go to bed at a later time. In addition, as prime-time evening shows air at 10 p.m. Eastern and Pacific, 9 p.m. Central and Mountain, TV programs may also affect bedtime and reduce or reinforce the effect of sunset time (Hamermesh et al., 2008). Note that if people were to compensate by waking up later, solar, and TV cues would have no effect on sleep duration. However, because of economic incentives, social schedules —such as working schedules, and school start times— tend to be rigid and unresponsive to solar cues. Thus, many individuals are not able to fully compensate in the morning by waking up at a later time.

Using data from the American Time Use Survey, we find that employed people living in

[3]Notable exceptions are the seminal paper by Biddle and Hamermesh (1990) analyzing the relationship between economic incentives and sleep duration and subsequent studies analyzing the determinants of sleep duration (e.g., Ásgeirsdóttir and Ólafsson, 2015). The discussion on the economics of sleeping began earlier in the 1970s with an article by El Hodiri (1973), continued by Bergstrom (1976) and extended by Hoffman (1977). However, Biddle and Hamermesh (1990) were the first to formalize the analysis of the sleeping decision and econometrically analyze its relationship with economic incentives.

[4]Interestingly, Aetna, a major US health insurance company, recently introduced an incentive scheme to promote employees' sleep. See http://www.huffingtonpost.com/entry/aetna-pays-employees-to-sleep-more_us_570e78abe4b03d8b7b9f1712.

counties late sunset counties sleep on average 19 fewer minutes than employed people living in neighboring counties on the opposite side of the border because of the one-hour difference in sunset time. More generally, individuals on the late sunset side of a time zone boundary are more likely to be sleep deprived, more likely to sleep less than 6 hours, and less likely to sleep at least 8 hours. The effects are larger among individuals with early working schedules and among individuals with children of school age.

We also find evidence of significant discontinuities in the likelihood of being overweight and obese. People on the late sunset side of a time zone boundary are 10% more likely to be overweight and 21% more likely to be obese. It is worth noting that, especially in the case of weight measures, these are the consequences of a long-term-exposure to circadian rhythms disruptions. Using data from the 2000 US Census, we find evidence that individuals living on the late sunset side of the time zone border are also more likely to report some cognitive impairment. Finally, we use county level data from the Centers for Disease Control and Prevention (CDC) and find that diabetes prevalence is 2% higher in late sunset counties.

There are several biological channels through which the discontinuity in sunset time at the time-zone border may affect weight gain, cognitive impairment, and health because of its effects on sleep duration. However, there may be alternative channels through which the timing of natural light may affect these outcomes. For instance, having more natural light in the evening (morning) may increase physical activity in the evening (morning). Furthermore, individuals may spend more time outside, have dinner at a later hour, etc. We explore the role of these alternative mechanisms and conclude that sleep deprivation is the prominent factor explaining the discontinuities in weight, cognitive impairment and health status. In particular, our findings rule out the hypothesis that changes in physical activity may explain the observed discontinuities in health outcomes. However, we do find evidence that individuals exposed to more sunlight in the evening tend to eat later and are more likely to dine-out. These effects contribute to explaining the detrimental impact of social jetlag on obesity and, in turn, diabetes.

Our results are robust to a large battery of robustness checks. First, we show that there are no discontinuities in our covariates and in predetermined characteristics known not to be affected by the treatment. Furthermore, we do not find any evidence of residential sorting across the time zone borders. Finally, our results are robust to the bandwidth choice and to the inclusion of state-fixed effects.

Our paper contributes to a small but growing number of studies in the economic literature analyzing the health effects of sleep deprivation, and more generally, the effects of circadian rhythms disruptions. In a recent study, Jin et al. (2015) study the health effects of Daylight Saving Time (DST) and find that health slightly improves in the short run (4 days) when clocks are set back by one hour in Fall but no evidence of detrimental effects when moving from standard time to DST in Spring. Using a similar strategy, Smith (2016) shows that DST increases fatal crashes. Exploiting the time and geographical variation in sunset time within each time zone, Gibson and Shrader (2014) find that a one-hour increase in average daily sleep increases productivity to a greater extent than does a one-year increase in education. Similarly, Bonke (2012) examines productivity differences between morning and evening chronotypes. Finally, this paper is also related to the studies analyzing the effects of school start times on academic achievement (Carrell et al., 2011; Edwards, 2012), and showing that even small differences in school start times can have large effects on academic outcomes. However, none of these papers exploits the sharp discontinuity at time zone borders or analyzes the medium and long-run health consequences of circadian rhythms disruptions.

This paper is organized as follows. In Section 2, we briefly discuss the context. Section 3 describes the data and our identification strategy. Section 4 discusses the main results while Section 5 investigates the mechanisms underlying our main results. Concluding remarks are provided in Section 6. Robustness checks are discussed in the Appendix.

2 Background: US Time Zones and Solar and TV Cues

2.1 US Time-zones

As shown in Figure 3, the United States are divided into 4 four main time zones (Eastern, Central, Mountain, and Pacific). The time zones were first introduced in the US in 1883 to regulate railroad traffic. However, even in relatively nearby areas, scheduling was far from being uniform at that time (Hamermesh et al., 2008; Winston et al., 2008). The four current U.S. time zones were officially established with the Standard Time Act of 1918, and there have only been minor changes since then, primarily at their boundaries. The Eastern time zone was set -5 hours with respect to Greenwich Mean Time (GMT), and the other three time zones (Central, Mountain and Pacific) differ from that by -1, -2, and -3 hours, respectively. It is worth noting that time zone borders do not always coincide with state borders. In 12 of the contiguous US states, different counties follow different time zones.

Since 1918, a few counties petitioned the Department of Transportation for a change in their time zones. Over time there has been a westward movement of time zone boundaries. While this movement clearly makes the time zone boundary endogenous, as Gibson and Shrader (2014) note, the westward movement of boundaries would have, if anything, negative effects on sleep duration, as counties moving to the late sunset side of a time zone boundary would move from early sunset areas to late sunset areas.

2.2 Timing of Television Programs

Television networks usually broadcast two separate feeds, namely the “eastern feed” that is aired at the same time in the Eastern and Central time zones and the “western feed” for the Pacific time zone. In the Mountain time zone, networks may broadcast a third feed on a one-hour delay from the Eastern time zone. Television schedules are typically posted in Eastern/Pacific time, and thus, programs are conventionally advertised as “tonight at 9:00/8:00 Central and Mountain”.

Therefore, in the two middle time zones, television programs start nominally an hour earlier than in the Eastern and Pacific time zones. As Hamermesh et al. (2008) and Winston et al. (2008) note, this practice originated in the 1920s when, because of the radio transmission technology available at the time, broadcasting would be simultaneous in the Central and Eastern time zones and the same program would be received an hour earlier in the Central time zone - while Mountain and Pacific time zones would receive repeats. With the beginning of TV broadcasting, it became customary for the Eastern feed to be delayed by one hour in the Mountain time zone. These differences in the timing of TV shows have persisted over time such that prime time in the two coastal zones runs from 8pm to 11pm, while in the two middle time zones, it runs from 7pm until 10pm. As this practice was introduced even before the beginning of TV broadcasting and responded to people's preferences for live performances at desirable times, Hamermesh et al. (2008) argue that TV cues can be considered external to agents, while nevertheless affecting their timing, and show that the scheduling of television programs affects timing and bedtime.

By construction sunset occurs an hour later on the late sunset side of each time zone border (EC, CM, MP). Prime time shows may reinforce or reduce the sunset effect on bedtime. In particular, prime time shows start nominally an hour later on the late sunset side of the time zone boundary between the Central and Eastern time zones, an hour earlier on the late sunset side of the time zone boundary between Mountain and Pacific, and at the same time along the counties bordering with the time zone border between Central and Mountain time zones.[5]

Thus, we expect that if TV schedules affect individual bedtime, the discontinuity in bedtime should be larger along the Central–Eastern time zone border and smaller along the Pacific–Mountain time zone border. We examine the role of TV schedules in Section A.3 in the Appendix showing that television schedules does not play a major role in explaining the discontinuity in sleep duration that we observe at the time zone border.

3 Data and Identification Strategy

3.1 Data

In this paper we mainly use data from the American Time Use Survey (ATUS) conducted by the U.S. Bureau of Labor Statistics (BLS) since 2003. Our sample covers the years 2003–2013. The ATUS sample is drawn from the exiting sample of Current Population Survey (CPS) participants. The respondents are asked to complete a detailed time use diary of their previous day that includes information on time spent sleeping and eating. In 2003, 20,720 individuals participated in the survey. Since 2004, on average, more than 1,100 individuals have participated in the survey each month since 2004, and the last available survey year is 2013. This yields a total sample of approximately 148,000 individuals. In our analysis, we restrict attention to individuals

[5] Note that in practice, we do not include Arkansas and Idaho as after imposing our sample restrictions we are left with no observations for these two states in the in the ATUS sample.

in the labor force (both employed and unemployed)[6] living within 250 miles of each time zone boundary (Pacific–Mountain, Mountain–Central, Central–Eastern). This is achieved by merging the ATUS individuals with CPS data to obtain information on the county of residence of ATUS respondents. Unfortunately, CPS does not release county information for individuals living in counties with fewer than 100,000 residents; thus, we can match only 44% of the sample. Our results are therefore representative of more urbanized and densely populated counties.

We further restrict our sample to people aged 18 to 55 years to avoid the confounding effect of retirement and the selection issue that might arise focusing on high-school age workers.[7] We also limit the analysis to individuals who sleep between 2 and 16 hours per night.[8] After imposing these restrictions, the sample comprises 18,639 individuals, of whom 16,557 were employed. Employment status was determined on the basis of responses to a series of questions relating to their activities during the preceding week. We also have information on whether the wake-up day was a workday for someone.

Our primary outcome of interest is sleep duration. We count only night sleeping by excluding naps (sleep starting and finishing between 7am and 7pm). However, the results are unchanged when including naps in the main variable (see Table A.2). We also consider alternative measures of sleep duration such as indicators for reported sleep of at least 8 hours (or less than 6), being asleep at 11pm or being awake at 7.30am. These metrics are often used in sleep studies (Cappuccio et al., 2010). In our analysis, we also include several socio-demographic controls, such as age, sex, education, race, marital status, nativity status, year of immigration, and number of children, that might affect individuals' sleeping behavior.

We then analyze the time zone discontinuities in overweight status (BMI$>$ 25), obesity (BMI$>$ 30), and the likelihood of reporting poor health status, defined as reporting poor or fair health status, as is common in the literature using metrics of self-reported health status. Measurement error in the weight variables is a natural concern. Since height and weight are self-reported in the ATUS, and previous studies documented systematic reporting error in such self-reports, as a robustness check we adjusted body mass for measurement error following Courtemanche et al. (2015). Results obtained using these adjusted measures are not substantially different from the main results (see Section A.1 for further details).

Unfortunately, information on these health outcomes is not available in all survey years. In particular, questions on self-reported health status are only available since 2006, while information on body weight is available in the Eating Module included in the survey in the 2006-2009 waves. For this reason, we also use data from the US Census and the Center for Disease Control and Prevention (CDC) on cognitive impairment and diabetes, two health outcomes that have

[6]We exclude people not in the labor force because this category includes individuals disabled due to an illness lasting at least 6 months.

[7]Our main results are substantially unchanged if we further restrict the sample to individuals aged 25 to 55 years old.

[8]Those so excluded are mostly individuals who did not report any sleep duration. However, including those sleeping less than 2 hours does not substantially affect the results, as they represent approximately 1% of the entire sample.

been associated with circadian rhythms disruptions and sleep deprivation.

We use the 2000 US Census to analyze discontinuities in an indicator of cognitive impairment which is equal to one if the respondents reported any cognitive difficulty.[9] In addition, we use 2004–2010 data on age-adjusted diabetes prevalence at county level from the CDC. Table A.1 in the Appendix reports summary statistics for the variables of interest. Note that approximately 50% of the ATUS sample is interviewed over the weekend, and thus the average sleep duration in the sample is longer than that observed during the workweek (see Figure A.1). Finally, it is worth noting that self-reported sleep tends to overestimate objective measures of sleep duration (Lauderdale et al., 2008). In particular, Basner et al. (2007) note that the values for sleep time may overestimate actual sleep because the ATUS Activity Lexicon includes transition states (e.g, falling asleep).

3.2 Identification Strategy

To analyze the effects of circadian rhythms disruptions on sleep and health outcomes we exploit the sharp discontinuity in the relationship between sunlight and clock time at the time zone border. By construction, we observe a clear discontinuity in sunset time at the border Figure 4, a discontinuity that is mirrored by the observed difference in average bedtime at the time zone border (Figure 5).[10] This difference can plausibly be attributed to the delayed production of melatonin on the late sunset side of the county border.

In Section 4, we show that the difference in average bedtime generates significant differences in sleeping behavior, as people on the late sunset border of a time zone boundary do not completely compensate for this difference by waking up later. This is especially true for workers who must cope with standard office hours and for people with children of school age. Gibson and Shrader (2014) note that differences in sunset time induce changes in sleep duration that are small enough to not create incentives for schedules adjustments, but are large enough to identify effects on our outcomes of interest.

Our identification strategy exploits this spatial discontinuity in sunset time and rests on the assumption that that there are no discontinuities in observable and unobservable characteristics that may potentially confound the relationship of interest. Different from a standard regression discontinuity design, we cannot simply compare all individuals living each side of a time zone border because this "unconditional approach" would compare individuals living at different latitudes (e.g., Tallahssee vs. Chicago) or around different time zone borders (e.g., Las Vegas vs. Atlanta). In order to compare nearby counties, we control for a set of geographic dummies that divide the United States in a grid of cells around US time zone boundaries and linearly control for latitude. In practice, we divide the US in 9 areas defined by the three time zones'

[9]The specific question is the following: *"Because of a physical, mental, or emotional condition, does this person have serious difficulty concentrating, remembering, or making decisions?"*

[10]We use data on the average bedtime of Jawbone's sleep trackers users across US counties, publicly available on the Jawbone website. Jawbone is one of the leading producers of wearable devices. The figure was downloaded from the Jawbone blog, `https://jawbone.com/blog/circadian-rhythm/`. We accessed the data on January 31, 2015

borders and three parallels (below the 34^{th} parallel, between 34^{th} and 40^{th} parallel and above the 40^{th} parallel). In our main analysis we also control for socio-demographic characteristics and interview characteristics, mainly to improve the precision of our estimates and reduce small sample biases. However, in Section 3.4, we show graphical evidence of discontinuities in our health outcomes only conditioning on our baseline geographic controls.

