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Osea Giuntella, Blavatnik School of Government, University of Oxford

Wei Han, Blavatnik School of Government, University of Oxford

Fabrizio Mazzonna, University of Lugano

Circadian Rhythms, Sleep and Cognitive Skills. Evidence From an Unsleeping Giant

Osea Giuntella
Blavatnik School of Government, University of Oxford
Wei Han
Blavatnik School of Government, University of Oxford
Fabrizio Mazzonna*
University of Lugano

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Abstract

Despite the growing number of studies on time-use and the fact that we spend roughly a third of our time sleeping, economists have largely ignored the effects of sleeping behavior on health, human capital and productivity. On the contrary, there are several medical studies showing that insufficient sleep is associated with adverse health outcomes. However, most of these studies are not able to distinguish between whether sleep deprivation negatively affects health or is a marker for poor health. Furthermore, we know relatively little about the effects of insufficient sleep on cognitive skills, and even less about the role of sleep deprivation in developing contexts. This paper analyzes the effects of sleep duration on cognitive skills of older workers in China. We exploit the relationship between circadian rhythms and bedtime to identify the effects of sleep using sunset time as an instrument. Using the Chinese Health and Retirement Longitudinal Study, we show that sleeping time significantly increases cognitive skills and eases depression symptoms of workers aged over 45 years. The results are driven by employed individuals living in urban areas, who are more likely to be constrained by rigid working schedules. Our results suggest that increasing the awareness of the negative effects of sleep deprivation is crucial for the design of policies aimed at reducing the cognitive decline associated with ageing. Increasing the attention on the importance of sleep may have non trivial effects on both cognitive skills and mental health of older workers. Interventions along this direction may be particularly beneficial in developing countries with an increasingly ageing population. Finally, our findings highlight that the misalignment between working schedules and our biological rhythms may have important negative effects on human capital.

Keywords: Sleep Deprivation, Cognitive Skills, Risky Behaviors
JEL Classification Numbers: I12

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1 Introduction

Growing evidence on a downward trend in average sleep duration, along with an increased incidence of sleep deprivation has raised concern about the potential effects on population health and health care costs (Roenneberg, 2013). Insufficient sleep is associated with a reduction in daytime alertness; excessive daytime sleepiness which impairs memory and cognitive ability (Alhola and Polo-Kantola, 2007; Killgore, 2010); occupational and automobile injuries (Dinges, 1995); poor health and obesity (see Cappuccio et al., 2010, for a systematic review). Though most sleep research has focused on developed countries, recent studies suggest that sleep disturbances in the developing world are far higher than previously thought (Stranges et al., 2012).

According to the estimates of the China Sleep Research Society, approximately 40% of Chinese suffer from a sleeping disorder.[1] Luo et al. (2013) also suggest that approximately two out of five elderly people living in urban China have sleep problems and that this rate increases rapidly with ageing. The rapid growth of the Chinese economy and the "electronification" of the bedroom have contributed to the observed increase in the number of people reporting insufficient sleep (e.g., Li et al., 2007). Besides, sleeping is often considered as an unproductive use of time, a cost that should be minimized especially in a period of rapid economic expansion, despite the common wisdom that sleeping a sufficient number of hours is important for health and performance. In addition, sleep is often regarded as a manifestation of laziness in the Chinese traditional culture, in which working hard and diligently is highly praised, so that people tend to belittle their sleep problems (Xiang et al., 2008; Pan, 2004; Liu, 2005). Paradoxically, the pressures of a rapidly growing economy may have unintended consequences on sleep quality and duration, and in turn individual performance.

The study on sleep deprivation in China, as in other developing countries, has been severely limited by the paucity of data on sleep duration. More generally, the inability to assess the causal relationship between sleep disturbances and physical or psychiatric disorders using observational studies is a problem that also affects the large number of studies based on people living in developed economies. This paper contributes to this research gap by analyzing the effects of sleep duration on the cognitive skills and depression symptoms of older workers (45 and above) in China.

As argued by Lei et al. (2012), the degradation of cognitive skills associated with ageing may have im-

[1] See also `http://www.asrsonline.org`.

portant effects in countries such as China with an ageing population and lacking intermediary institutions providing support to older people making decisions on income security or health care provision. Medical and psychiatric studies provide also evidence of an important association between sleep deprivation and depression (Tsuno et al., 2005; Wirz-Justice and Van den Hoofdakker, 1999). For long-time researchers thought China was characterized by a relatively low prevalence of depression, yet recent studies find high rates of depression among Chinese older adults (Lei et al., 2014).

