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Evidence from a regression discontinuity design

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If You Don't Snooze You Lose Health and Gain Weight: Evidence from a Regression Discontinuity Design

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Abstract

Sleep deprivation is increasingly recognized as a public health challenge. While several studies have provided evidence of important associations between sleep deprivation and health outcomes, it is less clear whether sleep deprivation is a cause or a marker of poor health. This paper studies the causal effects of sleep on health status and obesity exploiting the relationship between sunset time and circadian rhythms and the discontinuities in sunset time created by time zone boundaries. Using data from the American Time Use Survey, we show that individuals living in counties on the eastern side of a time zone boundary go to bed later and sleep less than individuals living in nearby counties on the opposite side of the time zone boundary. These findings are driven by individuals whose biological schedules and waking up times are constrained by social schedules (i.e., work schedules, school start times) which respond to returns to coordination and are not affected by solar cues. Indeed, we find that discontinuities in sleep duration are largest among people working in the public administration, health and school sectors, and lowest in the retail and wholesale industry. We find that sleep deprivation increases the likelihood of reporting poor health status and the incidence of obesity. Our results suggest that the increase in obesity is explained by both changes in eating behavior and a decrease in physical activity. Overall, our findings highlight the importance of developing a public awareness about the negative effect of sleep deprivation and suggest that policy makers should carefully consider how working schedules and time zone rules can affect sleep duration and quality. In fact, our results suggest that delaying morning work schedules and school start times may substantially improve average sleep duration.

Keywords: Health, Obesity, Sleep Deprivation, Time Use, Regression Discontinuity

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1 Introduction

Time is one of our scarcest resources and economists have long been interested in the analysis of individuals' time use. However, while we spend approximately a third of our time sleeping, and despite the evidence of important heterogeneity in sleeping in the population, the sources of these differences and the factors affecting sleep duration decisions are not well understood. Most economic models analyzing time allocation consider sleeping as a pre-determined and homogeneous constraint on individuals' time allocation. 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 (Ásgeirsdóttir and Ólafsson, 2015; Brochu et al., 2012; Szalontai, 2006).[1] If sleep deprivation has causal effects on health, the sleep deprivation epidemic may have substantial costs for the health care system. Yet, we know relatively little about the health and economic consequences of insufficient sleep. In particular, while there is a wide set of studies providing evidence of important association between sleeping and negative health outcomes, it is unclear whether sleep duration is a cause or a marker of poor health (Cappuccio et al., 2010). The goal of this paper is to analyze the causal effects of sleep duration on health, shedding light on the mechanisms behind this relationship and investigating how sleep duration is affected by social constructs (e.g., work schedules, school start times etc.).

Insufficient sleep is associated with higher incidence of chronic diseases (i.e. hypertension, diabetes), cancer, depression and early mortality (see Cappuccio et al., 2010, for a systematic review). Moreover, sleep duration may be an important regulator of body weight and metabolism (Taheri et al., 2004; Markwald et al., 2013). Insufficient sleep has been also linked to motor vehicle crashes (Lyznicki et al., 1998; Barger et al., 2005). Furthermore, anecdotical evidence suggests that sleep loss played an important role in major industrial disasters (e.g., the Chernobil accident).[2] Through its effects on health capital and cognitive skills (Giuntella et al., 2015), sleep deprivation can also have important effects on human capital and productivity (Gibson and Shrader, 2014). Sleep deprivation has been associated with a higher likelihood of medical errors and worse performance among doctors and nurses (Weinger and Ancoli-Israel, 2002).

Despite the increased attention on sleep deprivation, some estimates suggest that in many countries

[1]The discussion on the economics of sleeping started earlier on in the seventies with a first article by El Hodiri (1973) then discussed 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 test econometrically its relationship with economic incentives.

[2]See http://www.huffingtonpost.com/2013/12/03/sleep-deprivation-accidents-disasters_n_4380349.html.

individuals are sleeping as much as two hours less sleep a night than people used to sleep a hundred years ago (Roenneberg, 2013). Figure 1 illustrates the dramatic shift in the share of individuals reporting less than 6 hours sleep between 1942 and 1990. 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). Figure 2 shows that during the workweek individuals tend to sleep significantly less than the recommended 8 hours sleep, but with important heterogeneity by education and work schedules. Consistently with previous studies analyzing the relationship between wages, socio-economic status and sleeping time, we find evidence that education is negatively correlated with sleep duration suggesting a trade-off between sleeping and income (Ásgeirsdóttir and Ólafsson, 2015; Biddle and Hamermesh, 1990).[3] Furthermore, regardless of the educational group considered individuals who start to work later in the morning tend to sleep longer. In light of these trends, in a recent article on *Nature*, Roenneberg (2013) argues that unnatural sleeping and waking times could be the most prevalent high-risk behavior in modern society and proposes a global human sleep study to restructure work and school schedules in ways that may better suit our biological needs.

The causal evidence on the effects of sleep duration has been so far limited to laboratory studies. However, experimental studies conducted in the lab offer only a limited understanding of both the determinants and consequences of sleep deprivation (Roenneberg, 2013). They are usually based on people who have been instructed to follow certain sleep patterns (e.g., bedtime), are not sleeping on their beds, and are affected by laboratory settings (e.g., individuals are often required to sleep with electrodes fastened to their heads etc.). Moreover, most of the experimental evidence focuses on the effects of total sleep deprivation (awake continuously for 1 to 3 days) while only few studies evaluate consequences of chronic partial sleep deprivation (i.e. repeated exposure to sleep durations of less than 6-7 hours per night), a condition that is far more common in reality (Van Dongen et al., 2003).

This paper has two main contributions. First, we explore the importance of work schedules and other social constructs (e.g., school start times) in determining sleep duration. Second, we provide a causal estimate of the effects of sleep duration on health using time-use data that are more likely to capture real world sleeping habits. In particular, we focus on the effects of insufficient sleep on general health status and obesity. Both self-reported health status and obesity have been shown to have important effects on

[3] This is true even if we examine the relationship between hourly wages and sleep duration within each educational group.

individuals' productivity and on health care costs (Cawley, 2004; Cawley and Meyerhoefer, 2012; Burton et al., 2005).

There are several biological channels through which sleep deprivation may increase the risk of obesity. In particular, the medical literature associates sleep deprivation with a reduction of leptin, the so-called "satiety hormone", and with an increase of ghrelin, also known as the "hunger hormone" (Ulukavak et al., 2004). Moreover, behavioral studies show that sleep loss increases the likelihood of gaining excessive weight by increasing the consumption of fats and carbohydrates and by reducing the likelihood of being engaged in moderate or intense physical activity (Greer et al., 2013; Markwald et al., 2013).

To identify the effect of sleep duration, we exploit the discontinuities in sleep duration that occur at the boundary of a time-zone as a result of the discontinuity in sunset time. 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. Because of circadian rhythms, our body reacts to environmental light producing more melatonin when it becomes darker. This is a gradual process known as entrainment. Thus, because sunset occurs at a later hour, individuals on the eastern side of a time-zone boundary will tend to go to bed at a later time.[4] In addition, as prime-time evening shows screen at 10 p.m. Eastern and Pacific, 9 p.m. Central and Mountain, TV programs may affect bedtime and reduce or reinforce the effect of sunset time (Hamermesh et al., 2008). Note that if people would compensate by waking up later solar and TV cues would have no effect on sleep duration. However, because of economic incentives and returns to coordination, social schedules, such as working schedules and school start times, are usually less flexible than biological timing. Thus, many individuals are not be able to fully compensate in the morning by waking up at a later time.

Figure 3 illustrates the variation in average sunset time across US counties. Within a given time-zone, eastern counties have earlier sunset time than more western counties. At the time-zone border, there is a sharp discontinuity between counties on the eastern (right) side of the border (late sunset side) and counties on the western (left) side of the border (early sunset side).

[4]There is large medical evidence that shows how solar cues affect sleep timing (see Roenneberg et al., 2007, for a review). The daily light-dark cycle governs the so-called circadian rhythms, rhythmic changes in the behavior and the physiology of most species, including humans (e.g., Vitaterna et al., 2001). Studies have found that these circadian rhythms follow an approximately 24-hour cycle and are governed by the suprachiasmatic nucleus (SCN), or internal pacemaker also known as the body master's clock. The SCN synchronizes biological rhythms to the 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 (Aschoff et al., 1971; Duffy and Wright, 2005; Roenneberg et al., 2007; Roenneberg and Merrow, 2007).

Using data on the average bedtime of Jawbone's sleep trackers users across US counties, publicly available on the Jawbone website[5], Figure 4 illustrates the clear discontinuity in bedtime at each time zone border. The bottom figure provides a zoom at the north border between the Eastern and the Central time zone. The figure shows that people living in counties on the eastern (left) side of a time zone border go to sleep later than people in neighboring counties on the western (right) side of the time zone boundary. These differences in bedtime give rise to differences in sleep duration across time zone borders since many people cannot fully compensate by sleeping longer in the morning. We show that this is particularly true for workers, because standard office hours are the same across borders, and for parents with children, because they are likely constrained by school start times.

Using data from the American Time Use Survey, we show that employed people living in counties bordering on the eastern side of a time zone sleep on average 19 minutes less 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 eastern side of a time-zone boundary are more likely to be sleep deprived, being more likely to sleep less than 6 hours, less likely to sleep at least 8 hours, and less likely to sleep the recommended 7-8 hours of sleep.[6] The effects are larger among individuals with early working schedules and among individuals with children in school age. We find that TV plays only a limited role in explaining the discontinuities at the border. The difference in sleep duration across the time-zone borders gives rise to large differences in obesity and self-reported health. People on the eastern side of a time zone boundary have 6 percentage points higher probability of being obese and are 3 percentage points more likely to report a poor health status. It is worth noting that, especially in the case of obesity, these are the consequences of a long-term-exposure to sleep restrictions. This is confirmed by the evidence of larger effects among older workers (over 40) and it is consistent with previous evidence from animal studies (Knutson et al., 2007).

We then turn to the analysis of the possible mechanisms behind the relationship between sleeping, health, and obesity. We find evidence that individuals on the eastern side of the time-zone border are more likely to eat late in the evening than their neighbors on the western side of the time-zone border, regardless of the number of times or the time spent eating earlier in the day. They are also more likely to eat out

[5] 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

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

and less likely to engage in physically intensive activities. These results are consistent with some of the recent behavioral evidence on sleep deprivation and weight gain (Markwald et al., 2013) which notes that sleep deprivation may induce fatigued individuals to eat more– in particular to eat more carbohydrates– to sustain their wakefulness while at the same time their exhaustion may reduce their physical activity leading to an increase in weight gain.

Importantly, we also show that there is no discontinuity in predetermined characteristics known not to be affected by the treatment (sleeping). In particular, we find that individuals' height does not differ systematically across the time zone border and that there is no evidence of any significant relationship with human capital indicators at the beginning of the 20th century when the time zones had not yet been introduced in the United States. Moreover, by looking at the population density, home (and rent) values and commuting time, we do not find any evidence of residential sorting across the time-zone borders.

Overall, our results suggest that sleeping has important effects on health status and obesity. Furthermore, the heterogeneity of our results by occupational and demographic characteristics suggests that sleep duration is importantly affected by social constructs such as working schedules, school start times which can be restructured in ways that may better suit our biological needs. In particular, we find that the differences in sleep duration are driven by workers starting to work before 8.30am and larger among individuals waking up early to bring children to school. Delaying working start time after 8.30am would eliminate the differences in sleep duration at the time-zone border and, more generally, improve average sleep duration in the US.