It is worth noting that the health differences across time zone borders, particularly in the case of weight, diabetes and cognitive abilities are likely to be the result of long-term exposure to circadian rhythms disruptions as supported by recent experimental studies providing evidence of cumulative effects of short sleep duration (Van Dongen et al., 2003; Spiegel et al., 1999). In other words, what we measure is the average effect of a long-term exposure to differences in the timing of sunlight. Moreover, if people often change their residence, it is likely that the estimated effect on sleep and other health outcomes represents only a lower bound of the true effect, unless healthier individuals systematically move from the late sunset side to the early sunset side of each time zone border.

In the robustness checks reported in Section A.1, we implement a large battery of tests for residential sorting across bordering counties and find no evidence of it. In particular, we do not find evidence of discontinuities in population density, home (and rent) values and commuting time. Furthermore, in Figure A.2, we show the density of our running variable both unconditional and conditional to our baseline geographical controls. Again, the figure does not show any evidence of manipulation.

Finally, we indirectly test the continuity assumption behind our RDD showing that there are no discontinuities in many observed covariates and in two pre-determined characteristics that should have not been affected by the treatment—namely respondents' height and literacy rates in 1900 (before the official introduction of the time zones in 1918).

3.3 Empirical Specification

Formally, we exploit the geographical variation in sunset time at the border, estimating the following equation:

$$H_{ic} = \alpha_0 + \alpha_1 LS_c + \alpha_2 D_c + \alpha_3 D_c * LS_c + X'_{ic}\alpha_4 + C'_c\alpha_5 + I'_{ic}\alpha_6 + u_{ic} \tag{1}$$

(2)

where H_{ic} is one of our health outcomes of interest (sleep, weight measures, cognitive impairment, and diabetes) for the individual i in county c; LS_c is an indicator for the county being on the late sunset side of a time zone boundary; D_c is the distance to the time zone boundary, our "running variable" (or forcing variable), constructed using the county centroid as an individual's location; the vector X_{ic} contains standard socio-demographic characteristics such as age, sex, race, education, marital status, nativity status, year of immigration, and number of children; and C_c are county characteristics, such as area fixed effects (the geographical cells described above), a linear control in latitude, and an indicator for whether the respondent lives in a very large county.[11] We also account for interview characteristics that might affect an individual's sleeping behavior (I_{ic}), such as interview month and year, a dummy for whether the interview was conducted during DST, and two dummies that control for whether the interview was conducted during a public holiday or over the weekend.

We control for the running variable using a local linear regression approach with a varied slope on either side of the cutoff. As robustness check, we also use (and compare) higher polynomial orders to control for the distance from the border (see Section A.1). Standard errors are robust and clustered according to the distance from each time zone border (10-mile groups).[12]

The optimal bandwidth varies depending on the outcome of interest (sleep, body mass index, etc.) and depending on the different methodologies typically used in the literature for the bandwidth choice (cross-validation or the data-driven bandwidth algorithm proposed by Imbens and Kalyanaraman, 2011). For instance, in the case of sleeping the optimal bandwidth ranges between 100 and 252 miles from the border. For this reason, in Figures A.3 and A.4 we show the robustness of our results to different bandwidth choice. Point estimates are relatively stable but standard errors increase as we get close to the border. In particular, when we restrict the bandwidth below 90 miles the number of observations declines very rapidly and, as a consequence, the estimated effects start to be no longer statistically significant at conventional levels. Note that as we only know the respondent's county and have no information on their precise geographical residence, the bandwidth is calculated using the county centroid which is often several miles away from the time zone border, even when we restrict the analysis to counties bordering with a time zone. For these reason, in our baseline specification we use a bandwidth of 250 miles to ensure that areas on the late sunset /early sunset side of a time zone boundary do not overlap while maximizing our identification power. However, in the main text we also show that all our results are robust to the inclusion of state fixed effects and to the adoption of a (far) smaller bandwidth (100 miles).

Finally, the heterogeneity of our findings with respect to employment status, family composition, work schedule, and type of occupation is consistent with our hypothesis that employed people, parents with children in school age, and individuals with early work schedules are more likely to be affected by circadian rhythms disruptions because of their social schedules' constraints (see Section 4).

3.4 Graphical Analysis

To examine the effect of the sharp discontinuity in sunset time, we present a set of descriptive figures that show whether such discontinuity affects our health outcomes of interest. We start our analysis from sleep duration that represents our primary outcome. Figure 6 tests for the presence

[11]We control for the fact that in the case of very large counties, the distance based on the centroid might be a very noisy approximation of the individual sunset time.

[12]We alternatively clustered standard errors at the county level. As we obtained smaller standard errors, we opted for the most conservative clustering in our main analysis.

of a discontinuity in sleep duration at the time zone border by employment status. To compare only counties that are geographically close, we first regress sleep duration on our geographical controls and then plot the residuals. In particular, each point represents the mean residuals of sleep duration for a group of counties aggregated according to the distance from the border.[13]

As expected, we find evidence of a large discontinuity only for employed respondents. For this group the discontinuity in sleep duration is of approximately 20 minutes. In the next section, we show that the heterogeneity by employment status arises because of differences in waking time between employed and unemployed respondents. In the Appendix, we report similar evidence using non-linear metrics of sleep such as sleeping at least 8 hours and less then 6-hours (see Figure A.5).

The effect of the discontinuity in sunset time on other health outcomes is clearly noisier than for sleep duration (Figure 7). Still, the figure shows the presence of significant discontinuities in obesity, cognitive difficulties and diabetes with a higher incidence of these negative health outcomes on the late sunset side of the border. The effect goes in the same direction, but the discontinuity is less marked and less precisely estimated when analyzing self-reported health status.

Finally, we analyze the presence of discontinuities in other covariates and predetermined characteristics to indirectly test the continuity assumption behind our RDD (Figure 8). Specifically, we test for discontinuities in the probability of being white, black, native, female, married, in age, years of education, height (ATUS data) and in the literacy rate in 1900 (Census 1900) before the official introduction of the time zone in 1918. Age is the only covariate for which the linear fit predicts a discontinuity at the time zone border. However, the visual inspection of the data suggests that the discontinuity arises only as a consequence of the separated fit on the two sides of the cut-off. Furthermore, this is not a concern since all the specifications discussed later in the text condition on a full set of age dummies. We also find no evidence of discontinuities in employment status (see Figure A.6).

4 Results

4.1 Sleep Duration across Time Zone Boundaries

Table 1 illustrates the estimated effect of being on the late sunset side of a time zone boundary on sleep duration, as described in equation (1). In column 1, we show that our baseline estimates coincide with the unconditional evidence reported in Figure 6. After controlling for a set of socio-demographic, geographical and interview characteristics, the estimated effect of being on the late sunset side of the boundary ("late sunset border") is approximately 19 minutes, reducing

[13]We exclude from the graph Arizona and Indiana that did not adopt DST throughout the entire period under study (see Section 1.2). When including these states, the figure is substantially unchanged, but the confidence intervals become wider. However, we include Arizona and Indiana in the main analysis where we control for interview characteristics.

sleep duration by 0.2 standard deviations (see Table A.1). As twelve of the continental US states span multiple time zones, we re-estimate the first-stage model while including a full set of state fixed effects (column 2). Notably, the point estimates remain substantially unchanged.

In column 3, we restrict our attention to a bandwidth of 100 miles. The coefficient indicates that within 100 miles of the border, individuals on the late sunset side sleep on average 23 fewer minutes than their neighbors on the early sunset side of the border. Furthermore, this result is robust to the inclusion of state fixed effects (column 4). Finally, in column 5 we show that there is also a large effect on the probability of sleeping less than 8 hours. Being on the late sunset side of the boundary decreases the likelihood of sleeping at least 8 hours by 7.8 percentage points, which is equivalent to approximately 15% of the mean of the dependent variable in the sample.[14]

4.1.1 Early Morning Schedules and Sleep Duration

Comparing the effects for the employed and non-employed respondents we find, consistent with our hypothesis on working schedules constraints on sleep duration, that the late sunset time affects only the employed respondents (Table 2). Columns 3-6 clarify where the difference between employed and non-employed respondents lies. Regardless of their employment status, individuals on the late sunset side of the time zone border are always more likely to go to bed later (columns 3 and 4). The estimates show that being on the late sunset side of the boundary significantly increases the likelihood of being awake at 11pm for both the employed (+41%) and the non-employed (+34%). However, employed respondents are less likely to adjust their waking time accordingly. There is no significant difference across the border in the likelihood of being awake at 7:30am for employed people (column 5). Conversely, non-employed people on the late sunset side of the time zone border adjust their waking-up time in the morning. Non-employed people on the late sunset side are 13 percentage points less likely to be awake at 7:30am, a 32% effect with respect to the mean of the dependent variable (column 6).

We find that earlier working schedules corresponds to larger discontinuities at the time zone borders (Table 3).[15] More specifically, we find that among individuals starting work before 7 am a one-hour increase in average sunset time decreases sleep duration by 36 minutes (column 1), while the effect for individuals starting work between 7 and 8:30 am is approximately 18 minutes (column 2). By contrast, we find that there is small or no effect on individuals starting work between 8:30 am and noon (column 3).[16] However, even among those starting work after 8:30 am, individuals who left children at school before 8 am sleep substantially less and there is a large and significant effect of sunset time (column 4). In particular, among those entering

[14] As mentioned above, most respondents are interviewed over the weekend, and people tend to sleep longer over the weekend, thus to better gauge the magnitude of the sleep differences, we weighted the means reported at the bottom of the table to represent an average day.

[15] Note that to conduct this analysis, we restricted the sample to individuals who reported to work on the day of the interview. As 50% of the ATUS sample is interviewed over the weekend and only 23% of the employed sample reported having worked over the weekend, the sample is substantially restricted.

[16] We classify individuals in these 3 categories to compare groups of similar size and based on the distribution of working schedules.

work later in the morning, a one-hour increase in average sunset time decreases sleep duration by 27 minutes for those who brought children to school before 8 am. Consistent with these findings, we find larger effects for people with children younger than 13 even when including the non-employed (Table A.3).

We also hypothesize that the effects should be smaller in the retail and wholesale sector, as in most cases shops and stores in the US open relatively late in the morning (e.g, 10 or 11 am) and largest among individuals working in schools, in the health care sector or other public offices where standard schedules are likely to begin early in the morning or among individuals working in jobs requiring international coordination and synchronization with other markets (e.g., financial services). Consistent with our conjecture, there is evidence of significant heterogeneity across sectors, with large effects for people working in public offices and in the financial sectors and close to zero for those working in the retail and wholesale sector (see Table A.4).

These findings suggest that delaying work and school start times may have important effects on average sleep duration. When we analyze the entire ATUS sample, without restricting the analysis to counties closer to the time zone boundaries, individuals with early working schedules and/or whose children have early school start times sleep significantly less than individuals who are less likely to be constrained by social schedules in the morning (see Table A.5). Furthermore, the fact that the heterogeneity of the results presented in this section confirms our main hypotheses is reassuring and suggests that we are not confounding the effect of late sunset with that of other factors.

4.2 Effects on Weight and Health Status

We then turn to analyze potential discontinuities in body weight and self-reported health status from the ATUS. For consistency with the previous analysis we focus only on the employed population. As noted above, information on health status and body mass index is not available in all ATUS survey waves; thus, we have limited identification power. Nevertheless, the results in Table 4 show a significant effect for both health outcomes. Employed individuals living on the late sunset side of a time zone border are 11% more likely be overweight with respect to the mean (column 1). They are also 5.6 percentage points more likely to be obese, approximately a 21% increase with respect to the mean of the dependent variable in the sample under analysis (column 2). With regard to self-reported health status (column 3), the effect is equal to nearly 2 percentage points but not statistically significant. Given the binary nature of our outcome variables, we also replicate our analysis using the probit model. The marginal effects are identical up to the fourth decimal place. Consistent with the effects on sleep, we find that the effect on weight are concentrated among those with early work schedules (see Table A.6). Figure A.3 illustrates the sensitivity of our results to the bandwidth choice.

These estimates must be interpreted with caution. Especially in the case of obesity, these effects are likely to be the result of long-term exposure to sleep differences (caused by the different sunset time) on the two sides of a time zone border. These findings are consistent with the growing evidence that sleep debt is associated with metabolic and endocrine alterations that have long-term physiopathological consequences (Spiegel et al., 1999; Knutson and Van Cauter, 2008). Furthermore, the magnitude of the effects is comparable with the associations found in epidemiological studies (e.g., Hasler et al., 2004) and consistent with previous evidence from animal studies finding large effects of partial sleep deprivation on weight (Knutson et al., 2007).[17]

Consistent with our conjecture, the reduced-form effect on overweight status and obesity is concentrated among older workers, who have been exposed to the treatment for longer than have younger workers (Table A.7). Conversely, the age gradient is small and not statistically significant when examining health status. These differences are not surprising because self-reported health status is more likely to capture the short-term effects of sleep deprivation on health perception. In other words, self-reported health status is more likely to reflect the effects of short-term variations in sleep duration, while obesity is more likely to reflect the cumulative effect of sleep deprivation over time.

4.3 Other Health Outcomes

As already discussed, health information in ATUS is somewhat limited. Therefore, we also take advantage of other datasets to investigate the effect of the sharp discontinuity in sunset time at the time zone border on two health outcomes that the medical literature usually associates with circadian disruptions and sleep disorders: cognitive abilities and diabetes.

We find that individuals living on the late sunset side of the time zone boundary are more likely to report cognitive problems and diabetes (see Table 5) . In particular, being on the late sunset side of the border increases the likelihood of reporting cognitive problems by 0.002 percentage points (column 1), about 12% with respect to the mean of the dependent variable (0.016). The point estimate is larger when we include state fixed effect (column 2) or restrict the bandwidth to 100 miles (column 3). Interestingly, these results are consistent with what observed in a companion study analyzing the effects of sleep deprivation on cognitive skills in China using more standard measure of cognitive skills (Giuntella et al., 2015).

In the case of diabetes prevalence, point estimates vary substantially depending on whether we include state fixed effects or restrict the bandwidth to 100 miles. However, even in the more conservative estimate we find a statistical significant effect of roughly .2 percentage points, about 2% with respect to the mean of the dependent variable. Given the well-known relationship between obesity and diabetes and the results presented above, this result is not surprising.