There is a quite voluminous medical literature studying the associations between sleep deprivation, cognitive abilities, and mental health in laboratory settings. However, the experimental evidence focused mainly on the effects of acute sleep deprivation (being awake continuously for one to three days, or sleeping less than fours hours for few days in a row). Only few studies evaluate the consequences of chronic partial sleep deprivation (i.e. repeated exposure to sleep duration of less than six to seven hours per night), a condition that is far more common in reality (see Section 2 for a review). Furthermore, as recently remarked by Roenneberg (2013), laboratory studies offer a very limited understanding of both the determinants and consequences of sleep deprivation as they are usually based on people who have been instructed to follow certain sleep patterns (e.g., bedtime), and laboratory settings are unlikely to reflect real-world conditions. On the other hand, observational studies have mostly relied on descriptive analysis of survey data which does not allow to disentangle the causal effect of sleeping from that of other unobservable confounding factors. Despite a growing interest on the topic, we still know very little about the causal effects of sleep on health, human capital and productivity. Hence, evidence is lacking on the mechanisms that may underlie the relationship between sleeping duration and economic performance.

Our contribution with respect to the extant literature is two-fold. First, to the best of our knowledge there are no other studies using a quasi-natural experiment and survey data to identify the effects of sleep duration on cognitive skills. Second, there is very little evidence on the relationship between sleep duration and cognitive skills in developing countries, and in particular, we know very little about its effects among older workers.

Our study also contributes to a small but growing strand of the economic literature analyzing the determinants and consequences of sleeping. Though people spend a large part of their time sleeping and despite a large variation in sleeping patterns in the population, the determinants of sleeping choices and their consequences have been largely understudied in the economic literature. Most economic models, indeed, consider sleeping as a predetermined constraint on individual's time use or more generally as standard leisure time that can be traded-off when relative returns to market activities or to other leisure activities increase. A few notable exceptions have analyzed how sleeping duration responds to market incentives (Biddle and Hamermesh, 1990), yet their models did not consider the dynamic effects that sleeping may have on health, human capital and productivity. Empirical studies have examined the effect of daylight saving time on car crashes, work accidents, health, and financial markets (Barnes and Wagner, 2009; Sood and Ghosh, 2007; Monk, 2012; Kamstra et al., 2000; Jin and Ziebarth, 2015; Smith, forthcoming) as well as differences in productivity between different chronotypes, morning vs evening types (Bonke, 2012). In particular, our paper is closely related to two recent studies analyzing the effects of sleep deprivation on productivity (Gibson and Shrader, 2014) and health (Giuntella and Mazzonna, 2015).

This paper is also closely related to the growing number of studies on the effects of school start times on academic achievement (Carrell et al., 2011; Edwards, 2012; Stewart, 2014). These studies show that even differences of 20 or 30 minutes delay of school start times can have important effects on academic outcomes (Carrell et al., 2011; Owens et al., 2010). However, this literature focuses only on children and young adults and does not improve our understanding about the medium and long term effects of chronic restrictions to sleep duration. In addition, our study speaks to the previous literature analyzing the determinants of cognitive skills and mental health (Banks and Dinges, 2011; Banks and Oldfield, 2007; Mazzonna and Peracchi, 2012), and in particular to those studies focusing on older workers and on ageing and cognitive skills in China (Lei et al., 2012; Huang and Zhou, 2013; Lei et al., 2014).

To identify the effects of sleep duration on cognitive skills we adopt an instrumental variable strategy and follow the same approach used by Gibson and Shrader (2014) who examine the effects of sleep on productivity in the US by exploiting variation in sunset time and its effects on bedtime within US time zones. Our instrumental variable strategy exploits the same relationship between circadian rhythms and bedtime in the particular context of China, a country roughly as broad as continental US but following a single time zone. Due to circadian rhythms, our body reacts to environmental light producing more melatonin when darker. Thus, when sunset occurs at a later hour, individuals tend to go to bed at later time (Roenneberg and Merrow, 2007). While individuals, in principle, could compensate for a later bedtime by waking up later in the morning, social schedules (e.g., working schedules, school start times) are less responsive to solar cues and tend to respond to economic incentives and returns to coordination (Hamermesh et al., 2008). For these reasons, a later sunset can have important effects on sleep duration.