Our paper contributes to a small but growing number of studies analyzing the consequences of sleep deprivation. In a recent study Jin and Ziebarth (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 the fall, but no evidence of detrimental effects when moving from standard time to DST in the spring. Using a similar strategy, Smith (forthcoming) 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 one-hour increase in average daily sleep raises productivity by more than 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 analysing the effects of school start times on academic achievement (Carrell et al., 2011; Edwards, 2012; Stewart, 2014) 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 the time zone borders or analyze the medium and long-run health consequences of sleep restrictions.

This paper is organized as follows. In Section 2, we briefly discuss the context. Section 3 describes our identification strategy, the empirical specification and the data used in our analysis. In Section 4, we examine the relationship between sunset time and sleeping and its heterogeneity in the population. Section 5 discusses the main results and the mechanisms underlying our main results. Section 6 illustrates a battery of robustness checks. Concluding remarks are in Section 7.

2 Background: US Time Zones, Solar and TV Cues

2.1 US Time-zones

As shown in Figure 3, contiguous United States are divided into 4 four main time zones (Eastern, Central, Mountain, and Pacific). The time zones were first introduced in US in 1883 to regulate railroad traffic. However, even in relatively close areas scheduling was far from being uniform at that time (Hamermesh et al., 2008; Winston et al., 2008). The current four U.S. time zones were officially established with the Standard Time Act of 1918, and since then only minor changes occurred, mainly at their boundaries. The Eastern time zone was set -5 hours with respect to the 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.

The introduction of Daylight Saving Time (DST) was, instead, more troublesome. The DST was first adopted in 1918, during World War I, as in other countries as a way to save energy. Yet, because of its unpopularity it was repealed after war. The current DST was introduced in 1966 with the Uniform Time Act. Changes to the DST schedule were then made in 1976 and 2007, when DST was extended by 4 weeks. Since 2007, in most of the US, clocks are set one hour forward in early March, and are set one hour backward early in November. However, Arizona since 1967 never observed DST, while Indiana, with the exception of some counties at the border between the Central and the Eastern time-zone, did not follow DST until 2006.

Since 1918, a few counties petitioned to the Department of Transportation to switch time zones. Over time there has been a westward movement of time-zone boundaries. While clearly this movement makes the time-zone boundary endogenous, as noted by Gibson and Shrader (2014), the westward movement of boundaries would have, if anything, negative effects on sleep duration as counties moving to the eastern side of a time zone boundary would move from the 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 noted by Hamermesh et al. (2008) and Winston et al. (2008), this practice originated in the 1920s when, because of the radio transmission technology available at the time, Central and Eastern Time zone would simultaneous brodcast 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 brodcasting, it became a custom that the Eastern feed would be delayed an hour in the Mountain time zone. These differences in the timing of TV shows have persisted over time so that prime time in the two coastal zones goes from 8pm to 11pm, while in the two middle time zones it is from 7pm till 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 still affecting their timing, and show that the scheduling of television programs affects timing and bedtime.

While by construction sunset occurs an hour later on the eastern side of each time-zone border (EC,CM,MP), prime time shows may reinforce or reduce the sunset effect. In particular, prime time shows start nominally an hour later on the eastern side of the time-zone boundary between Central and Eastern, an hour earlier on the eastern 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. 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 lower along the Pacific-Mountain time-zone border. We examine the role of TV schedules in Section 4.3.

3 Identification Strategy and Empirical Specification

3.1 Identification Strategy

The empirical analysis of this paper focuses on the effect of sleep deprivation on health (obesity and self-reported health). A simple comparison of people with different sleeping behavior would not allow us to identify the causal effect of sleep deprivation on health because of both reverse causality and several potential confounding factors (e.g. stress, type of occupation etc.).

In this paper, we address the identification problem by using a spatial regression discontinuity (SRD) design that contrasts the sleeping behavior of residents on either side of the three main US time zone borders (Eastern–Central, Central–Mountain and Mountain–Pacific). The intuition is that, because of circadian rhythms, individuals in counties bordering on the eastern side of the time zone border go to bed later than people in neighboring counties on the opposite side of the border, because of the one-hour difference in sunset time. Yet, these individuals are otherwise very similar as we document in Section 3.3. Figure 5 illustrates the sharp discontinuity in sunset time at the border aggregating the average sunset time of the US counties based on the distance (in miles) from the closest time zone border. This discontinuity is mirrored by the observed difference in average bedtime at the time-zone border (see Figure 4). In section 4, we show that this difference in average bedtime generates significant differences in sleeping behavior as people on the eastern border of a time-zone boundary do not completely compensate for it by waking up later. This is especially true for workers that have to deal with standard office hours that are approximately the same across borders (office hours usually start at 8am or 9am) and for people with children in 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. As we mentioned earlier on, the discontinuity in bedtime may be more (less) marked on the Eastern-Central (Pacific-Mountain) border if individuals bedtime is affected by TV cues.

Our identification strategy exploits this spatial discontinuity in sleep duration. If we focus on a reasonably small bandwidth around each time zone and if we expect a causal relationship between sleep duration and health, the observed sleeping difference should generate differences in health (here measured using obesity and self-reported health) that should not be confounded by other observable and unobservable characteristics. For simplicity, we assume that the relationship between sleep duration and health is linear. Under this assumption, our estimation strategy allows us to estimate the effect of sleeping duration on health. However, we also consider non-linear metrics of sleep duration in the empirical analysis.

A natural concern is that the daylight exposure may vary across the time zone border and so violate the exclusion restriction assumption. 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 location at the same latitude but on the opposite side of a time-zone boundary will experience the same daylight duration differing only in the timing of daylight. Thus, sorting on daylight duration would not bias our estimates as daylight duration is fixed. Though, the timing of daylight may affect individuals' exposure to environmental light during their waking activities, it's worth noting that, if there is a difference in actual daylight exposure across the time zone border, this should advantage individuals living on the eastern side of the time-zone border who would be exposed to a later sunset time. A related concern is that unset time may directly affect obesity not only through the effects on sleep but also through its effects on daylight exposure and physical activity. However, previous studies suggest that if anything light exposure would increase physical activity (Roenneberg et al., 2012; Wolff and Makino, 2012). Thus, if ever, the difference in daylight exposure may introduce a downward bias in the estimated effect of sleep duration on health and obesity.

It is worth noting that the health differences across bordering counties, in particular in the case of obesity, are likely to be the result of a long-term exposure to chronic and partial "sleep deprivation". In other words, what we measure when analyzing the effect of an hour increase in sleep duration is not the effect of one-hour difference in sleep duration in the night preceding the survey interview, but rather the average effect of a long-term exposure to one-hour difference in sleep that depends on the time spent in a given location. Indeed, we show that this effect is larger for older people than for younger as older people have been exposed for a longer time period than younger people to differential sunset time. Moreover, if people often change their residence, it is likely that the estimated effect on health represents only a lower bound of the true effect, unless healthier individuals systematically move from the eastern to the western side of each time zone border. In the robustness checks reported in Section 6 we implement a large battery of tests for residential sorting across bordering counties and find no evidence for it. In particular, we test for the presence of discontinuities in pre-determined characteristics for which we have data –namely respondents' height and literacy rates in 1900– and for discontinuities in population density, home (and rent) values and commuting time.

From an econometric perspective, the general idea in a RD design is that the probability of receiving a treatment (an additional hour of sleep) is a discontinuous function of a continuous treatment determining variable (sunset time). However, the treatment in our case does not change from 0 to 1 at the time zone border. Our running variable, D, is the distance (in miles) from the time zone border. Distance is positive for counties on the eastern side of the border ($D > 0$) and negative for counties on the western side ($D < 0$). Let $E_e(H) \equiv \lim_{\epsilon \to 0} E(H|D = 0 + \epsilon)$ and $E_w(H) \equiv \lim_{\epsilon \to 0} E(H|D = 0 - \epsilon)$ define the two sides expectation of our observed health outcomes when approaching the border from East (e) and West (w).

If we assume that there are no other unobservable characteristics that change at the border, contrasting the health outcome H at the time zone border, $E_e(H) - E_w(H)$, measures the effect of the sleeping differences at the border generated by the time zone change. This identification is clearly fuzzy since it does not generate a sharp discontinuity in sleeping hours. In fact, people may partially offset the effect of the different sunset time by adjusting their sleeping or waking time. This means that we need to use a 2SLS strategy that "inflates" the reduced-form effect, $E_e(H) - E_w(H)$, taking into account the sleep duration (S) difference at the border, $E_e(S) - E_w(S)$. Therefore, our fuzzy SRD design may be seen as a Wald estimator around the time zone discontinuity:

$$\tau_{SRD} = \frac{E_e(H) - E_w(H)}{E_e(S) - E_w(S)}.$$

3.2 Empirical Specification

Specifically, we exploit the geographical variation in sunset time at the border estimating the following two equations:

$$H_{ic} = \alpha_0 + \alpha_1 S_{ic} + \alpha_2 D_c + \alpha_3 D_c * EB_c + X'_{ic}\alpha_4 + C'_c\alpha_5 + I'_{ic}\alpha_6 + u_{ic} \quad (1)$$

$$S_{ic} = \gamma_0 + \gamma_1 EB_c + \gamma_2 D_c + \gamma_3 D_c * EB_c + X'_{ic}\gamma_4 + C'_c\gamma_5 + I'_{ic}\gamma_6 + \nu_{ic} \quad (2)$$

where S_{ic} is the sleep duration of the individual i in county c; EB_c is an indicator for the county being on the eastern side of a time zone boundary; D_c is the distance to the time-zone boundary "running variable" (or forcing variable) 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, and number of children; C_c are county characteristics, such as region (northeast, midwest, south, west), latitude and longitude and whether the respondent lives in a very large county.[7] We also account for interview characteristics that might affect individual's sleeping behavior (I_{ic}), such as interview month and year, a dummy that controls for the adoption of DST in county c, and two dummies that control whether the interview was 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 6)

Substituting the treatment equation into the outcome equation yields the reduced-form equation:

$$H_{ics} = \beta_0 + \beta_1 EB_c + \beta_2 D_c + \beta_3 D_c * EB_c + X'_{ic}\beta_4 + C'_c\beta_5 + I'_{ic}\beta_6 + \epsilon_{ics}, \tag{3}$$

where $\beta_1 = \alpha_1 * \gamma_1$. Therefore, we can estimate the parameter of interest α_1 as the ratio of the reduced-form coefficients β_1/γ_1 via 2SLS. Standard errors are robust and clustered according to the distance from each time zone border (10 miles groups).

As mentioned earlier, the main assumption behind our identification strategy is that the observed differences in health at the time zone border only reflect differences in sleeping behavior generated by solar cues or by other exogenous cues (e.g., TV schedules) that may affect sleep duration.

Again, the underlying idea is that individuals in nearby counties are similar along other characteristics. As any identification assumption this is directly untestable. However, using both individual and county level data, Table 1 illustrates that a large set of observable characteristics is well balanced in a relatively small bandwidth from the time zone boundary (within 250 miles). We use a bandwidth of 250 miles to ensure that areas on the eastern/western side of a time-zone boundary don't overlap while maximizing our identification power. However, in Section 4, we show that the effect of the different sunset time at the border on sleep duration is robust to the inclusion of state fixed effects and to the restriction of our analysis to a very narrow bandwidth around the time zones (100 miles).