[17] Moreno et al. (2006) find that among Brazilian truck drivers sleep duration <8 h per day was associated with a 24% greater odds of obesity, while Hasler et al. (2004) find that every extra hour increase of sleep duration was associated with a 50% reduction in risk of obesity.

5 Potential Mechanisms Underlying the Effects on Health Outcomes

The medical literature offers clear biological explanations for the effects of sleep deprivation on weight, diabetes, and cognitive performance. Insufficient sleep affects the function regulating appetite and energy expenditure. Food intake is a physiological adaptation to provide energy needed to sustain additional wakefulness and sleep duration plays a key role in energy metabolism (Markwald et al., 2013), favoring the consumption of fats and carbohydrates. Furthermore, fatigue due to sleep loss may reduce physical activity, exacerbating the effects of sleep deprivation on weight gain. Thus, it is natural to think that the discontinuity in sleep duration may be the main mechanism explaining the observed discontinuities in weight, health and cognitive impairment observed at time zone boundary (see Section 4).

However, it is also possible that discontinuity in sunset time may affect health not only through the effects on sleep but also through its effects on daylight exposure. For instance, sunlight exposure increases the production of vitamin D, which is usually associated with mood and depression (e.g., Kjærgaard et al., 2012). As we control for latitude and compare nearby counties, two locations at the same latitude but on the opposite side of a time zone boundary will experience the same daylight duration and differ only in the timing of daylight.[18] Indeed, living in areas with a late sunset may affect various aspects of time use in the evening hours. Individuals may be more likely to work late, grill out, go for walks, and go out. The different timing of the daylight may directly affect individuals' eating behaviors and their likelihood to engage in physical activity and contribute to explaining the observed discontinuities in health, in particular for weight and diabetes.

Using ATUS data, we investigate whether individuals living on the late sunset border spent more time outside, attending social events or meeting friends etc., or worked longer (see Table 6). Point estimates suggest that individuals on the late sunset side of the time zone border spend on average 9 minutes more outside in the evening (between 4 pm and midnight). However, the difference is not statistically different from zero when we consider the whole day. Furthermore, there is no significant difference in total working time even tough point estimates suggest that individuals on the late sunset side of the time zone border work on average 6 minutes more in the evening than their counterparts on the early sunset side of the border. These results are consistent with the idea the shifting the light from the morning to the evening increases the time spent outside in the evening but without significant effects on the overall time spent outside throughout the day.

Examining eating behavior, we find that there are no differences in the total time spent eating (column 1) but the availability of more light at night shifts the timing of dinner by increasing the probability of having a late dinner (after 7 pm) by 6 percentage points (37% of the mean, see column 2). Results go in the same direction when considering the probability of having dinner after 8, or 9 pm. Previous evidence suggests that eating dinner at a later point in the day may

[18] In the robustness checks (Section A.1), we consider the potential impact of geographical and seasonal heterogeneity in daylight duration.

have direct effects on weight gain (Garaulet et al., 2013). This result holds when conditioning for the previous number of meals (or alternatively for the average time spent on previous meals) suggesting that people are not merely shifting eating time to a later hour but are also more likely to eat after a given hour regardless of the number of times they had already eaten (column 3), with a potential net increase in caloric intake. Thus, it is not possible to establish whether the late meals are the direct consequence of the light shift in the evening or a consequence of the fact that sleep deprived respondents on the late sunset border eat more to sustain their wakefulness (Spaeth et al., 2013).

We also investigate whether there are differences in the probability of dining out (columns 4 and 5). Because restaurants routinely serve food with more calories than needed, dining out represents a risk factor for overweight and obesity (Cohen and Story, 2014). We do not find significant differences in the probability of eating out throughout the day. Yet, individuals on the late sunset border are 25% more likely to have dinner (after 5 pm) away from home. Again, this may be because individuals are more likely to spend time out when there is more light outside, but it could also be an indirect effect of sleep loss. Individuals may be less willing to prepare food at home and self-control may be weaker increasing the likelihood of away from home consumption.

Previous evidence analyzing the effect of DST shows that, in the Spring —when individuals gain an hour of light in the evening— people tend to be more active burning an additional 10% of calories (Wolff and Makino, 2012). This suggests that, if anything, people on the late sunset border may be involved in more physical activity—which would decrease weight gain and improve health —because they experience more light in the evening. Consistent with the DST evidence, for individuals on the late sunset side of the border the probability of being engaged in any physical activity and sport activities is slightly higher (Table 8), in particular the likelihood of biking and walking in the evening (columns 3 and 6). However, we do not find any evidence of significant differences between individuals on opposite sides of time zone borders throughout the day (columns 1 and 4) and in the morning (columns 2 and 5).[19] Moreover, there are no significant differences in the minutes spent exercising in the gym (columns 7-9).

Instead, we do find some evidence that individuals on the late sunset side of the time zone border are less likely to engage in activities of moderate, vigorous, or very vigorous intensity using metabolic equivalents associated with each activity reported in the ATUS time diary (see Section A.2).[20] These results suggest that the effects of light on physical activity are unlikely to explain the discontinuity in weight, health status and cognitive skills. On the contrary, some of the evidence is consistent with recent findings from laboratory studies showing that sleep deprivation significantly reduces the likelihood of engaging in physically intense activities and, thus, caloric expenditure (Schmid et al., 2009).

[19] We also find no significant differences when considering minutes spent in any physical activity or walking.

[20] Metabolic equivalents are a physiological measure expressing the energy cost of physical activities and defined as the ratio of metabolic rate (and therefore the rate of energy consumption) during a specific physical activity to a reference metabolic rate.

Taken together the findings presented in Sections 4 and 5 suggest that sleep duration is the main mechanism through which the discontinuity in sunset time at the time zone border affects health. For this reason, in Table A.8 we report 2SLS estimates of the effects of sleep on our health outcomes of interest using the discontinuity in sunset time as a plausible source of exogenous variation. However, these estimates must be interpreted with caution. These health differences are likely to be the result of long-term exposure to sleep differences (caused by the different sunset time) on the two sides of a time zone border. Moreover, as discussed throughout the text, we cannot exclude that the shift in the timing of the dinner might also contribute to this effect inflating the IV estimates, especially in the case of obesity and diabetes. As Census data do not contain information on sleeping behavior, we estimate the effect of sleep duration on cognitive impairment using a two-sample two-stage least squares (TS2SLS). In particular, we match the individuals in the two samples (ATUS and 2000 US Census) using their geographical location and standard socio-democratic information (sex, age, race, education and marital status).

Circadian rhythms disruptions may not only affect sleep duration, but also importantly affect sleep quality. While we do not have good measures of sleep quality, we used ATUS data to compute the number of times subjects woke up during night (number of sleep episodes) and the times subject reported to be in bed but sleeplessness. Conditional on overall sleep duration, individuals on the late sunset side of the border tend to be more restless and to wake up more times at night (see Table A.14). However, the effects appear relatively small in magnitude. Individuals living in late sunset counties wake up 1% more times and tend to be restless 90 seconds more than their counterparts on the opposite side of the time zone boundary. Given the imperfect nature of these metrics, we cannot rule out sleep quality as one of the mechanisms underlying the effects of circadian rhythms disruptions on health outcomes, but overall our results suggest that sleep duration has a prominent role.

6 Conclusion

This paper investigated the causal effects of later sunset times induced by time-zone discontinuities on sleep, weight, self-reported health status, diabetes and cognitive skills, outcomes that are known to be importantly related to health care costs and individual productivity. We show that individuals living on the late sunset side of a time zone boundary tend to go to bed later than do individuals living in the neighboring counties on the opposite side of the time zone border. Because working schedules and school start times are less flexible than bedtimes, individuals on the late sunset side of the border do not fully compensate by waking up later in the morning. Thus, we find that employed individuals living on the late sunset side of a time zone border sleep less than people living in a neighboring county on the early sunset side of a time zone boundary. Though the average difference in sleep duration is relatively small (19 minutes), the effects are considerably larger among individuals with early working schedules. Furthermore, we find significant discontinuities in weight, diabetes and cognitive impairment with individuals living in counties laying on the late sunset border of the time zone being more likely to report higher BMI, cognitive impairment, and diabetes. The results are robust to the use of different models and bandwidths. Importantly, we find no evidence of any significant effect on outcomes that should not be affected by the time-zone discontinuity. We considered alternative mechanisms explaining the effects of late sunset on weight, diabetes, and cognitive impairment. Our results suggest that short sleep duration is the primary factor explaining the observed discontinuities in the health outcomes. Furthermore, we find evidence that the effects of late sunset times on the timing of meals and the likelihood of eating out at night are also likely to contribute to explain the results on weight and diabetes.

Economists have largely ignored the effects of circadian rhythms disruptions and sleep on health. Policies regulating DST and time-zone boundaries can affect sleep and have unintended consequences on health and productivity. Our results suggest that delaying morning work schedules and school start times may substantially improve average sleep duration. While we are unable to compare the economic gains that may result from coordination with its costs in terms of health and human capital, our results highlight that the latter are not negligible. As long work hours, work schedules, school start times and the timing of TV shows can create conflicts between our biological rhythms and social timing, our findings suggest that reshaping social schedules in ways that promote sleeping may have non-trivial effects on health. In particular, we find that delaying work start times until after 8:30 am would substantially increase average sleep duration.

Finally, considerable attention has been devoted in recent years to the obesity epidemic (Cawley, 2015), particularly in the United States, with the implementation of several state and federal programs intended to reduce obesity. Most of these programs promote healthy nutrition and physical activity. Our results suggest the importance of increasing the spectrum of these public health interventions by including policies intended to increase average sleep duration and a healthier use of our time. Sleep education programs should become a central part of any program seeking to reduce obesity and weight gain among at-risk populations.

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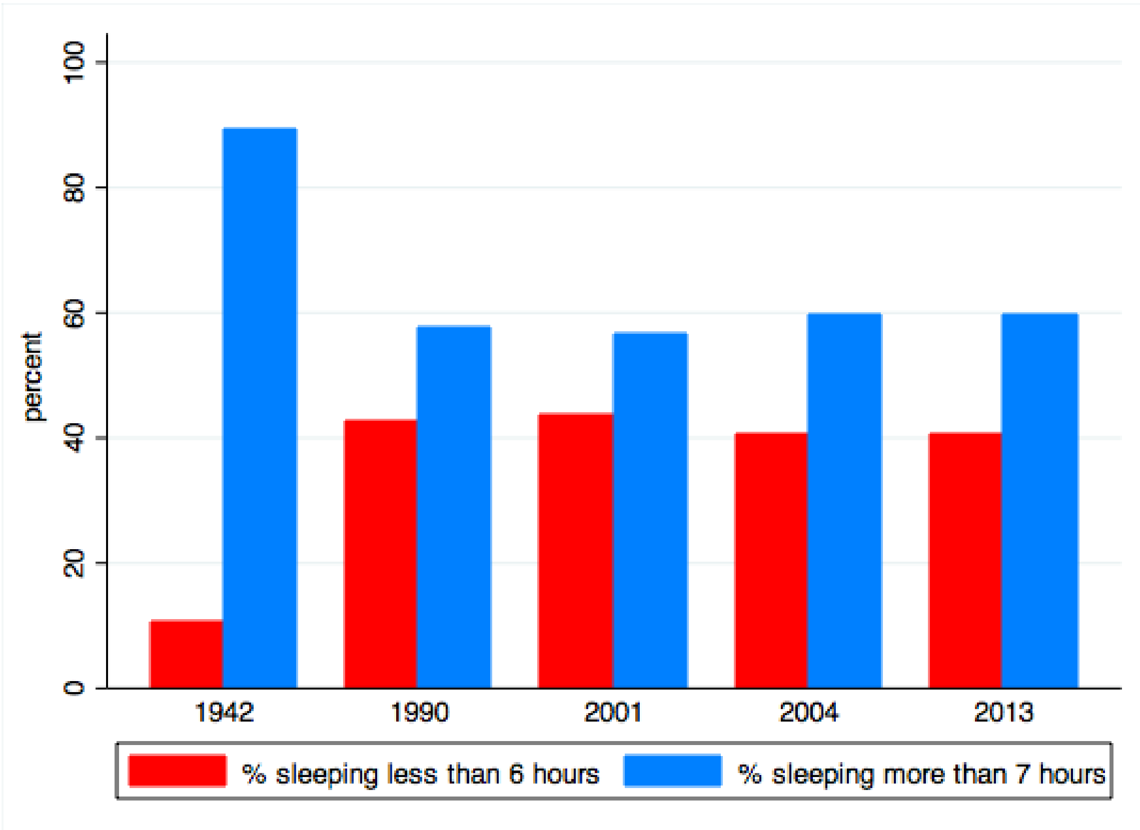
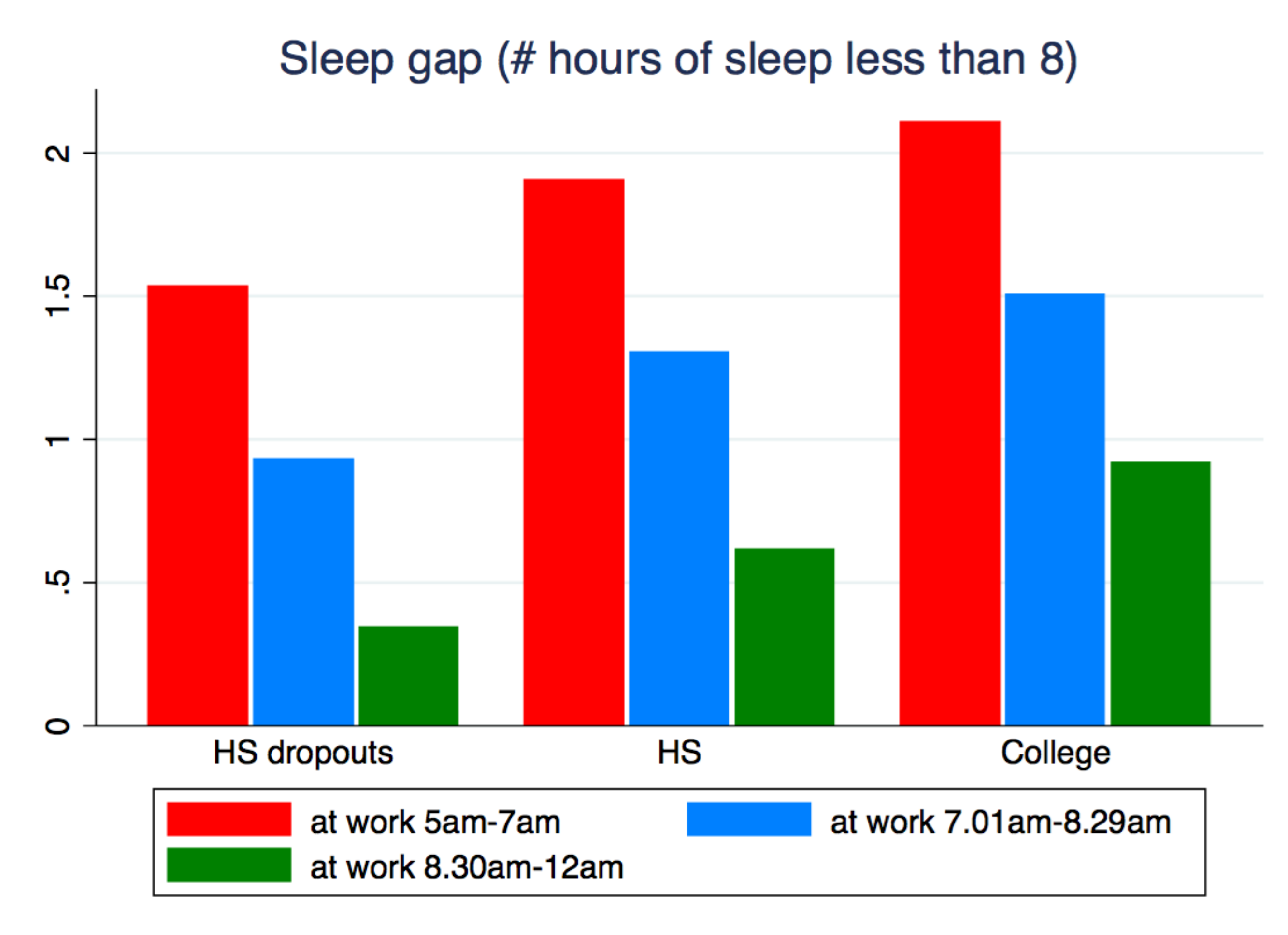
Figure 1: US Sleeping over Time