In the public debate in the US as in other countries that span over multiple time zones, some have suggested that there may be economic gains from following a unique time zone. In this discussion China's one time zone is often mentioned as an example providing a very interesting case study. While a unique time zone can clearly favor economic coordination, it creates some geographic distortions that can importantly affect individual behavior and well-being. Because of the single standard time zone, there are large differences in both sunrise and sunset time between cities, far larger than those exploited by Gibson and Shrader (2014) in the US. For instance, on June 21, in the city of Urumqui, in north-west China, the sun rises at 6.27am and sets at 9.56pm, with the solar noon occurring at 2.11pm, while in Harbin in north-east China, the sun rises at 3.43am and sets at 7.27pm, with the solar noon occurring at 11.35am (see Figure 1). There are also large differences between north and south due to the differences in latitude and solar declination.

Our identification strategy exploits this variation in sunset time to identify the effects of sleep duration on cognitive outcomes. The intuition behind our identification strategy is illustrated by Figure 2 which uses data on the average bedtime on a given date as reported by individuals using one of the leading sleep-tracking wearable (Jawbone) across Chinese cities. Though the sample is likely to be selected, Figure 2 shows evidence that Jawbone users tend to go to bed later in western areas of the country.[2] Ceteris paribus, people living in western cities, where sun sets at a later nominal hour, go to sleep later than people living in eastern cities because of the different sunset time.

Using data from the Chinese Health and Retirement Longitudinal Study (CHARLS), we focus on the effects of sleeping on cognitive skills of a relatively old population (45 and above). We show that individuals living in cities where the sun sets at a later time, ceteris paribus, sleep less than individuals living in early sunset cities. Using sunset time as an instrument for sleep duration, we show that increasing sleeping time by an hour increases significantly the scores reported in cognitive tests measuring mental and numerical skills. The effects are driven by the employed population living in urban areas. These results are consistent with the idea that in rural areas schedules tend to adjust to the daily solar cycle, while in urban contexts employed individuals are constrained in the morning by working schedules and cannot fully compensate for a later bedtime. Results go in a similar direction if using non-linear metrics of sleep duration.

A natural concern is that the geographical distribution of economic activity may confound our effect of interest. To partially address this issue we use only within-region variation and control extensively for

[2] Data were downloaded from https://jawbone.com/blog/sleep-china/ on October 2, 2015.

local economic conditions. Furthermore, it is reassuring that the relationship between sunset time and sleeping time is driven by individuals whose time use is constrained by working schedules. In particular we find that the results are statistically significant and economically important among the employed living in urban areas, while they are smaller and non-significant among non-employed, self-employed and individuals living in rural areas whose schedules are more flexible. Moreover, our results suggest that not controlling adequately for economic characteristics would downward bias (in absolute value) the relationship between sunset and sleeping time. Finally, we find non-significant effects on health outcomes that are usually correlated with economic activity but should not be affected by sleeping (or sunset) time such as the length of the knee and individual's health as a child (Huang et al., 2013).

Overall, our results suggest that sleeping has important effects on cognitive performance and depression symptoms. The heterogeneity of our results by occupational and demographic characteristics is consistent with recent findings from other countries (Giuntella and Mazzonna, 2015) and suggests that sleeping duration is importantly affected by social constructs such as working schedules that create a misalignment between social and biological time (Wittmann et al., 2006). Our findings also suggest that while coordination has clear economic advantages (Hamermesh et al., 2008), its costs should not be neglected.

The paper is organized as following. In Section 2 we provide a review of the literature analyzing sleep deprivation and cognitive skills. Section 3 illustrates our identification strategy and the data used in our analysis. Section 4 discusses the results. Conclusions are in Section 5.