Finally, the heterogeneity of our findings by employment status, family composition, work schedule and type of occupation is consistent with our hypothesis that employed people, parents with children, and

[7] We control for the fact that for very large county the distance based on centroid might be a very noisy approximation of the individual sunset time.

individuals with early work schedules are less likely to fully adjust their sleeping behavior as a response to the different sunset time on the two sides of the border (see Section 4).

3.3 Data and descriptive statistics

In this paper we 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 the Current Population Survey (CPS) participants. The respondents are asked to fill out a detailed time use diary of their previous day that includes information on time spent sleeping and eating. On average, more than 1,100 individuals participated to the survey each month since 2003 and the last available survey year is 2013. This yields a total sample of approximately 148,000 individuals. Our analysis restricts the attention to individuals in the labor force (both employed and unemployed)[8] living within 250 miles from each time zone boundary (Pacific-Mountain, Mountain-Central, Central-Eastern). This is done by merging the ATUS individuals to 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 less than 100,000 residents, thus we can match only 44% of the sample. We further restrict our sample to people aged 18 to 55 years old to avoid the confounding effect of retirement and the selection issue that might arise focusing on high-school age workers. We also limit the analysis to individuals who sleep between 2 hours and 16 hours per night.[9] After imposing these restrictions, the sample comprises 18,639 individuals of which 16,557 were employed. Employment status was determined on the basis of answers to a series of questions relating to their activities during the preceding week.

The variable of main interest is sleep duration. We count only the night sleeping by excluding naps (sleep starting and finishing between 7am and 7pm).[10] 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).

We evaluate the effect of sleep duration on obesity (BMI>30) and the likelihood of reporting a poor health status, defined as reporting poor or fair health status as commonly done in the literature using metrics of self-reported health status. Unfortunately, information on these health outcomes is not avail-

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

[9]These 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 are approximately 1% of the entire sample.

[10]Results are unchanged if including naps in the main variable (see Table A.1).

able 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.

In our analysis, we include several socio-demographic controls: age, sex, education, race, marital status and number of children that might affect individuals' sleeping behavior. Moreover, we use geographic controls, such as census region and latitude, to avoid other geographical factors confounding our analysis at the time-zone border.

Table 1 reports summary statistics for the variables of interest for each side of the border on our main sample that includes only employed people. However, there is no significant difference in the likelihood of being employed between individuals living on opposite sides of the time-zone (coef., -0.010; std. err., 0.013). Columns 1 and 2 report summary statistics for individual living, respectively, in the western (early sunset) and in the eastern (late sunset) side of one of the three main time zone borders. 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 the one observed during the workweek (see Figure 6). Furthermore, 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 as the ATUS Activity Lexicon includes transition states (e.g, falling asleep etc.). By construction, there is a large and significant difference in average sunset time between respondents living across the time zone border. This difference is correlated with individual sleeping behavior. Respondents living in early sunset counties have significantly higher sleep duration. They sleep on average 10 minutes more and have a 4% higher probability to sleep at least 8 hours. This difference arises from the fact that they go to sleep later, but they do not compensate by waking up later (compare awake at midnight and awake at 7.30 am).

Figure 7 confirms the presence of an even larger discontinuity in sleep duration at the time zone border for employed respondents of approximately 20 minutes. In particular, each point represents the sample mean of sleep duration for a group of counties aggregated according to the distance to the border.[11] For purely descriptive purposes, the fitted lines are based on a linear fit within 250 miles from the border on either side.

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

On the contrary, the other individual characteristics are well balanced across the two groups. The only significant coefficient among the covariates is the proportion of blacks (see Column 3). The higher presence of blacks on the eastern side of the time-zone boundary mostly reflects the high-density of African-Americans in the Eastern time zone in the South.[12] Including a control for the latitude (or Census region) this difference disappears.

4 Circadian Rhythms, Social Schedules, and Sleep Duration

4.1 First-Stage: Sleep Duration Across Time Zone Boundaries

Table 2 illustrates the estimated effect of being on the eastern side of a time-zone boundary on sleep duration as described in equation (2). In Column 1, we show that our baseline estimates coincide with the unconditional evidence reported in Figure 7. After controlling for a large set of socio-demographic, geographical and interview characteristics, the estimated effect of being on the eastern side of the boundary ("late sunset border") is approximately 19 minutes, reducing sleep duration by 0.2 standard deviations (see Table 1). The other three columns confirm the robustness of our findings to the inclusion of additional controls, the use of a narrower bandwidth and of an alternative metrics of sleep duration. As twelve of the continental US states span over multiple time zones, in Column 2 we can re-estimate the first-stage including a full set of state fixed effects. Notably, the point estimates remain substantially unchanged. In Column 3, we restrict the attention on a very narrow bandwidth of 100 miles. As the discontinuity in sunset time is larger at the border and diminishes with the distance from the border, it is not surprising to find even a larger effect on sleep duration. The coefficient indicates that within 100 miles from the border, individuals on the eastern side of the border sleep on average 23 minutes less than their neighbors on the western side. Finally column 4 shows that there is a large effect also on the probability of sleeping less than 8 hours. Being on the eastern side of the boundary decreases the likelihood of sleeping at least 8 hours by 8.2 percentage points, which is equivalent to approximately 16% of the mean of the dependent variable in the sample.[13]

[12] Note that we include controls for race, region and latitude in all our estimates.

[13] As mentioned above, most respondents are interviewed over the week-end 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.

4.2 Early Morning Schedules and Sleep Duration

In Table 3 we compare employed and non-employed respondents. Consistent with our hypothesis on working schedules' constraints on sleep duration, the first two columns show that the late sunset time on the eastearn side of the time zone boundary affects only the employed respondents. Columns 3-6 clarify where the difference between employed and non-employed respondents lies. In columns 3 and 4, we show that, regardless of their employment status, individual on the eastern side of the time zone border are always more likely to go to bed later. The estimates show that being on the eastern side of the boundary increases significantly the likelihood of being awake at midnight for both the employed (+41%) and the non-employed (+34%). However, employed respondents are less likely to adjust their waking time accordingly. Column 5 shows no significant difference across the border in the likelihood of being awake at 7.30am for employed people. On the contrary, non-employed people on the eastern side of the time zone border do adjust their waking up time in the morning. Column 6 shows that non-employed people on the eastern 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.

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 sectors or other public offices where standard schedules are likely to start 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, Table A.2 shows no evidence of significant effects among individuals in the wholesale and retail sector. The coefficient reported in column 2 is both small (in absolute value) and non-statistically significant. On the contrary, the effect of sunset is significantly larger among individuals working in the educational or in the health sector or in other public offices. The coefficient reported in column 3 suggests that an hour increase in the timing of sunset would decrease sleeping by approximately 40 minutes for individuals working in these sectors. Column 3 shows a similar effect for individuals working in financial services.

In Table 4, we analyze directly whether the discontinuity in sleep duration is affected by individuals' early morning constraints: working schedules and school start times. 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 to have worked over the weekend, the sample is substantially restricted. Column 1 shows that the first-stage is largest among individuals starting to work before 7am. For these workers an hour increase in average sunset time decreases sleep duration by 36 minutes. The coefficient is smaller but still negative and significant among individuals starting to work between 7 and 8.30am (column 2). For this group, an hour increase in average sunset time would reduce sleep duration by approximately 18 minutes. Instead, we find that there is no significant effect on individuals starting to work between 8.30am and noon (column 3).[14] The effect is not only statistically not significant but also very small in absolute value. However, even among those starting to work after 8.30 am, individuals who left children at school before 8am sleep substantially less and there is a large and significant effect of sunset time (column 4). In particular, among those entering work later in the morning, an hour increase in average sunset time decreases sleep duration by 27 minutes for those who brought children to school before 8am. Consistent with these findings, Table A.3 in the Appendix, shows that the estimated effect is larger for people with children younger than 13. As this constraint applies also to the non-employed population we report estimates for both the entire sample and our baseline sample of employed workers. Columns 1 and 2 document that when analyzing the entire sample (employed and non-employed) the effect is larger and significant for individuals with children under the age of 13. Focusing on the employed population, column 3 shows that among individuals with children those living on the eastern side of the time zone border sleep on average 26 minutes less, while the point estimate is substantially lower among individuals without young children (column 4).

These findings suggest that delaying work and school start times may have important effects on average sleep duration. Table A.4, shows that even when we analyze the entire ATUS sample, without restricting the analysis to the 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 columns 2 and 3). 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 the late sunset with that of other confounding factors.

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

4.3 The Role of TV Schedules

Next, we investigate the role that the television plays in affecting bedtime and sleep duration. The assumption behind 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 to understand the mechanisms behind our first-stage regression and what policies could affect sleeping duration. More specifically we want to determine to what extent the marked discontinuity we found in bedtime and sleep duration at the three time zone borders is affected by the different timing of TV shows and prime time across US time zones. As largely explained in Section 2.2, in the two middle time zones prime time shows usually run an hour earlier than in the Eastern and Pacific time zones. This difference in television schedule across time zones may exacerbate the effect of the different sunset time 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). On the contrary, 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).

More specifically, since prime time shows run an hour earlier in the middle time zone, we might expect, everything else constant, the discontinuity in bedtime to be larger along the Eastern-Central (EC) time-zone border, lower along the Mountain-Pacific (MP) time-zone border, while TV schedules should play no role at the Central-Mountain (CM) zone border. For this reason, in Table 5 we exploit the heterogeneity at the three time borders to investigate the role played by the television. In particular, in column (1) we estimate the effect of living on the eastern side of a time zone border on sleep duration (as in column (1) of Table 2) but adding to the model in equation (2), two dummies for the CM and and MP borders, that we interacted with the dummy identifying individuals living on the eastern 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 in the CM border than in the other two time zone borders. This evidence contrasts with the hypothesis that the TV is the main factor explaining the discontinuity we found at the time zone border in sleep duration. As above mentioned, since the TV shows are broadcasted earlier in the two middle time zone, we would have expected a larger effect in the EC time zone and a smaller effect in 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 selected mainly among the urban and populated areas, because we cannot identify counties or metropolitan areas with less than 100,000 residents.[15]

For this reason, in column (2) we also exploit the bedtime data from Jawbone already presented in Figure 4. This dataset is likely not to be representative of the US population[16] and does not allow us to focus only the employed people as in our sample, but different from ATUS it contains information on all US counties. Since we do not have 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 compensative behavior of the 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 show evidence of large heterogeneity across time zone borders. Different from column (1), we only have evidence of a significantly smaller effect at the MP border, consistent with a, rather small, mitigation effect of the TV.

4.3.1 Sweep Weeks and Sleep Duration

In a further attempt to test the importance of TV schedules and programs in determining individuals' bedtime, we also look at differences in sleep duration induced by the attractiveness of TV shows during the year. To this goal, we exploit the fact that all major TV broadcasts thrive to maximize audience rates during the Nielsen "sweeps" rating periods. Each year in the months of November, February, May and July[17], Nielsen Media Research, the company recording 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 watched. During these weeks, TV networks bring out new episodes, series and specials in an effort to boost their viewing figures, and hence the revenue from advertising. 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 the TV schedules during these weeks.

[15] In Table, A.6 we show that the effect of interest is larger in more populated metropolitan areas, the larger effect estimated along the CM border might be the consequence of the sample selection criterion.