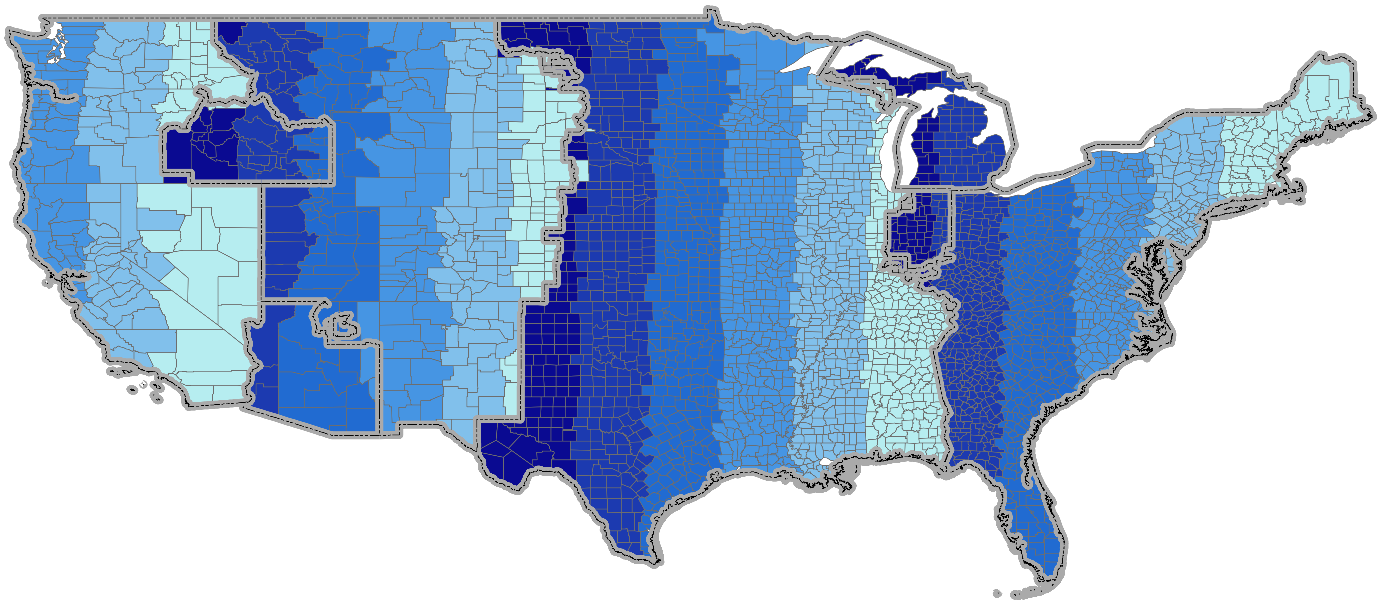
Notes - Source: Gallup, 1942-2013.

Figure 2: Sleep Deprivation by Education and Morning Work Schedule



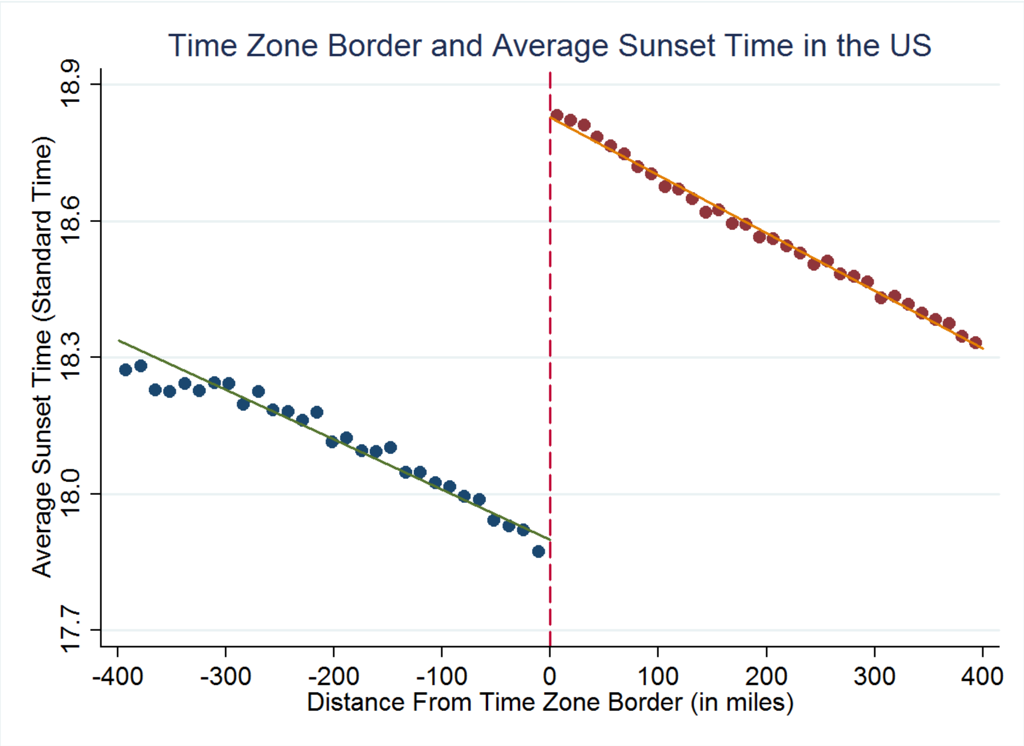
Notes - Data are drawn from the ATUS (2003-2013). The figure is based on the estimates of the determinant of sleep duration reported in Table A.5. To better visualize the estimated differences in sleep duration, we report the difference between the recommended 8 hours of sleep and the estimated sleep duration by education and working schedule for the average white man, aged between 40 and 50 years old, living on the East Coast.

Figure 3: Time Zones and Average Sunset Time



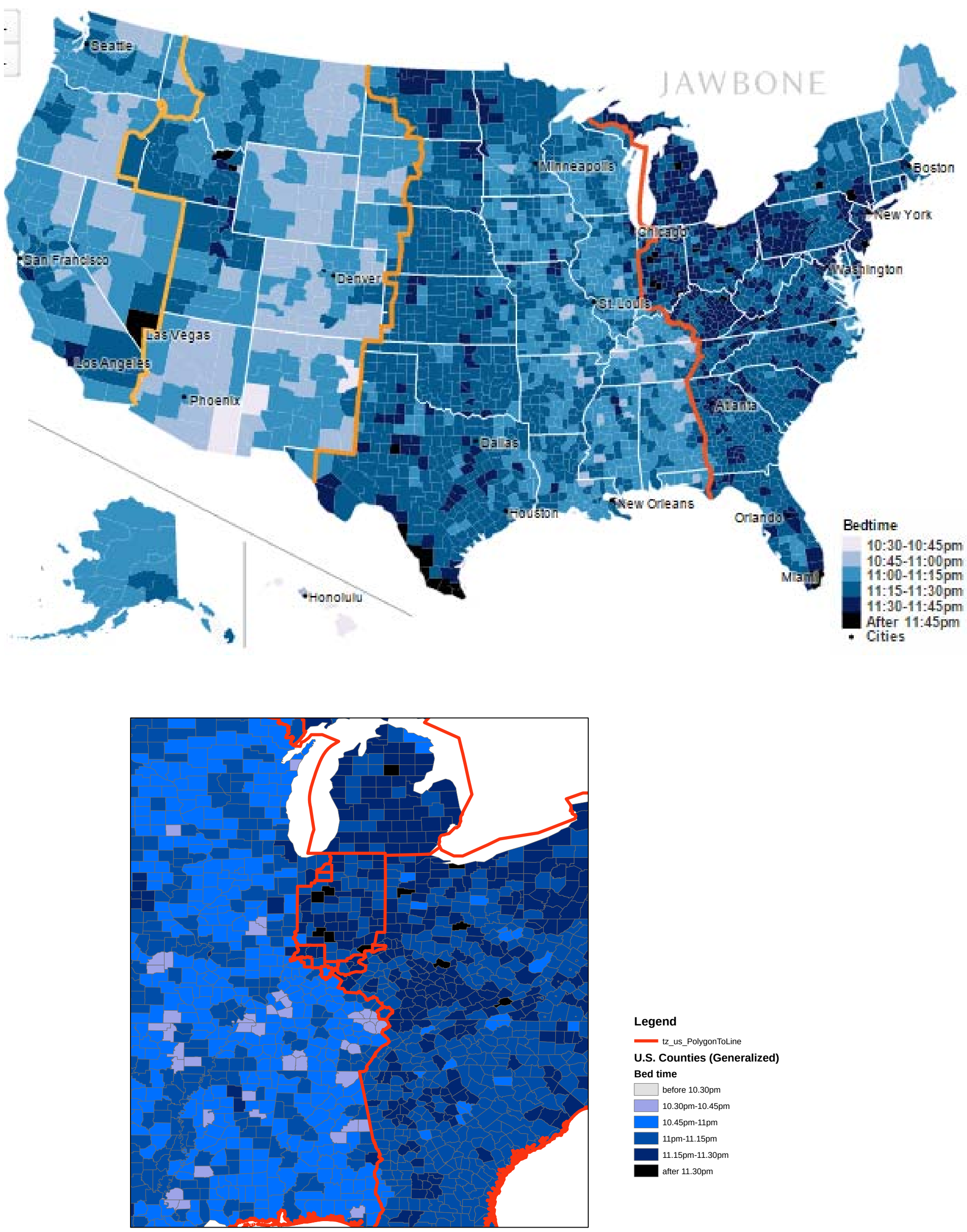
Notes - Average sunset time over a year was computed using the NOAA Sunrise/Sunset and Solar Position Calculators and information on the latitude and longitude of US counties' centroids. Counties were divided into 5 quintiles based on the average sunset time in a given year. The darker the circles, the later the average sunset time.

Figure 4: Discontinuity in Sunset Time



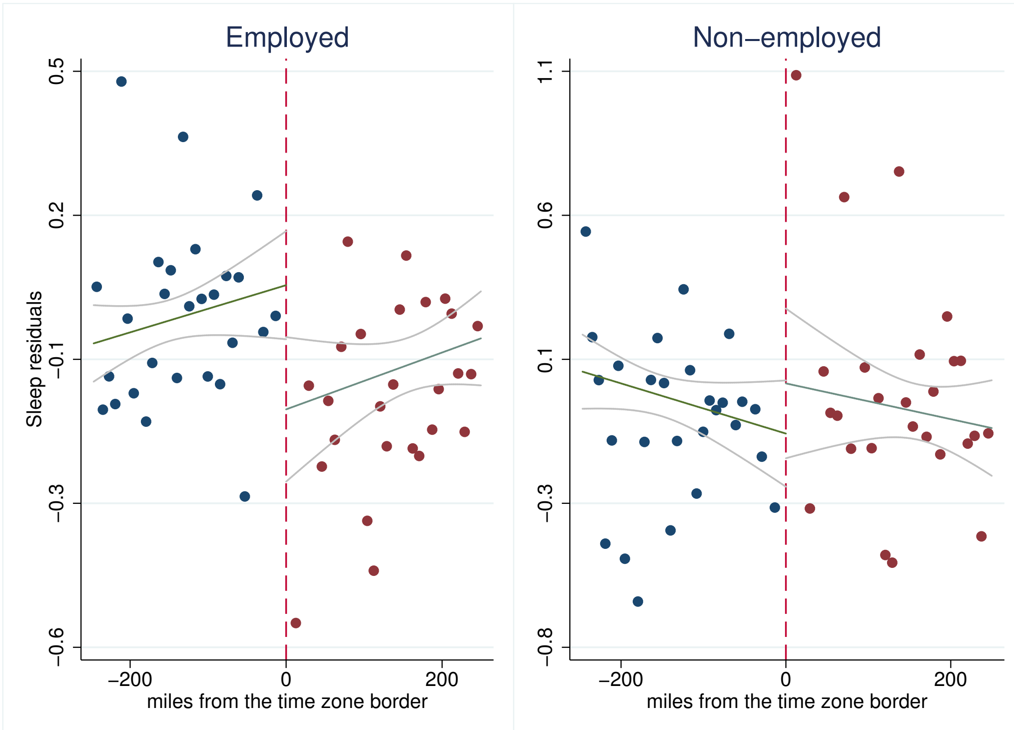
Notes - Average sunset time over a year was computed using the NOAA Sunrise/Sunset and Solar Position Calculators and information on the latitude and longitude of US counties' centroids. In this Figure, we show the discontinuity in sunset time according to the distance to the time zone border. The number of bins is automatically computed by the cmogram command of Stata 14 and corresponds to $\#bins = min\{sqrt(N), 10 * ln(N)/ln(10)\}$, where N is the (weighted) number of observations.