2 Sleep Deprivation and Cognitive Skills

The effects of sleep deprivation have been extensively studied in laboratory settings. The majority of experiments focus on acute total sleep deprivation, in which participants are kept awake continuously, generally for one to three days, and their cognitive performance is tested before, during and after experiments. Alhola and Polo-Kantola (2007) and Killgore (2010) reviewed the effects of acute total sleep deprivation on a wide range of cognitive processes, including basic cognitive functions such as attention, multiple aspects of sensory perception, emotional processing, learning, memory, and decision making. Despite the different methodologies, most studies suggest that sleep deprivation induces cognitive impairment, and that individual characteristics affect the tolerance of sleep deprivation. However, chronic partial sleep deprivation is more common in reality due to several factors, including sleep disorders, work demands, and social and domestic duties. The experimental evidence on chronic (partial) sleep deprivation is rather limited. While the earlier studies yielded mixed findings as a result of defectively designed experiments, the recent studies, with improved experimental control and appropriate control groups, consistently find that chronic sleep deprivation adversely affected cognitive performance, in particular behavioral alertness (Banks and Dinges, 2011). For instance, the most extensive, controlled dose-response experiment on chronic sleep restriction was based on 14 days of sleep limitation to no more than four, six, or eight hours (Van Dongen et al., 2003). Those with four or six hours of sleep report negative effects comparable to those individuals forced to stay awake for 24 or 48 hours. Unfortunately, the external validity of these experimental studies is rather limited. In the real world, people are often exposed to partial sleep deprivation for long time (months, years), a condition that cannot be reproduced and examined in a laboratory setting. On the other hand, there are several observational studies analyzing the relationship between sleep duration and cognitive skills. However, survey-based study can harldy establish any causal relationship (see Yaffe et al., 2014, for a comprehensive review). Overall, these existent survey-based studies yield mixed results (Benito-León et al., 2009; Hahn et al., 2014).

In the economic literature, a few studies have attempted to recover the causal effect of school start times on academic performance. Carrell et al. (2011) identify the causal effect of school start times on academic achievement by using two policy changes in the daily schedule at the US Air Force Academy along with the randomized placement of freshman students to courses and instructors. They find that starting the school day 30 minutes later has a significant and economically important positive effect on student achievement. However, this study does not provide any evidence regarding the effect of chronic sleep deprivation and does not consider the cumulative and long-run effects of partial sleep deprivation.

An important contribution of our paper is the focus on a developing economy. Most of the studies analyzing the effect of sleep deprivation focus on individuals living in advanced economies. In particular, because of the ongoing ageing of the population, there is increased attention on the sleep deprivation and sleep quality of older adults in low- and middle-income countries. Indeed, the evidence from the medical literature suggests a greater occurrence of sleep disorders among older adults due to deterioration of the suprachiasmatic nucleus region of the brain. The deterioration of sleep quality among the elderly may contribute to cognitive decline. Yet, there is very little evidence on the causal effects of sleep deprivation on cognitive skills, and sleep deprivation has been largely understudied in developing countries. Gildner et al. (2014) and Stranges et al. (2012) are two notable exceptions, analyzing the association between sleep deprivation and cognitive outcomes in low- and middle-income countries. However, as most other studies on the topic, they do not attempt to recover the causal effect of sleep deprivation.

In China sleep deprivation is an emerging public health challenge. Because of the rapidly ongoing ageing of the population, health care professionals and scholars have begun to pay increasing attention to the sleep quality of Chinese elderly population. In a recent study, Luo et al. (2013) analyzing 1086 community residents aged 60 years who completed the Chinese version of the Pittsburgh Sleep Quality Index (CPSQI) find that poor sleep quality is highly prevalent among elderly Chinese residents in urban Shanghai. The China Sleep Quality index 2014, published by Chinese Medical Doctor Association, shows that rural residents had higher sleep quality than that of urban, and highly-educated individuals (bachelor degree or above) had lower sleep quality than that of individuals with lower educational attainment. More generally, in more developed cities the quality of sleep was lower. Interestingly, 54% of the respondents reported that the top cause of sleep deprivation was related to work.

3 Identification Strategy and Empirical Specification

3.1 Background: Time Zones in China

China is the second largest country in the world by land area and the most populous. Its territory spans over 60 degrees of longitude and, as described in Figure 3, covers an area corresponding to five time zones ranging from UTC+5 to UTC+9. In 1912, the year after the collapse of the Qing Dynasty, the newly empowered Republic of China established five different time zones in the country, ranging from five and a half to eight and a half hours past Greenwich Mean Time. But in 1949 Mao Zedong decreed that all of China would henceforth be on Beijing time. As the Communist Party consolidated control of the country, the one time zone was meant to foster national unity. [3] For the past 60 years, all of China has shared a single official time zone. Since 1949, the official national standard time is eight hours ahead of Greenwich Mean Time (UTC+8), referred to as Beijing Time domestically and as China Standard Time internationally. This common national time produces some geographic distortions. When at sunrise in Beijing a daily flag raising ceremony takes place in Tiananmen Square, easternmost China has already experienced an hour of daylight, but in the westernmost part of China the sun will not rise for another three hours.