[16] It is not hard to believe that young people from urban areas are more likely to use personal wearables tracking sleep quality and calorie expenditure.

[17] 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.

Using the exact dates of sweeps weeks between 2003 and 2013, we exploit this exogenous change in the broadcast programming. Specifically, we test whether the discontinuity at the time zone border is larger (or smaller) during the sweep weeks (column 4, Table 5). If the television plays a role in explaining the large discontinuity in sleep duration at the time zone borders, we should find 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 in the eastern side of the time zone boundary with a dummy that is equal to one for interviews made 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 (roughly 6 minutes). All in all, even though the television schedule influences bedtime and sleep duration (as pointed out by Hamermesh et al. (2008)), our analysis suggests that the television does not play a major role in explaining the discontinuity we found at the time zone border.

5 Effects of Sleeping on Health Status and Obesity

We exploit the discontinuity in sleep duration to evaluate the effects of sleep on obesity and self-reported health status. Again, we focus on the employed population, as we have shown that there is no significant discontinuity in sleep duration among the non-employed. As already mentioned, information on health status and body mass index is not available in all ATUS survey waves, thus, we have limited identification power. Despite that, the results in Table 6 show a significant effect of both health outcomes. In particular, columns 1 and 2 show the reduced-form and the 2SLS estimates on obesity, while columns 3 and 4 illustrate the effects on poor health. Employed individuals living on the eastern side of the time zone border are 6 percentage points more likely to be obese, approximately 22% with respect to the mean of the dependent variable in the sample under analysis (column 1). With regard to self-reported health status, column 3 shows that the effect is of almost 3-percentage points, almost 30% of the sample mean.

The IV estimates are obviously larger because of the fuzzy design of our RD strategy. As already mentioned, these estimates must be interpreted with caution. In fact, these health differences, expecially in the case of obesity, are likely to be the result of a long-term exposure to sleep differences (caused by the different sunset time) on the two sides of the time zone border. Therefore, in the case of the IV estimates, the point estimates measure the causal effect of long-term exposure to “sleep deprivation" of one-hour.

In the case of obesity the estimated effect is of almost 15-percentage points (58% of the mean) while for poor health the coefficient points to a 8-percentage points difference (87% of the mean).

Decreasing sleep duration by 19 minutes[18], the average difference in sleep duration observed at the time-zone border in the whole sample, increases obesity by approximately 4 percentage points, a 16% effect with respect to the mean of the dependent variable, and increases the likelihood of reporting poor health status by 2.4 percentage points, a 26% effect with respect to the mean of the dependent variable.

Table 7 illustrates the heterogeneity of our results by age groups. Consistent with our conjecture, columns 1 and 2 show the reduced-form effect on obesity is concentrated among older workers (column 2), who have been exposed to the treatment for longer than younger workers (column 1). On the contrary, the age gradient is small and not statistically significant when examining health status (columns 3 and 4). These differences are not surprising as 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 idiosyncratic variations in sleep duration, while obesity is more likely to reflect the cumulative effect of sleep deprivation over time.

5.1 Potential Mechanisms

The medical literature offers clear biological explanations for the effects of sleep deprivation on obesity. As mentioned above, medical research has shown that insufficient sleep affects the function regulating appetite and expenditure of energy. Previous studies provided evidence that food intake is a physiological adaptation to provide energy needed to sustain additional wakefulness and that sleep duration plays a key role in energy metabolism (Markwald et al., 2013) favoring the consumption of fats and carbohydrates. Furthermore, the fatigue due to sleep loss may reduce physical activity exacerbating the effects of sleep deprivation on weight gain. In this section, we examine how individuals' time use and activities may respond to these biological mechanisms and affect caloric intake and expenditure.

[18]Note that the first-stage is larger in the sample for which we have information on BMI and health status indicating an average difference in sleep duration at the border of 27 and 23 minutes respectively. However, the standard errors are relatively large and, thus, the first-stage is not statistically different from the one reported in Table 2 that shows that individuals on the the eastern side of the time zone border sleep approximately 19 minutes less than their neighbors living in counties on the opposite side.

Eating Habits

Insufficient sleep may increase calorie intake, particularly at evening as individuals start feeling tired and feel the need of energy to keep themselves awake. Markwald et al. (2013) present evidence of how changes in circadian rhythms may contribute to the altered eating patterns during insufficient sleep. In particular, they argue that a delay in melatonin onset, altering the beginning of the biological night, may lead to a circadian drive for more food intake at night. To verify whether this channel may contribute to explaining our findings we examine individuals' eating patterns on the two sides of the time zone border.

Table 8 documents that individuals on the eastern side of a time-zone border are more likely than their neighbors on the opposite side of the border to eat after a given hour. In particular, they are 30% more likely to start a meal after 6pm, 46% more likely to start a meal after 7pm, and 50% more likely to start a meal after 8pm. These results hold accounting for the number of meals one has had before 6pm, 7pm, and 8pm respectively, suggesting that people are not just shifting eating time to a later hour, but they are more likely to be eating after a given hour regardless of the number of times they ate or the time spent eating earlier on during the day.

Another possible explanation for the effects of sleep deprivation on obesity is that if individuals sleeping less are more tired in the evening, they may also be less willing to eat-in and more willing to eat outside. Indeed, previous studies show that because restaurants routinely serve food with more calories than people need, dining out represents a risk factor for overweight and obesity (Cohen and Story, 2014). To test this hypothesis, in Table 9 we use information on the location of each activity reported in the ATUS time diary and construct indicators for whether individuals consumed their meal at home or out.

Column 1 shows that individuals on the eastern side of the time-zone boundary are 4 percentage points more likely to eat out. The coefficient remains stable once we control for the overall number of meals (column 2). However, the estimates are imprecise. Note also that column 1 and 2 include lunch-meals at the work-place. In column 3 and 4 we focus on the likelihood of having dinner out, measured as dining out after 5pm. Individuals on the eastern-side of the time zone border are 8 percentage points more likely to eat out after 5pm. On the contrary, we find no significant differences among non-employed individuals at the borders for both the likelihood of having late meals after a certain hour and the likelihood of dining out (results are available upon request). Again, the results hold if we control for the number of meals one had before 5 pm or the overall time spent eating. Together, these findings suggest that insufficient sleep may affect obesity through its effects on the likelihood of having more meals/snacks after a given hour as well as the likelihood of dining out. The fact that results are robust to the inclusion of controls for previous number of meals/average time spent in previous meals suggests these differences in eating behaviors may lead to a net increase in caloric intake.

Physical Activity

Another potential explanation for the effect of sleeping on obesity is that insufficient sleep may reduce calorie expenditure because tired individuals are less likely to engage in physical activities. Using ATUS data on time spent walking, biking, or doing any kind of sport activity we do not find any evidence of significant differences between individuals on opposite sides of time-zone borders. However, we find some evidence that individuals on the eastern side of the time zone border are less likely to engage in activities of moderate, vigorous, or very vigorous intensity using metabolic equivalents associated to each activity reported in the ATUS time diary.[19]

Tudor-Locke et al. (2009) used information from the Compendium of Physical Activities to code physical activities derived from the ATUS.[20] We follow the conventional criteria to classify the reported activities based on their intensity(Haskell et al., 2007; Tudor-Locke et al., 2009). More specifically, we classify activities in 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 10, we test whether individuals on the eastern side of the time zone boundary have different likelihood to engage in moderate or vigorous activities for more than 30 minutes.[21] We find that they spend less time doing moderate or vigorous physical activity. The coefficient reported in column 1 indicates that in counties on the eastern side 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

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

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

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

under the age of 13 in the household (column 2), while the estimate is non-significantly different from zero for individuals without children under the age of 13 (see column 3).

As noted by Tudor-Locke et al. (2009), the use of the ATUS dataset for the study of physical activity has a number of limitations as only one activity at a time is captured, so that any physical activity secondary to a primary activity would not be counted. Furthermore, the ATUS is based on the time diaries of randomly selected adults in the United States for a single 24-hour period and, thus, the data may not characterize habitual physical activity behaviors of individuals or selected population groups. For this reason, we present further analysis using county-level data on physical activity made available by the Institute for Health Metrics and Evaluation (IHME) (see Table 11). IHME provides data on physical activity as calculated by Dwyer-Lindgren et al. (2013) who used data from the Behavioral Risk Factor Surveillance System (BRFSS) to generate estimates of physical activity prevalence for each county annually for 2001 to 2011, using small area estimation methods (Srebotnjak et al., 2010).[22]

We used 2011 data for both men and women. Column 1 shows that individuals living on the eastern side of the time zone border are 1 percentage point less likely to report sufficient physical activity. Note that these are county-level estimates based on the entire population. Therefore, the estimated effect would be even larger if we could focus on employed aged 18-55 as in our main analysis. Consistent with this conjecture, column 2 shows that in high-unemployment areas (above the median) the effect is close to zero while column 3 indicates that the effects are larger in absolute value in counties with a lower share of over-65 (below the median). Again the heterogeneity across areas suggests that these results are driven by the employed population and that part of the effect on obesity may be explained by differences in physical activity.

The evidence obtained using ATUS and IHME data is consistent with recent evidence from lab studies showing that sleep deprivation reduces significantly physical activity and, thus, calories expenditure (Schmid et al., 2009; Opstad and Aakvaag, 1982).

6 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.

[22] Data can be downloaded at `http://www.healthdata.org/us-county-profiles`. IHME's US county performance research compiles available national and local health data from throughout the United States.

First, we test the unconfoundedness hypothesis behind our RD design. Following standard practice in RD designs, we verify whether there are discontinuities in predetermined characteristics known not to be affected by the treatment (sleeping). In fact, in the presence of other discontinuities, the estimated effect may be attributed erroneously to the treatment of interest.

As largely discussed in Section 3.1, a natural concern is that residential sorting across the time zone border will create correlation between unobservable individual characteristics and individual residence. As we control for latitude, and, thus, hold daylight duration fixed, sorting would bias our estimates only if individuals sort based on the timing of daylight. We conduct a variety of tests for residential sorting and find no evidence for it. Specifically, we test whether there are differences in body height using the same estimation strategy used to test the presence of discontinuities in sleeping. The results in the first column Table 12 do not show any difference in height on the two sides of the time zone border. This result is consistent with the evidence from the balancing test presented in Table 1.

Furthermore, we verify whether there were historical differences between the two sides of the time zones before the adoption of the time zones in the US in 1914. In particular, we use the 1900 US census to test whether there was a discontinuity in literacy rates across the current time zone borders. Column 2 of Table 12 shows the result from this test. As above, this test does not cast doubts on our identification strategy.

In Table A.5, 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 prefer to locate on a given side of the time-zone border.

While we cannot identify counties or metropolitan areas with less than 100,000 residents, in Table A.6 we illustrate the hetoregeneity in the first-stage 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.1 re-estimates the first-stage discussed in Table 2 using alternative metrics for sleep duration. Column 1 replicates the result presented in column 1 of Table 2 which excluded from the count naps, 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 eastern 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). On the contrary, we find no differences in naps measured as the total amount of time slept between 11am and 8pm (see column 6).

Furthermore, we verify the robustness of our results by leaving out 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.

Finally, we tested for the optimal polynomial order by comparing our local linear regression approach with higher polynomial orders (up to the fourth) using the well-known Akaike information criterion (AIC) and the Bayesian information criterion (BIC). Both the AIC and BIC are minimized using the local linear regression approach reported in our main text (results are available upon request).