Figure 5: Time Zones and Bedtime (Source: jawbone.com/blog)



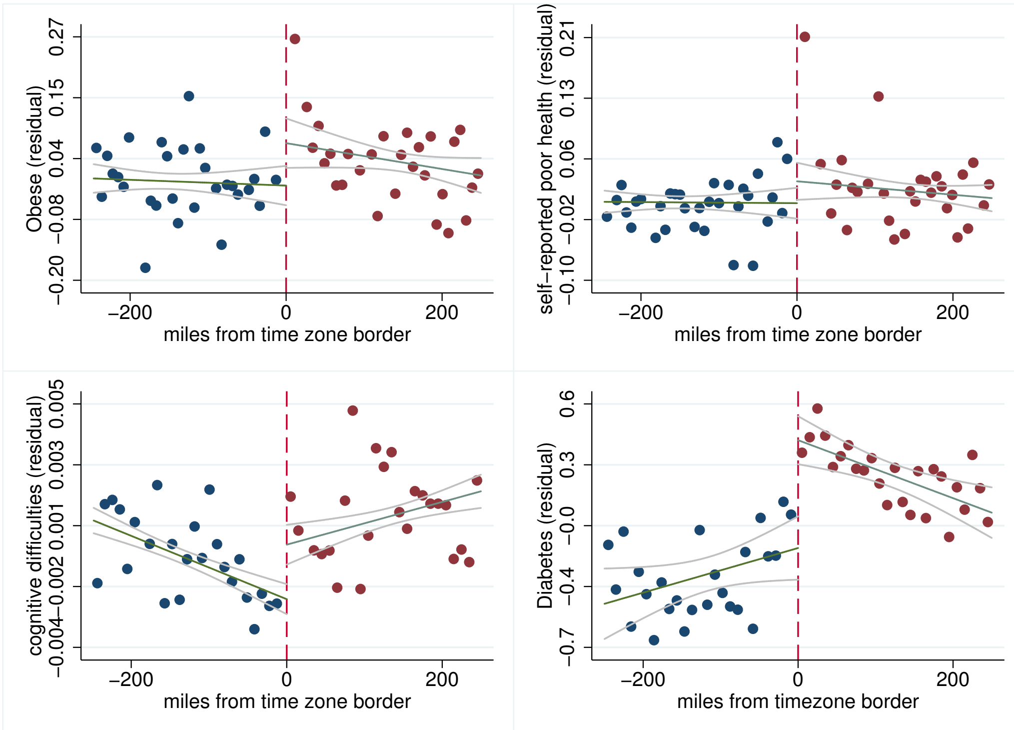
Notes - Data were drawn from the Jawbone website (last access: 22 July 2016). The bottom figure provides a zoom at the border between the Eastern and the Central time zones.

Figure 6: Discontinuity in Sleep Duration



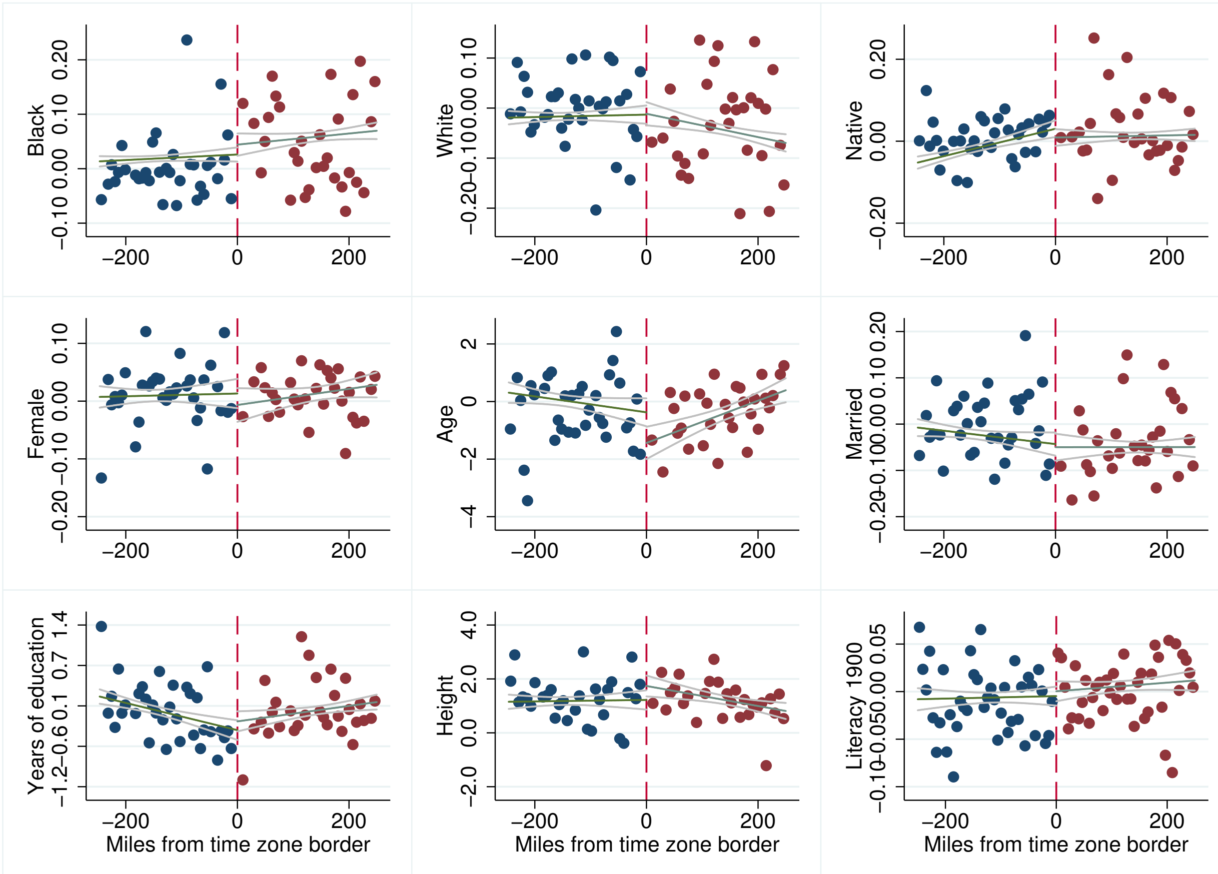
Notes - Data are drawn from the ATUS (2003-2013). Each point represents the mean residuals obtained from a regression of sleep duration on our set of geographic controls (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties). The number of bins is automatically computed by the cmogram command of Stata 14 and corresponds to $\#bins = min\{sqrt(N), 10 * ln(N)/ln(10)\}$, where N is the (weighted) number of observations.

Figure 7: Discontinuity in Other Health Outcomes



Notes - Data are drawn from the ATUS (2003-2013). Each point represents the mean residuals obtained from a regression of each outcome on our set of geographic controls (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties). The number of bins is automatically computed by the cmogram command of Stata 14 and corresponds to $\#bins = min\{sqrt(N), 10 * ln(N)/ln(10)\}$, where N is the (weighted) number of observations.

Figure 8: Discontinuity in Main Covariates



Notes - Data are drawn from the ATUS (2003-2013). Each point represents the mean residuals obtained from a regression of each outcome on our set of geographic controls (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties). The number of bins is automatically computed by the cmogram command of Stata 14 and corresponds to $\#bins = min\{sqrt(N), 10 * ln(N)/ln(10)\}$, where N is the (weighted) number of observations.

Table 1: Effect of Late Sunset Time on Sleeping (Only Employed)

	(1)	(2)	(3)	(4)	(5)
Dep.Var.:	Sleep Hours	Sleep Hours	Sleep Hours	Sleep Hours	Sleep$\geq$ 8 hours
Late Sunset Border	-.315***	-.307***	-.380**	-.419**	-.078***
	(.080)	(.107)	(.159)	(.175)	(.021)
Observations	16,557	16,557	3,918	3,918	16,557
Adj. R^2	.132	.133	.130	.129	.090
$F*_{(1,63)}$	15.73	8.25	5.74	5.75	13.47
Mean of Dep.Var.	8.283	8.283	8.248	8.248	0.899
Std.Dev. of Dep.Var.	1.965	1.965	1.999	1.999	0.300
State FE	NO	YES	NO	YES	NO
Bandwidth (miles)	250	250	100	100	250

Notes - Data are drawn from ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at geographical level (counties are grouped based on the distance from the time zone border).

*F-test on the significance of Late Sunset Border.

Table 2: Effect of Late Sunset Time on Sleeping (Employed vs. non-Employed)

	(1)	(2)	(3)	(4)	(5)	(6)
Variable:	Sleep Hours		Awake at midnight		Awake at 7.30 am	
Employed:	Yes	No	Yes	No	Yes	No
Late Sunset Border	-.315***	.115	.135***	.115*	-.022	-.138***
	(.080)	(.310)	(.030)	(.063)	(.033)	(.047)
Observations	16,557	2,082	16,557	2,082	16,557	2,082
Adj. R^2	0.132	0.040	0.047	0.082	0.193	0.128
State FE	NO	NO	NO	NO	NO	NO
Bandwidth (miles)	250	250	250	250	250	250

Notes - Data are drawn from ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at geographical level (counties are grouped based on the distance from the time zone border).

Table 3: Effect of Late Sunset Time on Sleeping by Work Start Time

	(1)	(2)	(3)	(4)
Work start :	5am-7am	7.01am-8.29am	8.30am-12am	8.30am-12am
Late Sunset Border	-0.587***	-0.304**	-0.031	-0.023
	(0.118)	(0.138)	(0.199)	(0.198)
Late Sunset Border* Leaving children at school before 8am				-0.450*
				(0.260)
Leaving children at school before 8 am				-0.356*
				(0.195)
N	2,207	3,046	2,240	2,240
Adj. R^2	0.071	0.073	0.078	0.083
Mean of Dep.Var.	7.148	7.698	8.230	8.230
Std. Dev. of Dep. Var.	1.324	1.378	1.565	1.565
Bandwidth (miles)	250	250	250	250

Notes - Data are drawn from ATUS (2003-2013) and restricted to people that worked at least one hours in the previous day. All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Column (4) interacts the late sunset border dummy with a dummy for people that leave their children at school before 8 am. Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at geographical level (counties are grouped based on the distance from the time zone border).

Table 4: Effect of Sunset Time on Overweight, Obesity and Poor Health (Only Employed)

	(1)	(2)	(3)
Dep.Var.:	Overweight	Obese	Poor health
Late Sunset Border	0.069**	0.056**	0.020
	(0.033)	(0.028)	(0.016)
Observations	4,331	4,331	9,696
Mean of Dep.Var.	0.627	0.263	0.091
Std. Dev. of Dep. Var.	0.483	0.440	0.287
Bandwidth (miles)	250	250	250

Notes - All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border). *F-test on the excluded instrument.

Table 5: Cognitive Impairment and Diabetes

	(1)	(2)	(3)	(4)	(5)	(6)
	Cognitive difficulties			Diabetes prevalence		
Sample:	Census 2000			CDC 2004–2010		
Late Sunset Border	0.002**	0.004**	0.005**	0.490***	0.179***	0.195*
	(0.001)	(0.001)	(0.002)	(0.095)	(0.063)	(0.104)
Observations	1,634,296	1,634,296	509,056	1,867	1,867	806
Mean of Dep. Var.	0.0190	0.0190	0.0179	8.255	8.255	8.388
Std. Dev. of Dep. Var.	0.136	0.136	0.132	1.801	1.801	1.754
Bandwidth	250	250	100	250	250	100
State FE	NO	YES	NO	NO	YES	NO

Notes - Data are drawn from the 2000 US CENSUS (column 1–3) and CDC 2004–2010 (column 4–6). All estimates include the distance to the time zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicator for nativity status and year of immigration, and number of children), county characteristics (region,9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties), interview characteristics (interview month and year and a dummy that controls for the application of DST). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

Table 6: Other Activities

Dependent variable:	(1) Time outside All day in minutes	(2) Time outside 4pm-12am in minutes	(3) Social Time All day in minutes	(4) Social Time 4pm-12am in minutes	(5) Time working All day in minutes	(6) Time working 4pm-12am in minutes
Late Sunset side	11.259	9.976**	-4.870	1.006	0.349	6.102
	(9.196)	(4.158)	(9.084)	(5.228)	(10.600)	(3.800)
Observations	16,557	16,557	16,557	16,557	9,591	9,591
Mean of Dep. Var.	172.3	66.23	227.2	138.6	456.4	25.33
Std. Dev. of Dep. Var.	188.4	95.35	172.9	98.66	175.6	68.04

Notes - Data are drawn from ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). The dependent variables are: column 1, the minutes spent outside during the previous 24 hours; column 2, the minutes spent outside between 4pm and midnight; column 3, the minutes spent in social activities during the previous 24 hours; column 4, the minutes spent in social activities between 4pm and midnight; column 5, the minutes spent working during the previous 24 hours; column 6, the minutes spent working between 4pm and midnight.In columns 5 and 6, we restricted the sample to individuals working at least 1 hour during the day of the interview. Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at geographical level (counties are grouped based on the distance from the time zone border).

Table 7: Time Zone Boundary and Eating Habits

Dependent Variable:	(1) Eating	(2) Late dinner	(3) Late Dinner	(4) Eating-Out	(5) Dining-Out
Late Sunset Border	-3.557	0.066***	0.066***	0.029	0.090***
	(3.940)	(0.015)	(0.015)	(0.020)	(0.017)
Controlling for the number of meal before	NO	NO	YES	NO	NO
Observations	16,557	16,557	16,557	16,557	16,557
Mean of Dep. Var.	74.34	0.163	0.163	0.232	0.312
Std. Dev. of Dep. Var.	72.94	0.470	0.370	0.422	0.463

Notes - Data are drawn from ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). The dependent variables are: column 1, the minutes spent eating during the previous 24 hours; column 2 and 3, the an indicator for whether an individual consumed a main meal (dinner) after 7 pm; column 4, an indicator for whether an individual consumed a meal out (including lunch); column 5, an indicator for whether an individual consumed a meal out after 5 pm (dinner time). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at geographical level (counties are grouped based on the distance from the time zone border).