[3] India had established a similar policy in 1947, after independence.

Mainland China is administered in 31 provincial level administrative divisions (22 provinces, five autonomous regions and four provincial level municipalities). Figure 3 shows that most provinces are located in UTC+7 and UTC+8 where 95% of the Chinese population lives. Thus, for most people in China the single time zone simply requires a little adjustment. The provincial level administrative divisions located within UTC+8 longitudes include Fujian, Jiangxi, Zhejiang, Anhui, Shanghai, Jiangsu, Shandong, Hebei, Beijing, Tianjin, Liaoning, at least half of the areas of Hubei, Henan, Shanxi, Guangdong, Jilin, Inner Mongolia, Heilongjiang, and about one-third of Hunan. As reported in Table 1, with an estimated population of 0.77 billion people (56%), the UTC+8 produced 65% of China's GDP in 2014.[4] Almost all the remaining population and economic activity is located in the UTC+7.

A number of minority Muslim Uighur citizens of Xinjiang Uyghur Autonomous Region province do not observe official "Beijing time". Indeed, Xinjiang, located in the westernmost part of the country, operates on a two-time zone system: the official "Beijing Time" and the unofficial "Xinjiang Time" (UTC+6). While schools, government offices, public service offices, airports and railway stations all adopt Beijing time; some bus lines and local shops use local Xinjiang Time. For those following Beijing Time, they implement a modified time schedule. For instance, schools start at 10am Beijing Time, which equals to 8am Xinjiang Time. For this reason, we excluded Xinjiang from the analysis and focus on individuals living in UTC+7, UTC+8, and UTC+9. In these three three areas, work schedules and economic activity are coordinated. Offices, shops, public transportation and schools follow the Beijing time. However, in farming communities individual schedules tend to be more responsive to the natural light, as agricultural work is directly affected by the daily solar cycle.

3.2 Identification Strategy

The goal of this paper is to recover the causal effects of sleep duration on cognition and depression. A simple comparison of people with different sleeping behavior would not allow us to identify a causal relationship. A natural concern is that there may be omitted variables that are both related to sleep duration and our outcomes of interest. Moreover, depression and cognitive impairment can affect sleep duration, generating a reverse causality problem. For these reasons, we rely on an instrumental variable (IV) strategy to identify the effects of sleep on cognitive skills and depression symptoms using information

[4] Author's own calculation based on China Statistical Yearbook (2014). For the provinces having at least half of the areas located within UTC+8 longitudes, we count 50% of their population and GDP; for Hunan, we count 30% of its population and GDP.

on sunset time. More specifically, our identification strategy exploits the geographical variation in sunset time across Chinese cities as sources of exogenous variation in sleep duration.

Our strategy is the same as the one used by Gibson and Shrader (2014) to analyze the effects of sleep duration on productivity in the US and it is closely related to the approach used by Giuntella and Mazzonna (2015) who use discontinuities in sunset at a time zone border to recover the causal effects of sleep deprivation on health. The main idea underlying these strategies is that circadian rhythms are important determinants of human sleeping patterns. Our internal pacemaker, the brain's suprachiasmatic nucleus (SCN), also known as the body's master clock, regulates the body's biological rhythms by changing the concentrations of the molecular components of the clock to levels consistent with the appropriate stage in the 24-hour cycle. This process is known as "entrainment". In practice, when the sun sets and it becomes darker, the SCN produces more melatonin facilitating sleep (Aschoff et al., 1971; Duffy and Wright, 2005; Roenneberg et al., 2007; Roenneberg and Merrow, 2007). Within a time zone people organize their lives according to common social time, yet differences in sunrise and sunset time can be very large as dawn and dusk progress from east to west (Roenneberg and Merrow, 2007; Gibson and Shrader, 2014). Previous studies show that wake-up time is less affected by solar cues than bedtime. Instead, wake-up times are importantly affected by work schedules and other social constraints (such as children's school start times) which, in turn, respond to social conventions, economic incentives, and regional coordination (Hamermesh et al., 2008; Giuntella and Mazzonna, 2015; Roenneberg, 2013). Thus sunset time can have important effects on sleep duration.