7 Conclusion

This paper investigated the causal effects of sleeping on health status and obesity, two outcomes that are known to be importantly related to health care costs and individual's productivity. We exploit discontinuities in bedtime that occur at a time-zone boundary because of solar cues, circadian rhythms and their conflict with social schedules. We show that individuals living on the eastern side of a time-zone boundary tend to go to bed at later times with respect to individuals living in the neigbhouring counties on the opposite side of the time-zone border. Because working schedules and school start times are less flexible than bedtime, individuals on the eastern side of the border do not fully compensate by waking up later in the morning. Thus, we find that employed individuals living on the eastern side of a time zone border sleep less than people living in a neighboring county on the western 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.

Using this exogenous variation in sleep duration we find large effects of sleeping on individuals' health status and obesity. These results are the effects of a cumulative exposure to sleep deprivation. Our findings suggest that the higher propensity to eat late in the evening, regardless of the time spent eating earlier in the day, as well as the higher likelihood of dining out and lower likelihood of engaging in moderate or intense physical activity contribute to explain the effects on obesity and health status. The results are robust to the use of different models and measures of sleep duration. Importantly, we find no evidence of any significant effect on outcomes that should not be affected by sleep duration.

Economists have largely ignored the effects of sleep on health and how economic incentives or changes in policies (e.g., changes of Daylight Saving Time dates), can affect sleeping and have unintended consequences on health and productivity. Our findings highlight the importance of developing a public awareness about the negative effect of sleep deprivation and suggest that policy makers should carefully consider how working schedules and time zone rules can affect sleep duration and quality. In fact, 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 conflict 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 after 8.30am would subtantially increase average sleep duration.

Finally, large attention has been devoted in the recent years to the obesity epidemic, in particular in the United States, with the implementation of several state and federal programs aimed to reduce obesity. Most of these programs are promoting healthy nutrition and physical activity. Our results suggest the importance of increasing the spectrum of these public health interventions by including policies aimed at increasing the average sleep duration and a healthier use of our time. Sleep education programs should become a central part of any program aiming at reducing obesity and weight gain in populations at risk.

References

Altevogt, B. M., Colten, H. R., et al., 2006. Sleep Disorders and Sleep Deprivation:: An Unmet Public Health Problem. National Academies Press.

Aschoff, J., Fatranska, M., Giedke, H., Doerr, P., Stamm, D., Wisser, H., 1971. Human circadian rhythms in continuous darkness: entrainment by social cues. Science 171 (3967), 213–215.

Ásgeirsdóttir, T. L., Ólafsson, S. P., 2015. An empirical analysis of the demand for sleep: Evidence from the american time use survey. Economics & Human Biology.

Barger, L. K., Cade, B. E., Ayas, N. T., Cronin, J. W., Rosner, B., Speizer, F. E., Czeisler, C. A., 2005. Extended work shifts and the risk of motor vehicle crashes among interns. New England Journal of Medicine 352 (2), 125–134.

Basner, M., Fomberstein, K. M., Razavi, F. M., Banks, S., William, J. H., Rosa, R. R., Dinges, D. F., 2007. American time use survey: sleep time and its relationship to waking activities. Sleep 30 (9), 1085.

Bergstrom, T., 1976. The deeper economics of sleeping. The Journal of Political Economy, 411–412.

Biddle, J. E., Hamermesh, D. S., 1990. Sleep and the allocation of time. Journal of Political Economy 98, 922–943.

Bonke, J., 2012. Do morning-type people earn more than evening-type people? How chronotypes influence income. Annals of Economics and Statistics/ANNALES D'ÉCONOMIE ET DE STATISTIQUE, 55–72.

Brochu, P., Armstrong, C. D., Morin, L.-P., 2012. The âĂŸtrendinessâĂŹ of sleep: an empirical investigation into the cyclical nature of sleep time. Empirical Economics 43 (2), 891–913.

Burton, W. N., Chen, C.-Y., Conti, D. J., Schultz, A. B., Pransky, G., Edington, D. W., 2005. The association of health risks with on-the-job productivity. Journal of Occupational and Environmental Medicine 47 (8), 769–777.

Cappuccio, F. P., D'Elia, L., Strazzullo, P., Miller, M. A., 2010. Sleep duration and all-cause mortality: a systematic review and meta-analysis of prospective studies. Sleep 33 (5), 585.

Carrell, S. E., Maghakian, T., West, J. E., 2011. A's from zzzz's? The causal effect of school start time on the academic achievement of adolescents. American Economic Journal: Economic Policy 3 (3), 62–81.

Cawley, J., 2004. The impact of obesity on wages. Journal of Human Resources 39 (2), 451–474.

Cawley, J., Meyerhoefer, C., 2012. The medical care costs of obesity: an instrumental variables approach. Journal of health economics 31 (1), 219–230.

Cohen, D. A., Story, M., 2014. Mitigating the health risks of dining out: the need for standardized portion sizes in restaurants. American journal of public health 104 (4), 586–590.

Duffy, J. F., Wright, K. P., 2005. Entrainment of the human circadian system by light. Journal of Biological Rhythms 20 (4), 326–338.

Dwyer-Lindgren, L., Freedman, G., Engell, R. E., Fleming, T. D., Lim, S. S., Murray, C., Mokdad, A. H., 2013. Prevalence of physical activity and obesity in us counties, 2001–2011: a road map for action. Popul Health Metr 11 (1), 7.

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

El Hodiri, M., 1973. The economics of sleeping. Unpublished manuscript, University of Kansas.

Gibson, M., Shrader, J., 2014. Time use and productivity: The wage returns to sleep.

Giuntella, O., Han, W., Mazzonna, F., 2015. Circardian rhythms, sleep deprivation and cognitive skills. evidence from an unsleeping giant. University of Oxford, Mimeo.

Greer, S. M., Goldstein, A. N., Walker, M. P., 2013. The impact of sleep deprivation on food desire in the human brain. Nature communications 4.

Hamermesh, D. S., Myers, C. K., Pocock, M. L., 2008. Cues for timing and coordination: latitude, letterman, and longitude. Journal of Labor Economics 26 (2), 223–246.

Haskell, W. L., Lee, I.-M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., Macera, C. A., Heath, G. W., Thompson, P. D., Bauman, A., 2007. Physical activity and public health: updated recommendation for adults from the american college of sports medicine and the american heart association. Circulation 116 (9), 1081.

Hoffman, E. P., 1977. The deeper economics of sleeping: important clues toward the discovery of activity x. The Journal of Political Economy, 647–649.

Jin, L., Ziebarth, N. R., 2015. Does daylight saving time really make us sick? Tech. rep., Institute for the Study of Labor (IZA).

Kjærgaard, M., Waterloo, K., Wang, C. E., Almås, B., Figenschau, Y., Hutchinson, M. S., Svartberg, J., Jorde, R., 2012. Effect of vitamin d supplement on depression scores in people with low levels of serum 25-hydroxyvitamin d: nested case–control study and randomised clinical trial. The British Journal of Psychiatry 201 (5), 360–368.

Knutson, K. L., Spiegel, K., Penev, P., Van Cauter, E., 2007. The metabolic consequences of sleep deprivation. Sleep medicine reviews 11 (3), 163–178.

Lauderdale, D. S., Knutson, K. L., Yan, L. L., Liu, K., Rathouz, P. J., 2008. Sleep duration: how well do self-reports reflect objective measures? The cardia sleep study. Epidemiology (Cambridge, Mass.) 19 (6), 838.

Lyznicki, J. M., Doege, T. C., Davis, R. M., Williams, M. A., et al., 1998. Sleepiness, driving, and motor vehicle crashes. Jama 279 (23), 1908–1913.

Markwald, R. R., Melanson, E. L., Smith, M. R., Higgins, J., Perreault, L., Eckel, R. H., Wright, K. P., 2013. Impact of insufficient sleep on total daily energy expenditure, food intake, and weight gain. Proceedings of the National Academy of Sciences 110 (14), 5695–5700.

Ohayon, M. M., Reynolds, C. F., Dauvilliers, Y., 2013. Excessive sleep duration and quality of life. Annals of neurology 73 (6), 785–794.

Opstad, P. K., Aakvaag, A., 1982. Decreased serum levels of oestradiol, testosterone and prolactin during prolonged physical strain and sleep deprivation, and the influence of a high calory diet. European journal of applied physiology and occupational physiology 49 (3), 343–348.

Roenneberg, T., 2013. Chronobiology: the human sleep project. Nature 498 (7455), 427–428.

Roenneberg, T., Allebrandt, K. V., Merrow, M., Vetter, C., 2012. Social jetlag and obesity. Current Biology 22 (10), 939–943.

Roenneberg, T., Kuehnle, T., Juda, M., Kantermann, T., Allebrandt, K., Gordijn, M., Merrow, M., 2007. Epidemiology of the human circadian clock. Sleep medicine reviews 11 (6), 429–438.

Roenneberg, T., Merrow, M., 2007. Entrainment of the human circadian clock. In: Cold Spring Harbor symposia on quantitative biology. Vol. 72. Cold Spring Harbor Laboratory Press, pp. 293–299.

Schmid, S. M., Hallschmid, M., Jauch-Chara, K., Wilms, B., Benedict, C., Lehnert, H., Born, J., Schultes, B., 2009. Short-term sleep loss decreases physical activity under free-living conditions but does not increase food intake under time-deprived laboratory conditions in healthy men. The American journal of clinical nutrition 90 (6), 1476–1482.

Smith, A. C., forthcoming. Spring forward at your own risk: Daylight saving time and fatal vehicle crashes. American Economic Journal: Applied Economics.

Srebotnjak, T., Mokdad, A. H., Murray, C., 2010. A novel framework for validating and applying standardized small area measurement strategies. Popul Health Metr 8, 26.

Stewart, J., 2014. Early to bed and earlier to rise: school, maternal employment, and childrenâĂŹs sleep. Review of Economics of the Household 12 (1), 29–50.

Szalontai, G., 2006. The demand for sleep: a south african study. Economic Modelling 23 (5), 854–874.

Taheri, S., Lin, L., Austin, D., Young, T., Mignot, E., 2004. Short sleep duration is associated with reduced leptin, elevated ghrelin, and increased body mass index. PLoS medicine 1 (3), e62.

Tudor-Locke, C., Washington, T. L., Ainsworth, B. E., Troiano, R. P., 2009. Linking the american time use survey (atus) and the compendium of physical activities: methods and rationale. Journal of Physical Activity and Health 6 (3), 347–353.

Ulukavak, C. T., Kokturk, O., Bukan, N., Bilgihan, A., 2004. Leptin and ghrelin levels in patients with obstructive sleep apnea syndrome. Respiration; international review of thoracic diseases 72 (4), 395–401.

Van Dongen, H. P., Maislin, G., Mullington, J. M., Dinges, D. F., 2003. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. SLEEP-NEW YORK THEN WESTCHESTER- 26 (2), 117–129.