Table 8: Time Zone Border and Physical Activity, ATUS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent Variable	Any Sport, Walking, Biking etc.			Any Walking			Time at the Gym (minutes)		
	All day	Morning (5am-9am)	Evening (4pm-10pm)	All day	Morning (5am-9am)	Evening (4pm-10pm)	All day	Morning (5am-9am)	Evening (4pm-10pm)
Laste Sunset Border	0.014	0.001	0.014*	0.008	0.001	0.007*	2.048	-0.035	0.510
	(0.019)	(0.012)	(0.008)	(0.010)	(0.004)	(0.004)	(1.591)	(0.446)	(0.620)
Observations	16,557	16,557	16,557	16,557	16,557	16,557	16,557	16,557	16,557
Mean of Dep. Var.	0.121	0.0373	0.0475	0.0350	0.00900	0.0144	6.585	1.052	1.824
Std. Dev. of Dep. Var.	0.326	0.190	0.213	0.184	0.0944	0.119	32.31	8.971	13.05

Notes - Data are drawn from the ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, a linear control for latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). The dependent variables are: an indicator for whether individuals engaged in any physical activity (sport, walking, biking) throughout the day (column 1), the morning (column 2), and the evening (column 3); in any waling throughout the day (column 4), the morning (column 5), and the evening (column 6);the minutes spent exercising at the gym throughout the day (column 7), the morning (column 8), and the evening (column 9). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

A Appendix - For Online Pubblication

A.1 Robustness Checks

In this section, we present additional tests that we implement to verify the validity of our identification strategy and the robustness of our results. As discussed in Section 3.2, a natural concern is that residential sorting across the time zone border will create correlation between unobservable individual characteristics and individual residence. We conduct a variety of tests for residential sorting and find no evidence for it.

We already show in Figure 8 that there is no evidence of discontinuity in employment, in a large set of covariates and in predetermined characteristics (i.e. height and literacy rate in 1900). Moreover, in Table A.9 we test for the presence of discontinuities in home and rent prices, population density and commuting time. We find no evidence of residential sorting on these important local characteristics that should be affected if people systematically preferred to locate on a given side of the time zone border.

While we cannot identify counties or metropolitan areas with fewer than 100,000 residents, in Table A.10 we illustrate the heterogeneity in the first-stage estimates by the size of the metropolitan area of residence. The results suggest that the effect is larger in more populated metropolitan areas, likely reflecting differences in the occupational and demographic characteristics of individuals living in smaller cities but also the longer commuting that many people may face in the morning in large metropolitan areas.

Table A.2 re-estimates the first-stage discussed in Table 1 using alternative metrics for sleep duration. Column 1 replicates the result presented in column 1 of Table 1 that excluded naps from the count, defined as any sleep duration occurring between 7am and 7pm and lasting less than 2 hours. In column 2, we show that the coefficient is substantially unchanged if we include naps. We then focus on non-linear metrics of sleep duration that have been used in medical studies (Ohayon et al., 2013; Markwald et al., 2013). In particular, we examine the likelihood of sleeping less than 6 hours (insufficient sleep, column 3), at least 8 hours (sufficient sleep, column 4), and at least 8 hours but no more than 9 (sufficient but not excessive sleep, column 5). Individuals on the late sunset side of the time zone border are 4 percentage points more likely to report less than 6 hours sleep (column 3), 8 percentage points less likely to report at least 8 hours' sleep (column 4), and 3 percentage points less likely to report sufficient but not excessive sleep (column 5). However, we find no differences in naps measured as the total amount of time slept between 11am and 8pm (see column 6).

In Table A.6, we investigate the heterogeneity of the reduced form effects by morning work schedules. Point estimates for overweight and obesity are proportional to the first stage results. In particular, as for the first-stage estimates analyzed in Table 4, point estimates are (at least) twice the average effect in column (1), very similar to the average effect in column 2 and closer to zero (or even negative) in column (3). Unfortunately, standard errors are very large because the sample size for this analysis is very small. Despite this, the point estimates for early schedule workers are still statistically different from zero. It is worth noting these results could also be explained by the presence of non-linearity because those with very early schedule sleep much less on average. Unfortunately, with such data we cannot disentangle the presence of non-linearity from a "compliance" explanation—where the estimated effect is driven by those that are constrained and then more likely to be exposed to the negative effects of a late sunset.

Furthermore, we verify the robustness of our results by excluding one US state at a time from our estimates. This exercise is meant to determine whether our results are driven by the presence of one particular state. The results, available upon request, confirm the robustness of our findings.

We also investigate the presence of seasonal and geographical heterogeneity in the discontinuity at the time zone borders and whether this heterogeneity is related to the daylight duration. For instance, in the North daylight duration varies far more across seasons than in the South. However, Table A.11 shows that differences across seasons (DST vs. solar time) and latitudes (North, Center and South) are never statically significant. More generally ATUS data show that individuals tend to go to bed later in the summer on both sides of the time zone border, but if anything the difference between the late and early sunset sides of the borders is smaller during the summer time.

As already mentioned, measurement error in self-reported weight and height in survey might be an important concern because of systematic misreporting that varies across several socio-demographic characteristics (e.g., race and sex). However, if the continuity assumption behind our RDD is valid we should not observe a systematic change in misreporting across time zone border and then our results should not be affected by misreporting. To verify this, we correct for misreporting using the new correction method proposed by Courtemanche et al. (2015) that uses the National Health and Nutrition Examination Surveys (NHANES) as validation sample and quite weak assumptions about the relationship between measured and reported values in the primary and validation datasets. As expected, the point estimates using the corrected BMI are very similar to those reported in the main text (coef., 0.062, std.err., 0.032 for overweight status; and coef., 0.063, std.err., 0.030 for obesity status).

Finally, we tested for the optimal polynomial order by comparing our local linear regression approach with higher polynomial orders, up to the fourth, on the full (feasible) bandwidth (280 miles). Table A.12 shows that the point estimates are relatively stable up to the third order polynomial (around 0.3 of an hour, namely 18 minutes), while they become unreasonably large using the forth order polynomial (50 minutes). As shown in Figures 4 and 6 the linear approximation for the distance from the time zone seems to fit the data very well. Moreover, Figure 6 does not show evidence of a discontinuity of more than 20 minutes. This suggest a overfitting problem when using higher order polynomial. The Bayesian information criterion (BIC) is minimized using the forth order polynomial but the local linear regression is clearly preferred over the quadratic and the cubic polynomials.

Figure A.1: Sleep Duration over the Week

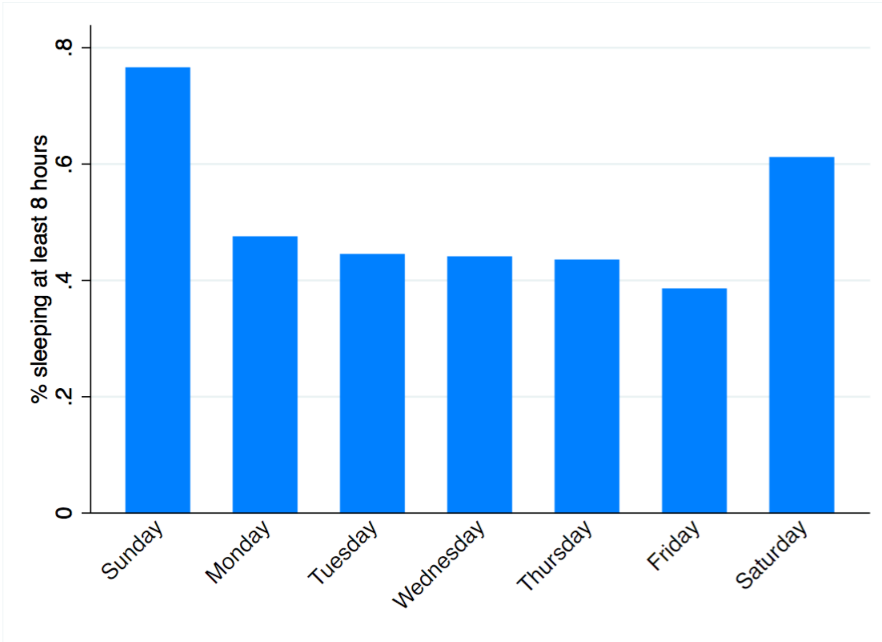
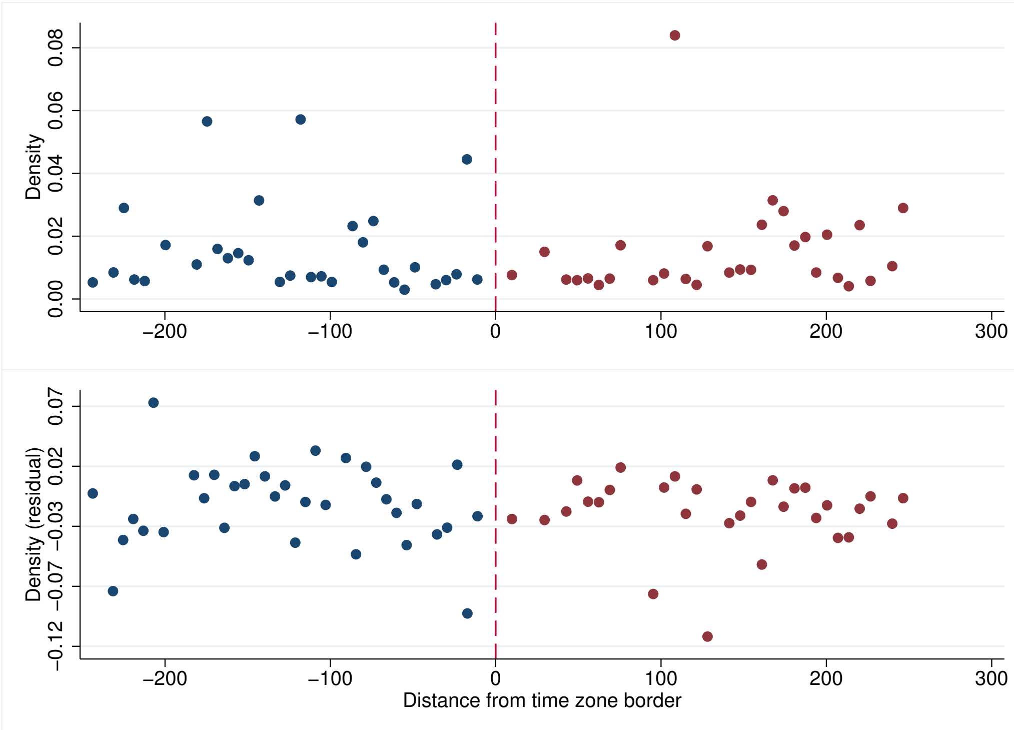
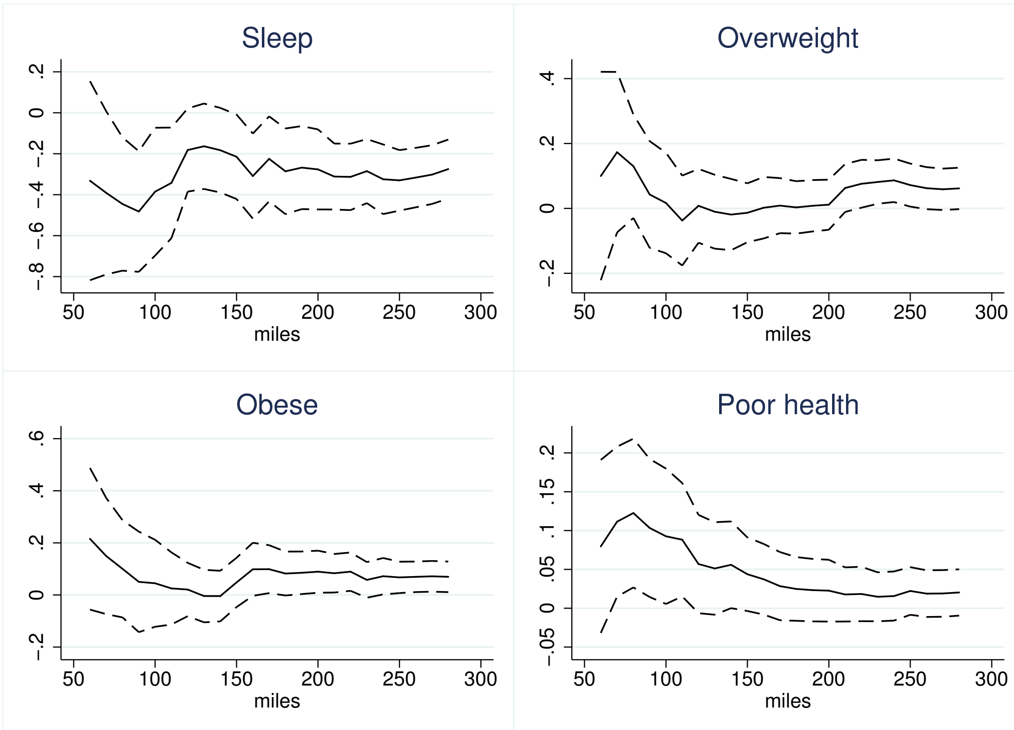


Figure A.2: Density of the Running Variable



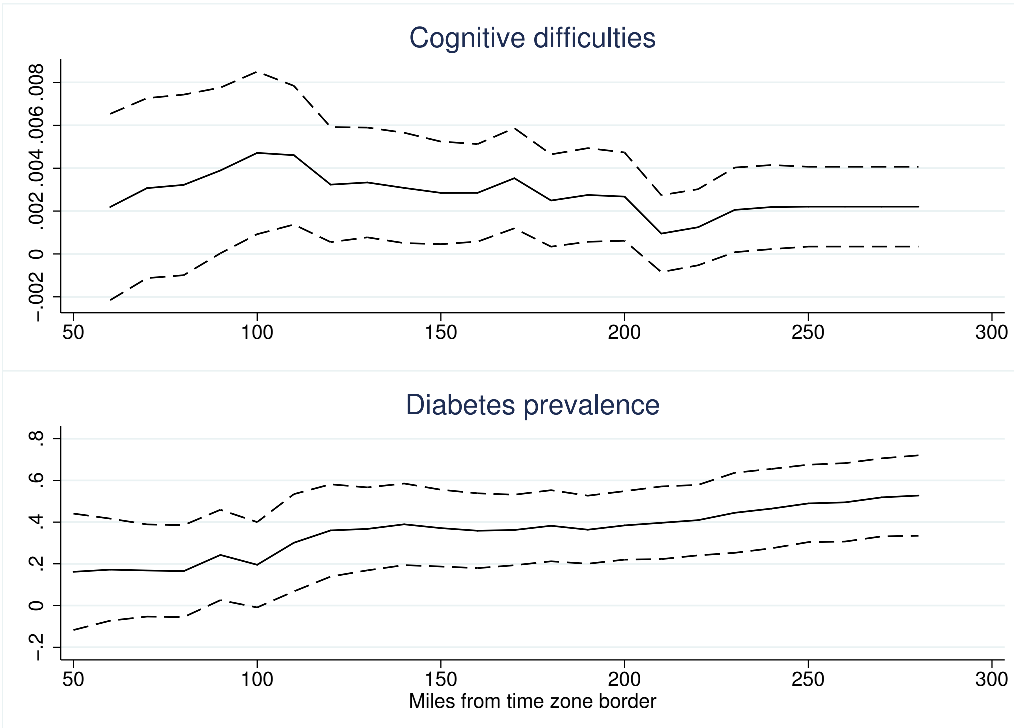
Notes - The top figure show the unconditional density of the forcing variable, while the bottom figure the density conditional on our baseline geographical controls (9 geographical areas (grid) plus latitude).