Figure 1 illustrates the variation in sunset time across Chinese cities on Summer Solstice, June 21st. Because China follows a unique time zone the differences between the easternmost and the westernmost regions of China are marked.[5] If people would compensate by waking up later this would have no effect on sleep duration. However, because of economic incentives and coordination, many individuals are not able to fully compensate in the morning by waking up at a later time. In particular, we expect sunset time to have larger effects on sleep duration among employed people in urban areas, as they are more likely to be constrained by standardized office hours. On the other hand, we expect that the sleeping behavior of people who are not employed or live in rural areas are less affected by these differences in sunset time

[5] It is worth reminding that sunset differences are not only determined by the longitude of a location but also by the latitude, with northern cities having longer days in the summer and shorter days in the winter with respect to cities in the south of the country. However, as we control for month fixed effects in all our specification, we in practice exploit only the cross-sectional variation in sunset time within a given season.

because their daily activities are more likely to respond to the daily solar cycle.

As economic activity in China is clustered along the eastern coast and most of the western areas are particularly underdeveloped, we control for regional fixed effects in all our specifications. We consider four regions in accordance with the definition used in the Twelfth Five-Year Plan for National Economic and Social Development of China (see Figure 4).[6] The eastern region, the most developed area, consists of 10 provincial level administrative divisions, eight of which are entirely within UTC+8. The north-eastern region covers three provinces located either in UTC+8 or UTC+9. The central region includes four provinces stretching over UTC+7 and UTC+8 as well as two provinces located in UTC+8 only. The remaining 12 provincial level administrative divisions constitute the western region, a vast territory characterized by lower socio-economic status and higher poverty rates. The western region ranges from UTC+5 to UTC+7 but only Xinjiang, Tibet, part of Gansu and Qinghai provinces are located in UTC+5 and UTC+6, all of which have a low population density.[7] Therefore, focusing only on individuals living in UTC+7, UTC+8, and UTC+9 only excludes a tiny fraction of the population. In addition, we include controls for urban/rural status, GDP, population, type of landscape and level of air pollution at the city level. In practice, we exploit cross-sectional variation in average sunset time within regions that are considered to be homogeneous with respect to socio-economic characteristics. We acknowledge that there may be other unobserved confounding factors that may be correlated with average sunset time and our main outcomes of interest. Yet, we think that this concern is substantially mitigated by the inclusion of regional fixed effects and economic controls at the city level.

Our identification relies on the assumption that conditional on our set of controls at the individual and regional level, sunset time is orthogonal to other characteristics that can affect our outcomes of interest. As any identification assumption, it is directly untestable. However, we show that individuals living in early and late sunset cities are well-balanced on most covariates and we implement some robustness checks on predetermined characteristics, such as child health and the length of the knee, that should not be affected by our instrument, but that are likely to be correlated with the level of economic development of the city. Furthermore, the heterogeneity of our findings by employment status and urban area appears to be consistent with our identification assumption. As previously noted, we expect and show that the largest effect of sunset time on sleeping behavior is observed among employed individuals living in urban

[6] See http://www.gov.cn/2011lh/content_1825838.htm.

[7] For a list of provinces by region, please see China Statistical Yearbook for Regional Economy (2012).

areas. Instead, we find no evidence of significant effects of sunset on population that are more flexible with their individual schedules (self-employed) or more likely to adapt to the daily solar cycle (individuals in rural areas). For this reason, our main sample consists of people still employed and living in urban areas.

As above noted, the economic activity in China is clustered on the eastern side of the country. Thus, one may confound the positive effect of an early sunset on the eastern side of the country with the economic development of these areas. In Section 4.1, we show that not adequately controlling for socio-economic differences leads to a downward bias (in absolute value), as individuals in richer areas tend to sleep less, but a higher socio-economic status is positively associated with cognitive and health outcomes (Cutler et al., 2011).

It is worth noting that the cognitive differences that arise from contrasting cities with different sunset times are likely to be the result of a long-term exposure to sleep deprivation and are not the result of the effect of differences in sleeping behavior in the last month as measured in the data used in this paper (see Section 3.4). In other words, what we measure with our two-stage least squares (2SLS) strategy is not the effect of one-hour difference in average sleeping in the previous month, but rather the average effect of a long term exposure to one-hour difference in sleeping. Moreover, if the negative effects of a long exposure to sleep deprivation are long lasting, we should find the presence of a reduced-form effect of the average sunset time on cognitive abilities also among subgroups that are no longer "treated"—people whose sleeping behavior is no longer affected by average sunset time. Specifically, we can find a reduced-form effect also on retired individuals that used to be treated but that can now compensate by waking up later in the morning, because social constraints (e.g. working schedules) are no longer binding. This suggests that we should interpret our 2SLS results with caution taking into account the fact that they can reflect both short and long term effects.