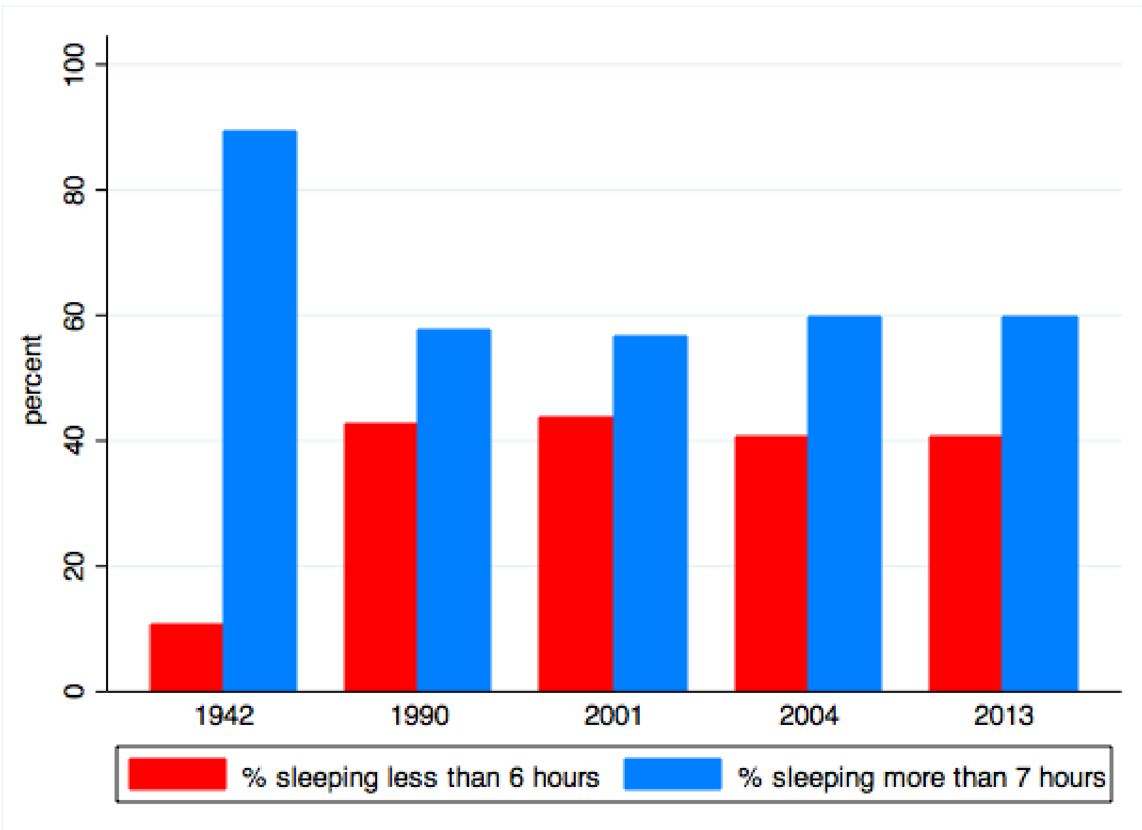
Vitaterna, M. H., Takahashi, J. S., Turek, F. W., 2001. Overview of circadian rhythms. Alcohol Research and Health 25 (2), 85–93.

Weinger, M. B., Ancoli-Israel, S., 2002. Sleep deprivation and clinical performance. Jama 287 (8), 955–957.

Winston, G. C., et al., 2008. The timing of economic activities. Cambridge Books.

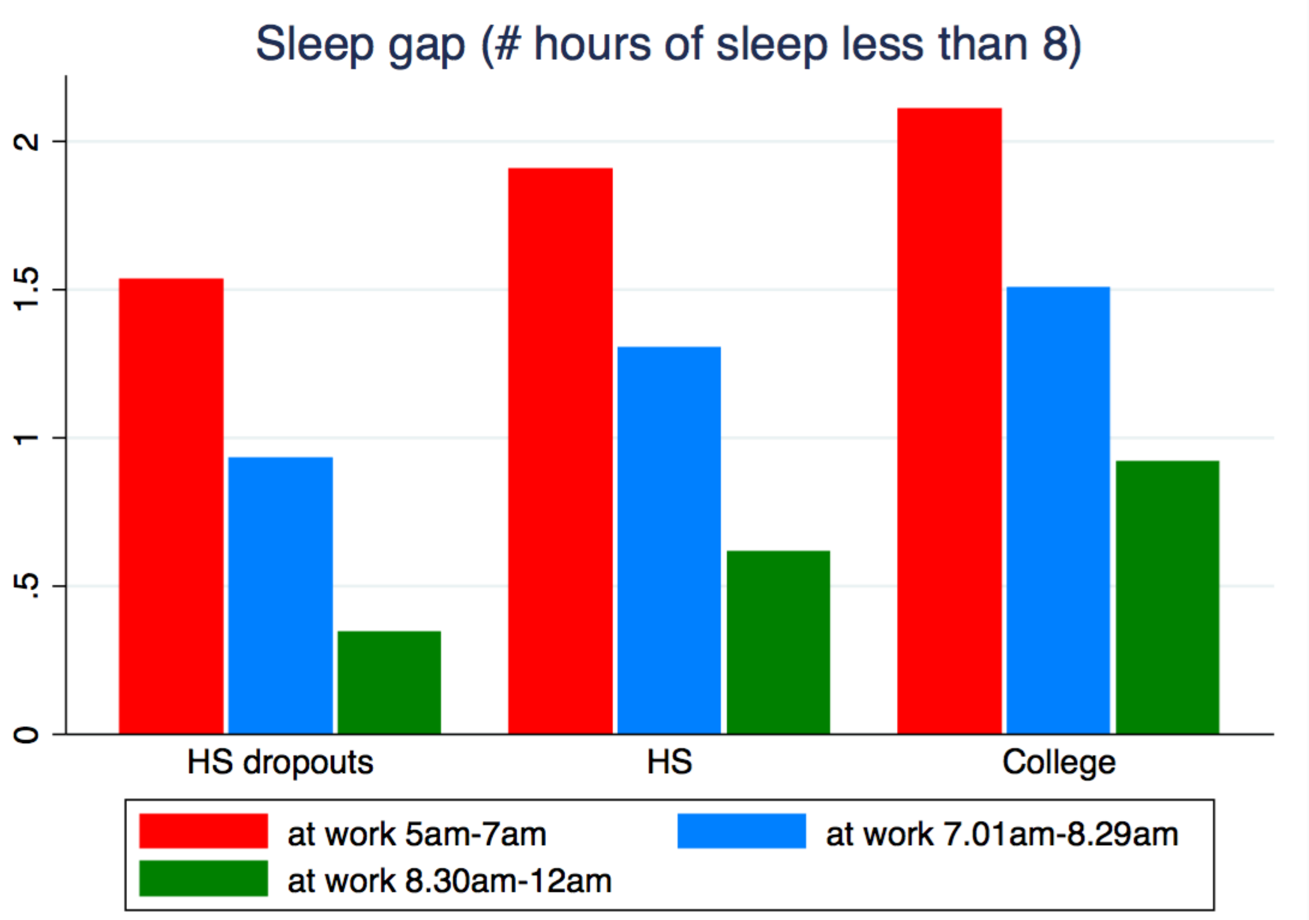
Wolff, H., Makino, M., 2012. Extending becker's time allocation theory to model continuous time blocks: Evidence from daylight saving time.

Figure 1: US sleeping over time



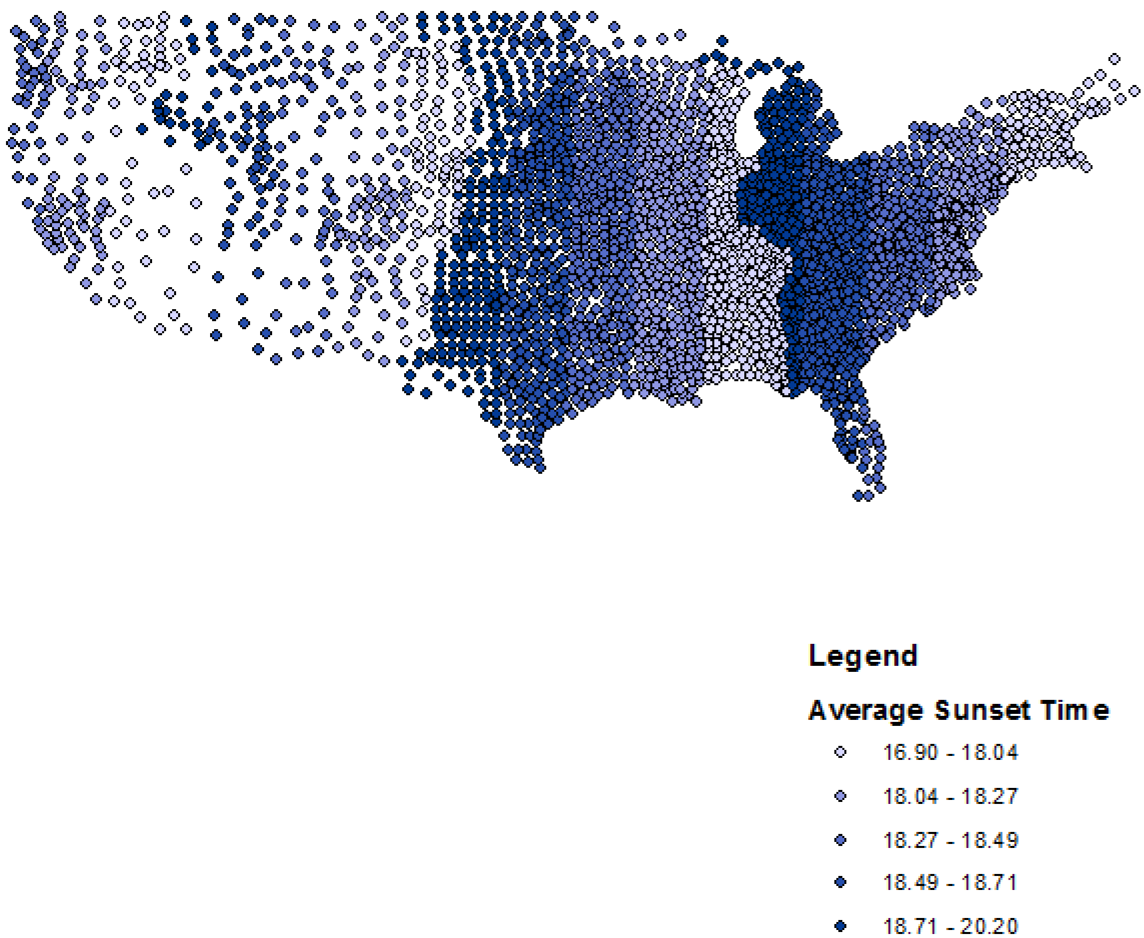
Notes - Source: Gallup, 1942-2013

Figure 2: Sleep Deprivation by Education and Morning Work Schedule



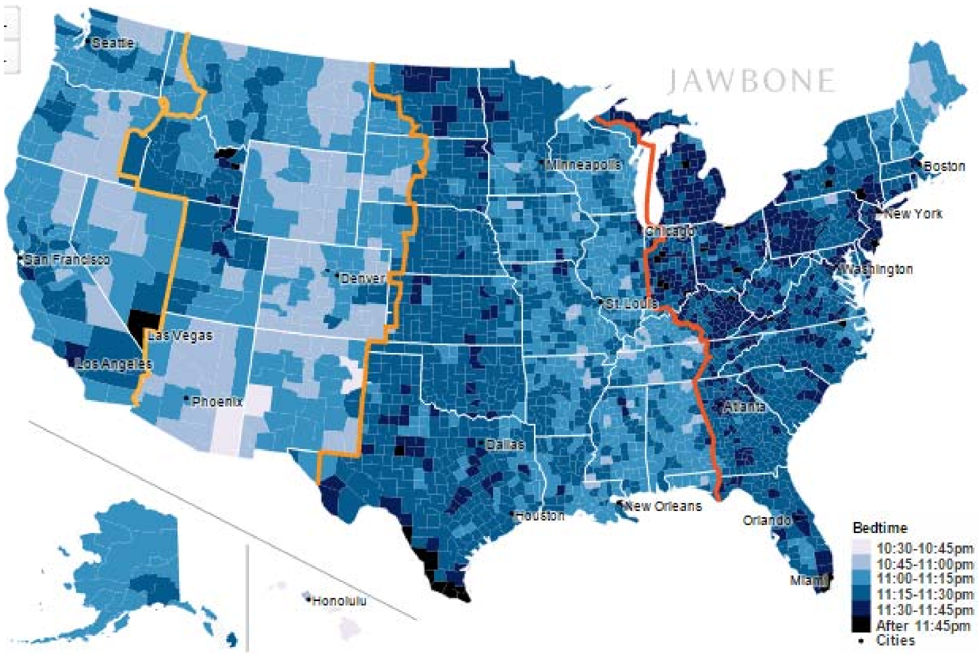
Notes - To better visualize differences in sleep duration we report the difference between the reccomended 8 hours of sleep and the observed sleep duration by education and working schedule for the average white man, aged between 40 and 50 years old, living on the East coast.