Figure A.3: Effect of Late Sunset Time on Sleep, Overweight and poor Health by Bandwidth (ATUS)



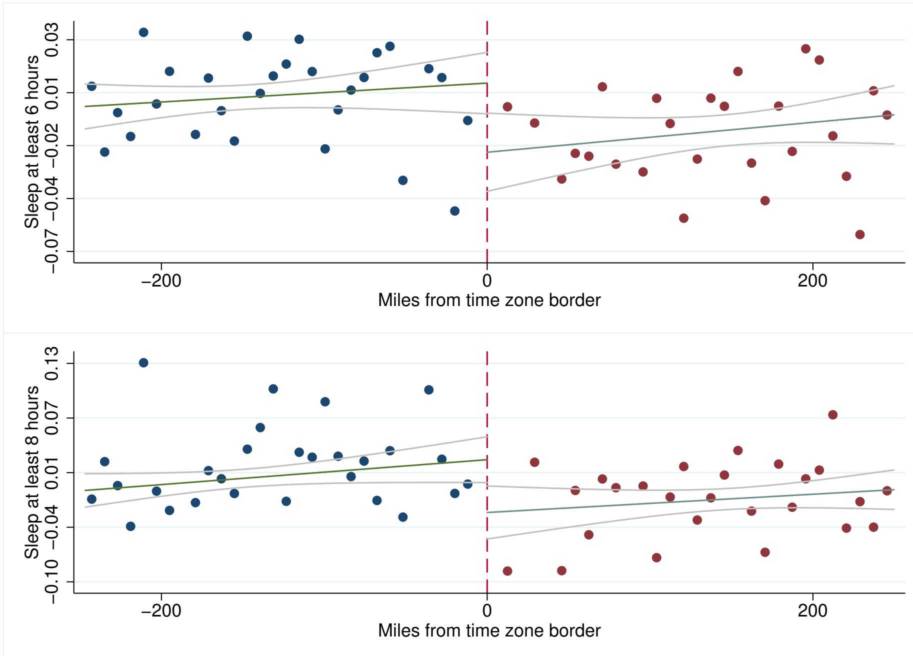
Notes - The figure illustrates the sensitivity of our results to the bandwidth choice. The solid line represents the point estimate for a given bandwidth while the two dashed lines the 95% confidence interval. The specification includes the same set of controls as in Table 1. Data are drawn from ATUS (2003-2013).

Figure A.4: Effect of Late Sunset Time on Cognitive Difficulties and Diabetes Prevalence by Bandwidth (Census and CDC)



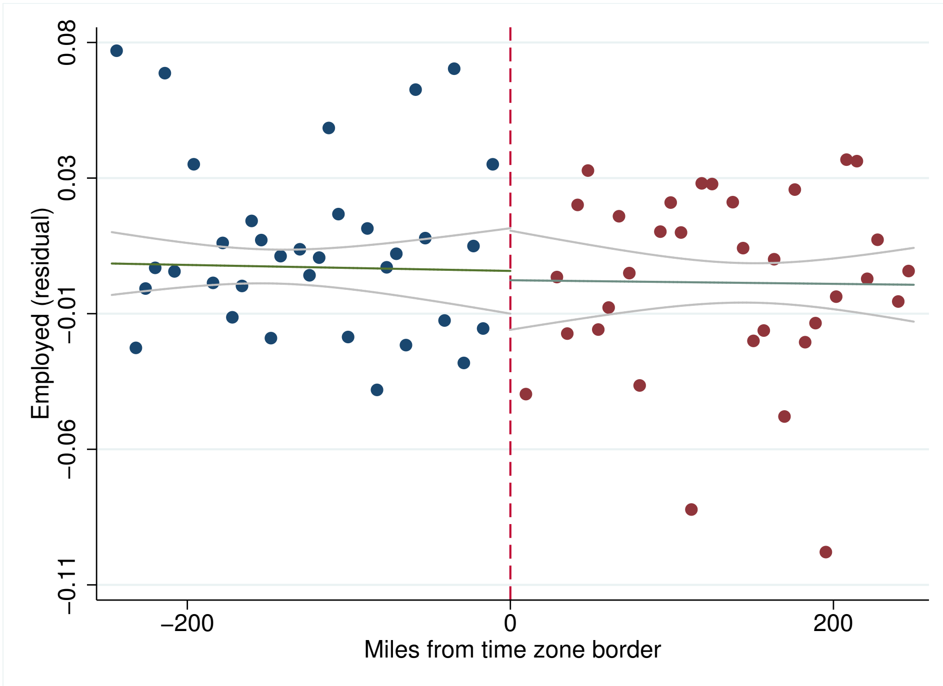
Notes - The figure illustrates the sensitivity of our results to the bandwidth choice. The solid line represents the point estimate for a given bandwidth while the two dashed lines the 95% confidence interval. The specification includes the same set of controls as in Table 1. Data are drawn from 2000 Census for cognitive difficulties and CDC (2004–2010) for diabetes prevalence.

Figure A.5: Discontinuity in Other Sleep Metrics



Notes - Data are drawn from the ATUS (2003-2013). Each point represents the mean residuals obtained from a regression of each outcome on our set of geographic controls (see Section 3).

Figure A.6: Discontinuity in Employment Status



Notes - Data are drawn from the ATUS (2003-2013). Each point represents the mean residuals obtained from a regression of an indicator for employment status on our set of geographic controls (see Section 3).

Table A.1: Descriptive Statistics (ATUS), by employment status

	Employed			Not-Employed		
Variable	Mean	S.D.	*N*	Mean	S.D.	*N*
Sleep hours	8.284	1.965	16,557	8.905	2.024	2,082
Sleep at least 6 hours	0.900	0.301	16,557	0.932	0.251	2,082
Sleep at least 8 hours	0.570	0.495	16,557	0.693	0.461	2,082
Awake at 7 am	0.578	0.494	16,557	0.375	0.484	2,082
Awake at 11pm	0.542	0.498	10,509	0.594	0.491	1,368
Overweight	0.619	0.486	4,331	0.595	0.491	479
Obese	0.258	0.437	4,331	0.273	0.446	479
Self-reported poor health	0.094	0.292	9696	0.146	0.353	1,119
Female	0.506	0.500	16,557	0.580	0.494	2,082
Age	38.543	9.605	16,557	36.381	10.821	2,082
White	0.826	0.379	16,557	0.754	0.431	2,082
Black	0.104	0.306	16,557	0.178	0.383	2,082
High School	0.523	0.500	16,557	0.559	0.497	2,082
College	0.390	0.488	16,557	0.269	0.444	2,082
Number of kids	1.114	1.161	16,557	1.195	1.242	2,082
Married	0.559	0.497	16,557	0.458	0.498	2,082
Interview characteristics:						
Holiday	0.016	0.127	16,557	0.024	0.153	2,082
Weekend	0.502	0.500	16,557	0.526	0.499	2,082
DST	0.560	0.496	16,557	0.562	0.496	2,082

Notes - Data are drawn from the ATUS (2003-2013). The sample is restricted to people in the labor force (employed and not-employed) aged 18-55.

Table A.2: Effect of Late Sunset Time on Sleeping (Only Employed)

Dep.Var.:	(1) Sleep Hours (naps excluded)	(2) Sleep Hours (naps included)	(3) Sleep $\leq 6h$ (naps excluded)	(4) Sleep $\geq 8h$ (naps excluded)	(5) Sleep $\in [8h, 9h])$ (naps excluded)	(6) Naps
Late Sunset Border	-0.318***	-0.298***	0.041***	-0.082***	-0.032*	0.021
	(0.079)	(0.101)	(0.012)	(0.021)	(0.017)	(0.047)
Observations	16,557	16,675	16,557	16,557	16,557	16,675
Mean of Dep. Var.	8.284	8.553	0.112	0.570	0.232	0.326
Std. Dev.	1.965	2.127	0.315	0.495	0.422	1.012

Notes - Data are drawn from the ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

Table A.3: Effect of Late Sunset Time on Sleeping by Household Composition

	(1)	(2)	(3)	(4)
Sample:	All		Employed	
Child (age $\leq$ 13) in HH:	YES	NO	YES	NO
Late Sunset Border	-0.247**	-0.157	-0.436***	-0.263**
	(.098)	(.110)	(.106)	(.114)
Observations	10,393	11,923	7,511	9,046
Adj. R^2	.128	.108	.139	.131
Mean of Dep.Var.	8.237	8.248	8.030	8.040
Std. Dev.	1.903	2.0905	1.870	2.040
Bandwidth (miles)	250	250	250	250

Notes - Data are drawn from the ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

Table A.4: Effect of Late Sunset Time on Sleeping by Sector

Sample	(1) Overall Sleep hours	(2) Retail & Wholesale Sleep hours	(3) Education, Health Public administration Sleep hours	(4) Financial services Sleep hours
Late Sunset Border	-0.329***	0.003	-0.661***	-0.717***
	(0.077)	(0.215)	(0.194)	(0.235)
Observations	17,917	2,357	3,259	1,449
Adj. R^2	0.133	0.169	0.125	0.237
Mean of Dep. Var.	8.497	8.497	8.497	8.497
Std. Dev.	1.970	1.970	1.970	1.970

Notes - Data are drawn from the ATUS (2003-2013). All estimates include the distance to the time zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, married and number of children), county characteristics (region, latitude and longitude and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control for whether the interview was conducted during a public holiday or over the weekend). Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

Table A.5: Determinants of Sleep Duration

	(1)	(2)	(3)
Sample:	All	Working on interview day	Not working on interview day
weekend	1.120***	0.160***	0.484***
	(0.016)	(0.029)	(0.023)
female	0.213***	0.017	0.027
	(0.016)	(0.020)	(0.021)
age 25–30	-0.041	0.016	0.059
	(0.034)	(0.044)	(0.039)
age 30–39	-0.236***	-0.031	-0.160***
	(0.031)	(0.041)	(0.035)
age 40–49	-0.394***	-0.108**	-0.345***
	(0.033)	(0.043)	(0.036)
age 50–55	-0.521***	-0.116**	-0.554***
	(0.035)	(0.046)	(0.039)
black	-0.194***	-0.207***	0.039
	(0.039)	(0.049)	(0.045)
high-school dropout	0.374***	0.361***	0.302***
	(0.037)	(0.043)	(0.038)
some college	-0.105***	-0.167***	-0.203***
	(0.023)	(.028)	(.028)
college degree or more	-0.126***	-0.200***	-0.424***
	(0.021)	(0.026)	(0.026)
start work before 7am		-.622***	
		(0.023)	
start work after 8.30am		0.576***	
		(0.025)	
leave children at school		-0.219***	-0.794***
before 8am		(0.029)	(0.051)
Constant	7.168***	6.808***	8.333***
	(0.150)	(0.176)	(0.183)
Observations	76,785	32,277	53,490
Adj. R^2	0.105	0.111	0.047
Mean of Dep.Var.	8.00	7.65	9.01
Std. Dev.	1.77	1.52	1.95

Notes - Data are drawn from ATUS (2003-2013). The OLS estimates indicate the marginal difference with respect to a white male individual interviewed on a weekday with a high-school degree, starting work between 7am and 8.30am and not having to leave children at school before 8am. Column 1 focuses on our preferred sample of employed individuals aged between 18 and 55. Column 2 restricts the analysis to individuals who reported to work on the day of the interview. Column 3 restricts the sample to individuals who did not work on the day of the interview (including non-employed). Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. Robust standard errors are reported in parentheses.

Table A.6: Reduced Form Effects by Schedule

	(1)	(2)	(3)
Work start :	5-7am	7.01-8.29am	8.30am-12pm
		Overweight	
Late Sunset Border	0.214***	0.066	-0.189
	(0.065)	(0.089)	(0.144)
Observations	725	740	571
Mean of Dep.Var.	0.701	0.581	0.576
Std.Dev.	0.457	0.489	0.495
		Obese	
Late Sunset Border	0.172**	0.081	-0.054
	(.089)	(.099)	(.130)
Observations	725	740	571
Mean of Dep.Var.	0.279	0.231	0.251
Std.Dev.	0.457	0.422	0.434
		Poor health	
Late Sunset Border	0.032	0.015	0.015
	(0.031)	(0.037)	(0.044)
Observations	1,590	1,678	1,202
Mean of Dep.Var.	0.085	0.085	0.089
Std.Dev.	0.302	0.278	0.283
Bandwidth (miles)	250	250	250

Notes - The sample is restricted to individuals who reported having worked on the day of the ATUS interview. All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border). *F-test on the excluded instrument.