Another concern that might arise is that our identification strategy could also reflect differences in sunlight exposure and, thus, violate the exclusion restriction assumption. In other words, if the differences in sunset time are correlated with the sunlight exposure we might confound the effect of sleep duration with that of the sunlight. For instance, sunlight exposure increases the production of vitamin D which is usually associated with mood and depression (e.g., Kjærgaard et al., 2012). If we consider that the average sleep duration in our sample is 6.3 hours it is very likely that, regardless of their location, most of the Chinese people are usually awake (and then potentially exposed to sunlight) during all sunshine hours.

Nevertheless, in our study, if there is a difference in sunlight exposure across Chinese cities, this should advantage individuals living in late sunset cities. Yet, we show that these individuals tend to sleep less. This means that, if ever, the difference in daily exposure to sunset light may introduce a downward bias in the estimated effect of sunset time on sleep duration and cognitive abilities.

3.3 Empirical Specification

Formally, we estimate the following equation:

$$C_{ict} = \beta_0 + \beta_1 S_{ict} + \beta_2 X_{ict} + \beta_3 K_{ct} + \beta_4 I_{ict} + \eta_r + \epsilon_{ict} \tag{1}$$

where C_{ict} is a metric for cognitive skills or depression measure for individual i, living in city c and interviewed on date t; S_{ict} is the self-reported average sleep duration in the last month for individual i in city c on date t; X_{ict} are standard socio-demographic controls at the individual level (age, gender, education, marital status, employment status, subjective income, household consumption, living in urban or rural area); K_{ct} are a set of economic and geographic characteristics of the city c (GDP, population, pollution level, landscape); I_{ict} are the interview characteristics (survey wave and month fixed effects); and η_r are regional fixed effects.

As already mentioned, ordinary least squares do not allow the recovery of unbiased estimates of the effect of sleeping on cognition (β_1) because of both reverse causality and unobservable individual characteristics that are not included in our large set of controls (e.g., stress or latent health). For this reason we use an IV strategy that exploits differences in sunset time across Chinese cities as sources of exogenous variation in sleep duration. More specifically, we estimate the following first-stage equation:

$$S_{ict} = \alpha_0 + \alpha_1 sunset_{ct} + \alpha_2 X_{ict} + \alpha_3 K_{ct} + \alpha_4 I_{ict} + \eta_r + v_{ict} \tag{2}$$

where $sunset_{ct}$ is the average sunset time in city c at time t. To take into account the potential correlation across individuals living in the same city we cluster standard errors at the city level.

Another relevant concern is the quality of the data as we use self-reported measures of sleep (see also Section 3.4). As any self-reported measure, self-reported sleep duration might poorly represent the real sleeping habits (Lauderdale et al., 2008) and introduce large measurement error in the analysis. However, if the measurement error is uncorrelated with our instrument (sunset time), our instrumental variable strategy allows us to obtain consistent estimates of the parameter of interest. Furthermore, in the data used in our analysis (see Section 3.4), the question on sleep duration explicitly asked the respondents to report only the time spent sleeping excluding time spent in bed awake (e.g., watching a movie). Finally, it is also worth noting that the large correlation we found between self-reported measures of sleep duration and average sunset time across Chinese cities is consistent with the differences observed in bedtime using data drawn from Jawbone personal wearables tracking sleep quality (as shown in Figure 2).

3.4 Data

The Chinese Health and Retirement Longitudinal Study (CHARLS) was designed to study Chinese residents aged 45 and older and to be complementary the Health and Retirement Study (HRS) in the United States, and other related ageing surveys such as the English Longitudinal Study of Ageing (ELSA) and the Survey of Health, Ageing and Retirement in Europe (SHARE).

The first national wave of CHARLS was fielded in 2011 and includes about 10,000 households and 17,500 individuals in 150 counties/districts and 450 villages/resident committees. The data includes 28 provinces. The second wave was fielded in 2013.[8] The survey includes information on demographics, family structure/transfer, health status and functioning, biomarkers, health care and insurance, work, retirement and pension, income and consumption, assets (individual and household), and community level information.[9]

CHARLS contains information on average sleep duration in the last month. Respondents are asked to report how many hours they slept on average over the month preceding the interview.[10] Using this question we constructed both a linear measure of sleep duration in hours and indicators for whether individuals slept at most six or at least eight hours, or between seven and nine hours.[11] Yearly average sunset time for Chinese cities was computed using the National Ocean and Atmospheric Administration

[8] CHARLS adopts multi-stage stratified PPS sampling.