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 in 5 quintiles based on the average sunset time in a given year. The darker the circles the later the average sunset time.

Figure 4: Time zones and bedtime (Source: jawbone.com/blog)



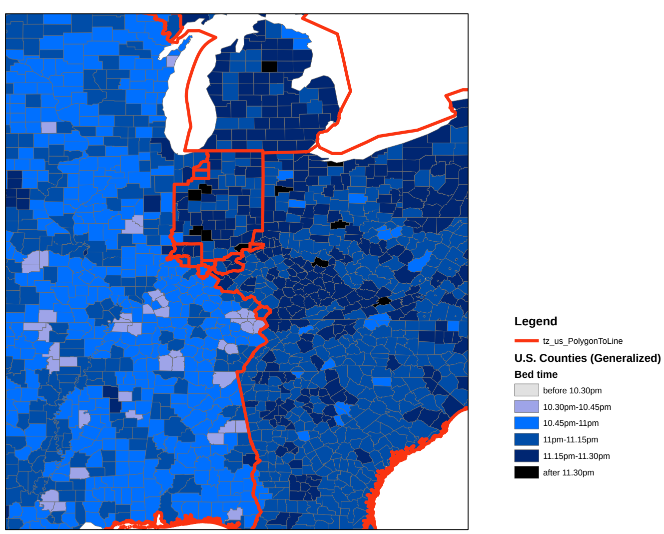


Figure 5: Discontinuity in sunset time

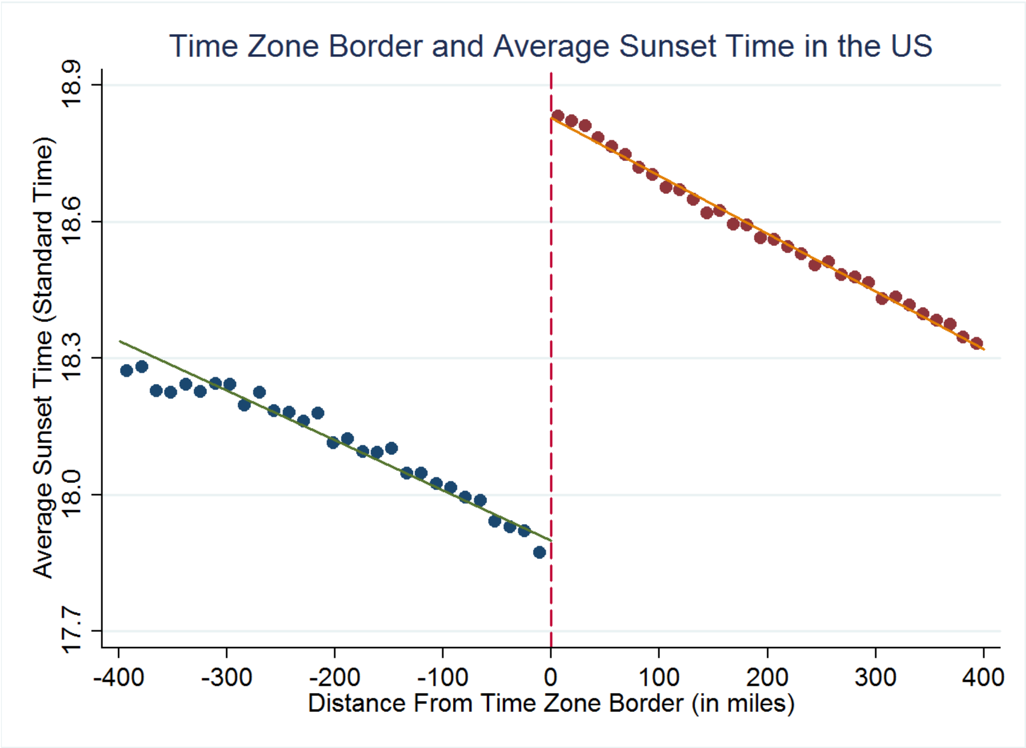


Figure 6: Sleep duration over the week

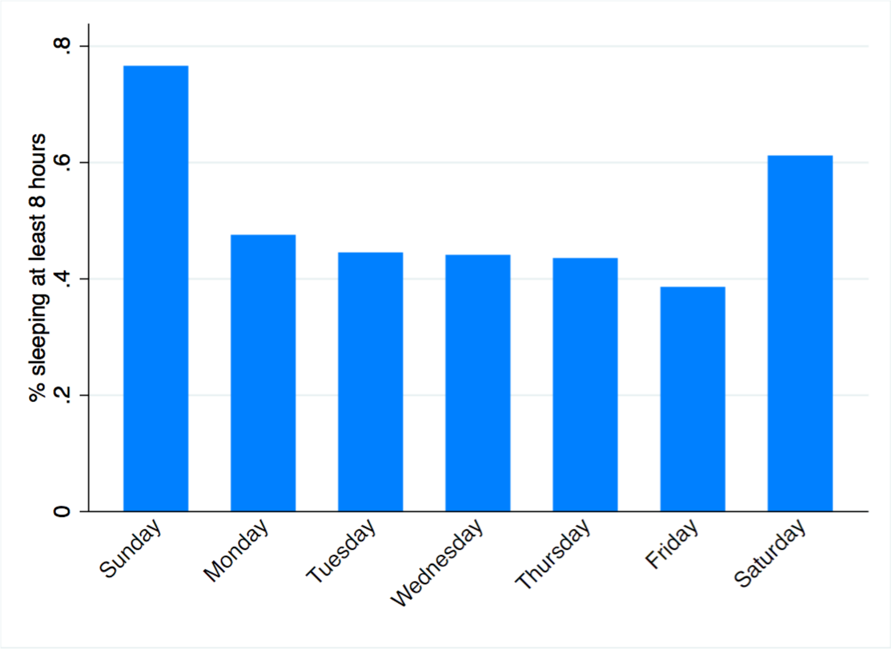


Figure 7: Discontinuity in sleep duration

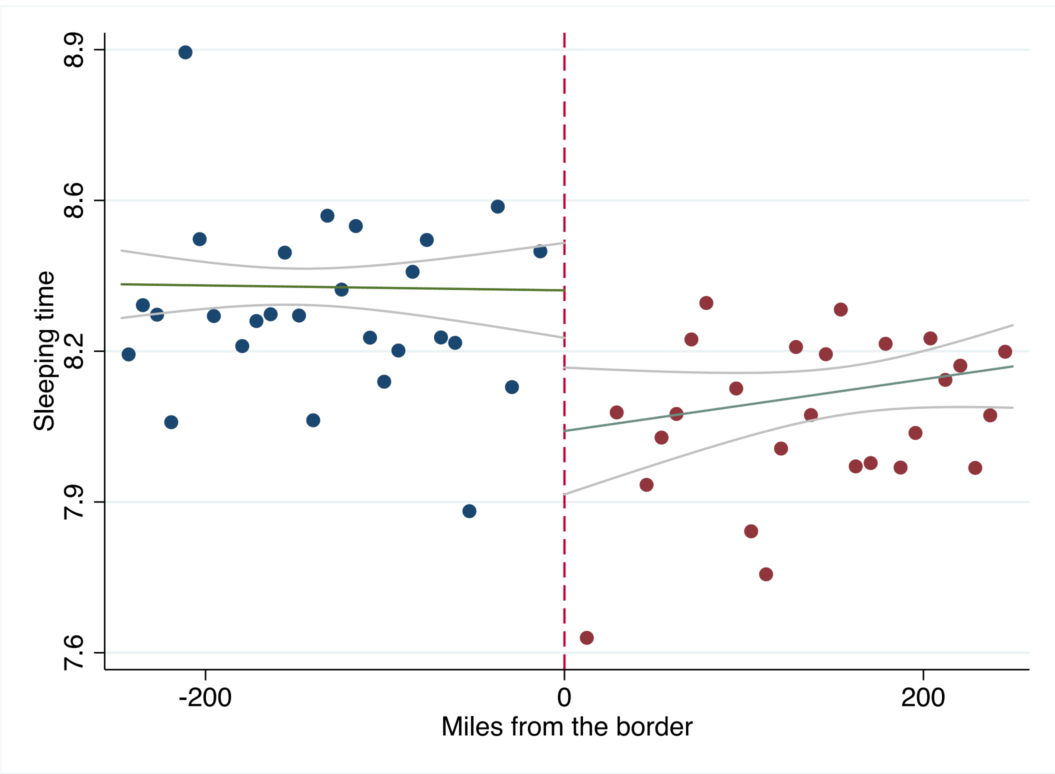


Table 1: Balancing Test

	Early Sunset Border Within 250 miles	Late Sunset Border Within 250 miles	Counties at the border Within 250 miles Late-Early Sunset Side of Time Zone	Observations
Average Sunset Time	18.007	18.588	0.572***	16,557
	(0.970)	(0.909)	(0.039)	
Sleep Hours	8.382	8.188	-0.188***	16,557
	(1.921)	(1.965)	(0.051)	
Sleep at least 8 hours	0.591	0.544	-0.046***	16,557
	(0.492)	(0.498)	(0.010)	
Awake at 11pm	0.311	0.385	0.069***	16,557
	(0.464)	(0.486)	(0.016)	
Awake at 7.30am	0.575	0.558	-0.017	16,557
	(0.494)	(0.497)	(0.017)	
Obese	0.244	0.268	0.036**	4,331
	(0.430)	(0.443)	(0.015)	
Poor Health Status	0.099	0.081	-0.015	9,696
	(0.298)	(0.273)	(0.011)	
Female	0.490	0.498	0.009	16,557
	(0.500)	(0.500)	(0.010)	
Age	38.478	38.913	0.489	16,557
	(10.311)	(10.500)	(0.385)	
Black	0.0481	0.0963	0.049***	16,557
	(0.214)	(0.295)	(0.016)	
White	0.858	0.848	-0.010	16,557
	(0.349)	(0.359)	(0.021)	
Holiday	0.018	0.018	-0.000	16,557
	(0.133)	(0.133)	(0.003)	
Weekend	0.510	0.489	-0.018	16,557
	(0.500)	(0.500)	(0.016)	
Less than High-School	0.307	0.303	0.003	16,557
	(0.461)	(0.460)	(0.021)	
Some College	0.309	0.316	0.009	16,557
	(0.462)	(0.465)	(0.014)	
College or More	0.3836	0.380	-0.012	16,557
	(0.486)	(0.486)	(0.019)	
Number of children	0.977	0.922	-0.046	16,557
	(1.178)	(1.134)	(0.033)	
Married	0.587	0.596	0.009	16,557
	(0.492)	(0.490)	(0.019)	
Weekly earnings	863.253	831.308	-31.513	14,829
	(643.282)	(603.732)	(24.246)	
Hourly Wage	15.826	15.114	-0.602	8,325
	(9.671)	(8.996)	(0.446)	

Notes - Data are drawn from the ATUS (2003-2013). The sample is restricted to employed individuals aged 18-55.