Table A.7: Heterogeneity by Age Group (Only Employed)

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Var.:	Overweight		Obese		Poor health	
	age $<$ 40	age $\geq$ 40	age $<$ 40	age $\geq$ 40	age$<$40	age $\geq$ 40
Late Sunset Border	0.047	0.091*	0.010	0.120**	0.029	0.033*
	(0.055)	(0.047)	(0.043)	(0.055)	(0.019)	(0.019)
N						
Observations	2,216	1,906	2,216	1,906	4,939	4,238
Mean of Dep.Var.	0.588	0.674	0.255	0.268	0.082	0.0100
Std.Dev.	0.469	0.437	0.436	0.443	0.275	0.300
Bandwidth (miles)	250	250	250	250	250	250

Notes - All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

Table A.8: Effect of Sleeping on Overweight, Obesity and Poor Health (Only Employed)

	(1)	(2)	(3)	(4)
	2SLS	2SLS	2SLS	TS2SLS
Dep.Var.:	Overweight	Obese	Poor health	Cognitive Impairment
Sleep Hours	-0.143*	-0.139**	-0.085***	-0.014***
	(0.088)	(0.061)	(0.033)	(0.003)
Observations	4,122	4,122	9,177	1,447,115
$F^*_{(1,61)}$	11.72	11.72	17.96	
Mean of Dep.Var.	0.627	0.263	0.091	0.0163
Std. Dev.	0.483	0.440	0.287	0.127
Bandwidth (miles)	250	250	250	250

Notes - All estimates include the distance to the time zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, married and number of children), county characteristics (region, latitude and longitude and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control for whether the interview was conducted during a public holiday or over the weekend). We exclude from the estimates recent cohorts of immigrants (post 2005). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border). *F-test on the excluded instrument.

Table A.9: Residential Sorting Tests

	(1) log(House value)	(2) log(monthly rent)	(3) commuting time (minutes)	(4) pop. density (per sq.mile)
Late Sunset Border	0.041	0.044	0.400	-7.437
	(0.035)	(0.029)	(0.0383)	(33.052)
Observations	2,041	2,041	2,041	2,041
Adj. R^2	0.353	0.187	0.390	0.088
Mean of Dep. Var.	11.597	6.325	22.273	128.172
Std. Dev.	0.394	0.306	5.201	354.381

Notes - Data are drawn from the ACS (2009-2013). All estimates also include the distance to the time zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county characteristics ((9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year and a dummy that controls for the application of DST. Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

Table A.10: Sleeping and Time-Zone Border, by MSA Size

	(1)	(2)	(3)
Dep.Var.:	Sleep Hours Overall Sample	Sleep Hours Fewer than 500,000 MSA residents	Sleep Hours More than 500,000 MSA residents
Late Sunset Border	-0.318***	-0.216*	-0.422***
	(0.079)	(0.123)	(0.085)
Observations	16,557	4,394	12,163
Adj. R^2	0.137	0.156	0.139
Mean of Dep. Var.	8.284	8.186	8.319
Std. Dev.	1.965	1.898	1.988

Notes - Data are drawn from the ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

Table A.11: Effect of Late Sunset Time on Sleeping by Season and Latitude (Only Employed)

	(1)	(2)	(3)	(4)	(5)
Dep.Var.:	Sleep Hours	Sleep Hours	Sleep Hours	Sleep Hours	Sleep Hours
Sample:	DST= 0	DST= 1	North	Central	South
Late Sunset Border	-.311**	-.255**	-.374***	-.310**	-.386**
	(.130)	(.108)	(.127)	(.134)	(.164)
Observations	7282	9275	4442	6969	5146
Adj. R^2	.134	.138	.154	.127	.142
Mean of Dep.Var.	8.248	8.329	8.195	8.334	8.292
Std.Dev. of Dep.Var.	1.954	1.979	1.913	1.989	1.976
State FE	NO	YES	NO	YES	NO

Notes - All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). In column 1 we include only respondents interviewed during the solar time, while in column 2 only respondents interviewed during DST. In column 3 we consider only respondents living in northern counties (latitude$\geq$ 41); in column 4 only people living central counties (34$\leq$ latitude$<$41); in column 5 only people living in southern counties (latitude$<$34). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at geographical level (counties are grouped based on the distance from the time zone border).

Table A.12: Effect of Late Sunset Time on Sleep, by Polynomial Order (Only Employed)

Polynomial:	1	2	3	4
Dep.Var.:	Sleep Hours	Sleep Hours	Sleep Hours	Sleep Hours
Late sunset border	-0.266***	-0.340***	-0.308*	-0.830***
	(0.074)	(0.123)	(0.183)	(0.210)
Observations	17,767	17,767	17,767	17,767
R^2	.135	.135	.135	.135
BIC	72068.83	72107.36	72112.39	72065.89
Bandwidth (miles)	280	280	280	280

Notes - Data are drawn from ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at geographical level (counties are grouped based on the distance from the time zone border).

A.2 Physical Activity

Following Tudor-Locke et al. (2009), who use information from the Compendium of Physical Activities to code physical activities derived from the ATUS, we classify the reported activities based on their intensity (see also Haskell et al. (2007)).[21] Specifically, we classify activities into sleeping ($MET < 0.9$), sitting ($MET \in [0.9; 1.5]$), light activities ($MET \in [1.5; 3]$), moderate activities ($MET \in [3; 6]$), vigorous activities ($MET \in [6; 9]$), and very vigorous activities ($MET > 9$). Using this classification, in Table A.13, we test whether individuals on the late sunset side of the time zone boundary are more or less likely to engage in moderate or vigorous activities for more than 30 minutes.[22] We find that they spend less time performing moderate or vigorous physical activity. The coefficient reported in column 1 indicates that in counties on the late sunset of the time zone boundary, individuals are two percentage points less likely to conduct moderate or vigorous physical activity for longer than 30 minutes. The coefficient reported in column 1 is only marginally significant. However the point estimate becomes larger and more precisely estimated when, as in Table A.3, we focus on individuals with children under the age of 13 in the household (column 2), while the estimate is not significantly different from zero for individuals without children under the age of 13 (see column 3).[23]

[21] The Compendium of Physical Activities is used to code physical activities derived from various sources to facilitate their comparability.

[22] The 2008 Physical Activity Guidelines for Americans guidelines indicate that adults should engage in 150 minutes of moderate-intensity aerobic activity, 75 minutes of vigorous activity or an equivalent combination of moderate and vigorous aerobic activity each week. Adults should engage in muscle-strengthening activities at least 2 days per week. See `http://www.health.gov/paguidelines`.

[23] We obtain qualitatively similar results using county-level data on physical activity made available by the Institute for Health Metrics and Evaluation (IHME).

Table A.13: Time Zone Border and Physical Activity (More than 30 Minutes Vigorous or Moderate), ATUS

Dep.Var.	(1) Physically Active All	(2) Physically Active Child ≤13	(3) Physically Active No Child ≤13
Late Sunset Border	-0.024	-0.052**	-0.007
	(0.016)	(0.022)	(0.023)
Observations	16,557	7,452	9,105
Mean of Dep.Var.	0.385	0.474	0.311
Std. Dev.	0.487	0.499	0.463

Notes - Data are drawn from the ATUS (2003-2013). The dependent variable is the an indicator for whether individuals conducted at least 30 minutes of moderate/vigorous activity in the day preceding the interview based on metabolic equivalents associated with individual activities reported in the ATUS (Tudor et al., 2009). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).

Table A.14: Sunset and Sleep Quality

Dependent variable:	(1) Time restless 9pm-9am	(2) Sleep Episodes 9pm-9am
Late Sunset Border	1.485**	0.033*
	(0.570)	(0.018)
Observations	16,557	16,556
Mean of Dep. Var.	2.038	2.090
Std. Dev. of Dep. Var.	16.40	0.487

Notes - Data are drawn from ATUS (2003-2013). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, standard socio-demographic characteristics (age, race, sex, education, marital status, indicators for nativity status and year of immigration, and number of children), county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties), interview characteristics (interview month and year, a dummy that controls for the application of DST, and two dummies that control whether the interview was during a public holiday or over the weekend). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at geographical level (counties are grouped based on the distance from the time zone border).

A.3 The Role of TV Schedules

Next, we investigate the role that the television plays in affecting bedtime and sleep duration. The assumption underlying our identification holds as long as differences in sleeping are induced by differences in exogenous natural or artificial factors. However, understanding whether TV schedules mediate the effect of sunset cues is important for understanding the mechanisms underlying our first-stage regression and what policies could affect sleeping duration. Specifically, we want to determine to the extent to which the marked discontinuity we observed in bedtime and sleep duration at the three time zone borders is affected by the different timing of TV shows and prime times across US time zones. As largely explained in Section 2.2, in the two middle time zones, prime time shows typically air an hour earlier than in the Eastern and Pacific time zones. This difference in television schedules across time zones may exacerbate the effect of the different sunset times at the time zone border in areas where the later sunset is associated with a later TV schedule (e.g., counties in the Eastern time zone at the boarder with the Central time zone). Conversely, we would expect television schedules to mitigate the effect of a later sunset on sleeping in areas where the later sunset is associated with an earlier TV schedule (e.g., counties in the Mountain time zone at the boarder with the Pacific time zone).

Specifically, as prime time shows air an hour earlier in the middle time zones, we might expect, holding all else constant, the discontinuity in bedtime to be larger along the Eastern — Central (EC) time zone border and lower along the Mountain— Pacific (MP) time zone border, while TV schedules should play no role at the Central–Mountain (CM) zone border. In Table A.15, we exploit the heterogeneity at the three time zone borders to investigate the role played by television. In particular, in column 1, we estimate the effect of living on the late sunset side of a time zone border on sleep duration (as in column 1 of Table 2) but adding to the model in equation (1) two dummies for the CM and MP borders that we interact with the dummy identifying individuals living on the late sunset side of the time zone boundary (EB_c). In this way, we can test whether there is evidence of heterogeneity in the effect of interest across time zone borders. The results reported in column 1 show that the effect is significantly larger at the CM border than at the other two time zone borders. This evidence contrasts with the hypothesis that TV is the main factor explaining the discontinuity in sleep duration we observed at the time zone border. As mentioned above, as TV shows are broadcast earlier in the two middle time zones, we would have expected a larger effect at the EC time zone boundary and a smaller effect along the MP border. However, it is worth noting that, in our sample, we have only 1,742 observations from the CM border. These individuals are likely to be concentrated primarily in urban and populated areas because we cannot identify counties or metropolitan areas with fewer than 100,000 residents.[24] For this reason, in column 2, we also exploit the bedtime data from Jawbone presented in Figure 5. This dataset is likely not to be representative of the US

[24] In Table, A.10, we show that the effect of interest is larger in more populated metropolitan areas, and the larger effect estimated along the CM border might be the consequence of the sample selection criterion.

population[25] and does not allow us to focus solely on the employed people as in our sample, but in contrast to the ATUS, it contains information on all US counties. As we lack information on individual sleeping time and on individual socio-economic characteristics, we use county-level controls. Furthermore, we focus only on bedtime because wake-time data might be affected by the compensatory behavior of non-employed people (as already shown in column 6 of Table 3) and may be more sensitive to the particular personal wearable model used to track sleep. The results using Jawbone data do not reveal evidence of substantial heterogeneity across time zone borders. In contrast to column 1, we only have evidence of a significantly smaller effect at the MP border, consistent with a, rather small, mitigating effect of TV.

A.3.1 Sweeps Weeks and Sleep Duration

In a further attempt to assess the importance of TV schedules and programs in determining individuals' bedtimes, we also consider differences in sleep duration induced by the attractiveness of TV shows during the year. To this end, we exploit the fact that all major TV broadcasters strive to maximize audience ratings during the Nielsen "sweeps" rating periods. Each year in the months of November, February, May and July[26], Nielsen Media Research, the company that records viewing figures for television programs, sends out diaries to sample homes in the various markets around the country for the residents to record the shows they viewed. During these weeks, TV networks air new episodes, series and specials in an effort to boost their viewing figures and, hence, advertising revenue. As a consequence, during these weeks, we might expect that if TV is a major determinant of individual bedtime habits, people would tend to sleep later than in other periods of the year because of the particular appeal of TV schedules during these weeks.

Using the exact dates of sweeps weeks between 2003 and 2013, we exploit this exogenous change in broadcast programming. Specifically, we test whether the discontinuity at the time zone border is larger (or smaller) during sweeps weeks (column 4, Table A.15). If television plays a role in explaining the large discontinuity in sleep duration at the time zone borders, we should observe a larger effect during these weeks when more people are likely to watch TV shows. To test this hypothesis, we interact the dummy identifying individuals living on the late sunset side of a time zone boundary with a dummy that is equal to one for interviews conducted during a sweeps week. The results clearly show that there is no evidence of heterogeneity in the discontinuity at the time zone border during these sweeps weeks. However, we do find evidence that during these weeks people tend to go to bed later and sleep less (approximately 6 minutes). Ultimately, although television schedules influence bedtime and sleep duration (as noted by Hamermesh et al., 2008), our analysis suggests that television does not play a major role in explaining the discontinuity we observed at the time zone border.

[25]It is reasonable to expect that young people from urban areas are more likely to use personal wearables tracking sleep quality and calorie expenditure.

[26]They are 4 consecutive weeks that lie mainly in the months of November, February, May and July usually starting from the Thursday of the previous month.

Table A.15: Heterogeneity Across Time Zone Border and Sweeps Weeks

	(1) Sleep duration (ATUS)	(2) Bedtime (Jawbone)	(3) Sleep duration (ATUS)
Late Sunset Border	-0.262***	0.303***	-0.374***
	(0.088)	(0.046)	(0.082)
Late Sunset Border*CM	-0.289**	-0.015	
	(0.114)	(0.049)	
Late Sunset Border*MP	-0.085	-0.073**	
	(0.091)	(0.034)	
Late Sunset Border*sweeps			0.092
			(0.067)
Sweeps weeks			-0.103***
			(0.036)
Observations	16,653	2,041	16,653
Adj. R^2	0.136	0.631	0.136
Mean of Dep.Var.	8.040	4.307	8.040
Std. Dev.	1.784	0.200	1.784

Notes - Data are drawn from the ATUS (2003-2013). All estimates include county and geographic characteristics (9 cells constructed using time zone borders and latitude parallels, latitude, and a dummy for large counties). Columns (1) and (3) also include the same socio-demographic and interview controls as in Table 1, while Column (2) includes socio-demographic characteristics at the county level (share of people over 65, under 25, female, white, black and with high school). Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors are robust and clustered at the geographical level (counties are grouped based on the distance from the time zone border).