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

	(1)	(2)	(3)	(4)
Dep.Var.:	Sleep Hours	Sleep Hours	Sleep Hours	Sleep$\geq$ 8 hours
Late Sunset Border	-0.319***	-0.319***	-0.386**	-0.082***
	(0.080)	(0.119)	(0.162)	(0.021)
Observations	16,557	16,557	3,918	16,557
Adj. R^2	0.132	0.132	0.129	0.090
$F^*_{(1,63)}$	15.84	7.16	5.71	15.69
Mean of Dep.Var.	8.040	8.040	8.040	0.517
Std.Err.	1.784	1.790	1.80	0.484
State FE	NO	YES	NO	NO
Bandwidth (miles)	250	250	100	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, 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 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 3: Effect of Late Sunset Time on Sleeping (Employed vs. Unemployed)

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Var.:	Sleep Hours		Awake at 11pm		Awake at 7.30 am	
Sample	Employed	Unemployed	Employed	Unemployed	Employed	Unemployed
Late sunset border	-0.319***	0.142	0.138***	0.129**	-0.011	-0.134**
	(0.080)	(0.325)	(0.031)	(0.066)	(0.034)	(0.055)
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
Mean of Dep.Var.	8.04	8.79	0.337	0.383	0.658	0.414
Std.Err.	1.965	2.023	0.498	0.491	0.4993	0.484
Bandwidth (miles)	250	250	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, 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 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 4: Effect of late sunset time on sleeping by work start time

	(1)	(2)	(3)	(4)
Work start :	5-7am	7.01-8.29am	8.30am-12pm	8.30am-12pm
Late Sunset Border	-0.587***	-0.304**	-0.031	-0.023
	(.118)	(.138)	(.199)	(.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.Err.	1.324	1.378	1.565	1.565
Bandwidth (miles)	250	250	250	250

Notes - Data are drawn from the ATUS (2003-2013). The sample is restricted to individuals who reported to have worked on the day of the ATUS interview. 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, 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 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 5: Heterogeneity Across Time-Zone Border and Sweep Weeks

	(1) Sleep duration (ATUS)	(2) Bedtime (Jawbone)	(3) Sleep duration (ATUS)
Late sunset	-0.262***	0.303***	-0.374***
	(0.088)	(0.046)	(0.082)
Late sunset*CM	-0.289**	-0.015	
	(0.114)	(0.049)	
Late sunset*MP	-0.085	-0.073**	
	(0.091)	(0.034)	
Late sunset*sweeps			0.092
			(0.067)
Sweeps weeks			-0.103***
			(0.036)
Observations	16,653	2041	16,653
R-squared	0.136	0.631	0.136

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, latitude, longitude, census regions, and a dummy for large counties. Column (1) and (3) include also the same socio-demographic and interview controls as in Table 2, 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 geographical level (counties are grouped based on the distance from the time zone border).

Table 6: Effect of Sleeping on Obesity and Poor Health (Only Employed)

	(1)	(2)	(3)	(4)
Dep.Var.:	Obese		Poor health	
	Reduce form	IV	Reduce form	IV
Late sunset border	0.061**		0.029**	
	(0.031)		(0.014)	
sleeping		-0.148**		-0.081**
		(0.065)		(0.033)
Observations	4,154	4,154	9,177	9,177
$F^*_{(1,61)}$		9.37		17.96
Mean of Dep.Var.	0.261	0.261	0.090	0.090
Std.Err.	0.439	0.439	0.287	0.287
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 whether the interview was 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 geographical level (counties are grouped based on the distance from the time zone border).

$^{*}F$-test on the excluded instrument.

Table 7: Heterogeneity by Age Group (Only Employed)

	(1)	(2)	(3)	(4)
Dep.Var.:	Obese		Poor health	
	age$<$ 40	age $\geq$ 40	age$<$40	age $\geq$ 40
Late Sunset Border	0.027	0.120**	0.027	0.031
	(0.019)	(0.054)	(0.014)	(0.019)
Observations	2,235	1,919	4,939	4,238
Mean of Dep.Var.	0.255	0.268	0.082	0.0100
Std.Err.	0.436	0.443	0.275	0.300
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 whether the interview was 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 geographical level (counties are grouped based on the distance from the time zone border).

Table 8: Time-Zone Boundary and Late Meals

Dep.Var.:	(1) Started meal after 6pm	(2) Started meal after 7pm	(3) Started meal after 8pm	(4) Started meal after 9pm	(5) Started meal after 10pm
Late sunset border	0.099***	0.066***	0.035***	0.011	0.009*
	(0.024)	(0.015)	(0.012)	(0.009)	(0.005)
Number of meals before	YES	YES	YES	YES	YES
Observations	16,557	16,557	16,557	16,557	16,557
R-squared	0.028	0.029	0.028	0.026	0.018
Mean of Dep.Var.	0.311	0.163	0.077	0.033	0.011
Std.Dev.	(0.463)	(0.370)	(0.267)	(0.179)	(0.105)

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 whether the interview was during a public holiday or over the weekend), and dummies for the number of meals occurred before 5pm.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 9: Time-Zone Boundary and Dining Out

	(1)	(2)	(3)	(4)
Dependent Variable:	Eating Out	Eating Out	Dinner Out	Dinner Out
Late sunset	0.038	0.037	0.084***	0.084***
of time zone	(0.025)	(0.022)	(0.017)	(0.017)
Observations	16,557	16,557	16,557	16,557
Number of meals before 5pm	NO	YES	NO	YES
R-squared	0.049	0.170	0.051	0.076
Mean of Dep. Var.	0.550	0.550	0.312	0.312
Std.Err. of Dep. Var.	0.498	0.498	0.463	0.463

Notes - Data are drawn from the ATUS (2003-2013). The dependent variable in column 1 and 2 is an indicator for whether an individual consumed a meal out (including lunch), while in columns 3 and 4 the dependent variable is an indicator for whether an individual consumed a meal out after 5pm (dinner time). 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 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 10: 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	-0.024	-0.052**	-0.007
	(0.016)	(0.022)	(0.023)
Observations	16,557	7,452	9,105
R-squared	0.085	0.072	0.082
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 to 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, 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 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 11: Time Zone Border and Physical Activity at County Level (BRFSS, 150 Minutes of Moderate Physical Activity per Week)

	(1)	(2)	(3)
Dep.Var.	Physically Active (%)	Physically Active (%)	Physically Active (%)
Late sunset border	-1.031***	-1.547***	-1.408***
	(0.372)	(0.438)	(0.452)
Late sunset*high unemployment		1.392***	
		(.455)	
Late sunset*high share65+			0.812**
			(0.414)
Observations	2,031	2,031	2,031
Adj. R^2	0.537	0.568	0.547
Mean of Dep.Var.	51.371	51.371	51.371
Std. Dev.	6.556	6.556	6.556

Notes - The dependent variable is the share of people in the county that report in 2011 a sufficient level of physical activity according to the BFRSS definition (at least 150 minutes of moderate physical activity per week). All estimates include the distance to the time-zone boundary and its interaction with the late sunset border, socio-demographic characteristics at county level (share of people over 65, under 25, female, white, black and with high school), latitude, longitude, census regions, and a dummy for large counties. The second specification adds a dummy for counties with unemployment rate higher than the median and its interaction with the right border (late sunset time). The third specification adds to the first one a dummy for counties with a share of people over 65 higher than the median and its interaction with the right border (late sunset 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 12: Unconfoundness Tests: Discontinuities in Height and Historical Literacy

	(1)	(2)
Variable:	Height (in cm)	Literacy in 1900
Late sunset	0.161	0.013
	(0.521)	(0.016)
N	4,614	18,381
Adj. R^2	0.079	0.146
Mean of Dep.Var.	170.964	0.877
Std.Err.	10.461	0.315

Notes - The first column tests for the presence of discontinuities in height using the same specification and sample as in Table 2 column 1. The second column tests for the presence of discontinuities in literacy using the 1900 census and controlling for standard socio-demographic characteristics (age, race, sex, married and number of children), county characteristics (region fixed effects, latitude and longitude and a dummy for large counties). 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).

Appendix A

Table A.1: 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
R-squared	0.137	0.146	0.034	0.095	0.015	0.036
Mean of Dep. Var.	8.284	8.553	0.112	0.570	0.232	0.326
Std.Err. of Dep. Var.	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, 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 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 A.2: Effect of Late Sunset Time on Sleeping by Sector

Sample	(1) Overall Sleep hours	(2) Retail & Whoselale Sleep hours	(3) Education, Health Public administration Sleep hours	(4) Financial services Sleep hours
Eastern 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
R-squared	0.133	0.169	0.125	0.237
Mean of Dep. Var.	8.497	8.497	8.497	8.497
Std.Err. of Dep. Var.	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 whether the interview was during a public holiday or over the weekend). The second specification adds a dummy for counties with unemployment rate higher than the median and its interaction with the right border (late sunset time). The third specification adds to the first specification a dummy for counties with a share of people over 65 higher than the median and its interaction with the right border (late sunset time). Standard errors are robust and clustered at 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
$F^*_{(1,63)}$	15.84	7.16	5.71	15.69
Mean of Dep.Var.	8.237	8.248	8.030	8.040
Std.Err.	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, 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 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 A.4: 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

Notes - Data are drawn from ATUS (2003-2013). The estimates indicate the marginal difference with respect to a white male individual interviewed on a weekday with high-school degree, starting to 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.5: Residential sorting tests

	(1) log(House value)	(2) log(monthly rent)	(3) commuting time (minutes)	(4) pop. density (per sq.mile)
late sunset	0.041	0.044	0.400	-7.437
	(0.035)	(0.029)	(0.0383)	(33.052)
N.	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.Er..	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, 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. 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.6: Sleeping and Time-Zone Border, by MSA size

Dep.Var.:	(1) Sleep Hours Overall Sample	(2) Sleep Hours Less than 500,000 MSA residents	(3) Sleep Hours More than 500,000 MSA residents
Late sunset	-0.318***	-0.216*	-0.422***
	(0.079)	(0.123)	(0.085)
Observations	16,557	4,394	12,163
R-squared	0.137	0.156	0.139
Mean of Dep. Var.	8.284	8.186	8.319
Std.Err. of Dep. Var.	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, 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 whether the interview was during a public holiday or over the weekend). The second specification adds a dummy for counties with unemployment rate higher than the median and its interaction with the right border (late sunset time). The third specification adds to the first specification a dummy for counties with a share of people over 65 higher than the median and its interaction with the right border (late sunset 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).