[9] Huang et al. (2013) provide an extensive description of the data.

[10] *"During the past month, how many hours of actual sleep did you get at night (average hours for one night)?"*

[11] Information on sleep duration is missing in 10% of the sample. To avoid double selection due to the missing responses in both the sleeping and cognitive tests variables, we impute the missing information on sleeping behavior using the standard Stata routine to impute missing variables values and individual information on gender, age, education, employment status, province of residence, rural status of residence, and interview wave. We use Stata command -mi impute- to impute the missing sleeping hours. The imputed sleeping hours used in the regressions is the mean of 20 rounds non-negative imputations. If we exclude individuals with missing information on sleeping, the standard errors become larger and the coefficients are less precisely estimated, but the point-estimates of first-stage and 2SLS are substantially identical and remain statistically significant in our main sample of employed individuals living in urban areas.

(NOAA) and the information on the city of residence available in the survey.[12]

Since the sleeping variable in CHARLS measures the self-reported average sleep duration in the last month, in principle, we could also use the average sunset time in the last month preceding the interview as instrument to exploit the seasonal variation in sunset time. Unfortunately, most of the interviews took place in July and August,so we do not have sufficient seasonal variation to exploit. Moreover, since our aim is to evaluate the long term effects of chronic sleep deprivation on cognitive abilities, we believe that the average sunset time should better capture these long term effects than short-term sleep restriction caused by seasonal variation in sunset time.

The CHARLS data contains several questions measuring cognition and depression. In particular we measure the level of individual cognitive abilities using the result of five cognitive tests: *Mental*, *Numerical*, *TICS*, *Memorial*, and *Draw*.

The *Mental* test measures the awareness of the date, the day of the week, and the season of the interview to capture the mental intactness of the respondent (McArdle et al., 2011). The score is based on the number of correct answers, ranging from zero to five. The *Numerical* test measures individual's ability to compute simple mathematical subtractions (successively subtract 7 from 100 for five times). The score is based on the number of correct answers, ranging from zero to five. The Telephone Interview of Cognitive Status, abbreviated to *TICS*, is a well-known indicator to measure the mental capacity of the respondent. It is the sum of the score from *Mental* test and *Numerical* test. The *Memorial* or *Word recall* test measures episodic memory (McArdle et al., 2011). Interviews read a list of 10 nouns to respondents who were asked to recall them immediately as well as 10 minutes later. The score is based on the average number of correct answers during two recall sessions, ranging from zero to ten. Finally, the *Draw* test examines the ability to redraw a picture of two overlapping pentagons. Respondents score one if the task is successfully performed; zero otherwise. Following Huang et al. (2013), we also measure individual's depression status by using a Chinese version of the *CES-D 10* questionnaire and constructing an indicator ranging from zero to thirty based on the answer of respondents. The higher the CES-D score, the more severe the depression is.

As already mentioned, we restrict our analysis to individuals living in UTC+7, UTC+8, and UTC+9. Although, geographically, Xinjiang, Tibet, part of Gansu and Qinghai provinces are located in UTC+5 and UTC+6, CHARLS was only fielded in one city (i.e. Aksu from Xinjiang) within this area, where a two-time

[12] `http://www.esrl.noaa.gov/gmd/grad/solcalc/`.

zone system, i.e. the official "Beijing Time" and the unofficial "Xinjiang Time", is operating (see Section 3.2).[13] We exclude individuals aged over 70, mostly to avoid selection issues due to the fact that average life expectancy in China is 74 years for men and 77 years for women (WHO, 2013).[14] Furthermore, since in our main analysis we focus on older workers, the share of individuals over 70 reporting to work is less than 2% and thus represents a very selected sample of the population.[15]

Table 2 reports summary statistics for all the variables used in the analysis. Column 1 presents the summary statistics for the entire sample. In column 2, we focus on the employed population living in the urban areas, who, as explained above, are those more likely to be affected by social and economic schedules and thus less able to compensate a later bedtime with a later wake-up time (see also Giuntella and Mazzonna, 2015).

It is worth noting that the average sleep duration reported in our sample is less than 6.5 hours. This means that the average sleep duration in China is far below the sufficient number of hours of sleep usually recommended in the literature (between seven and nine hours of sleep). Therefore, according to the results of the experimental literature on partial sleep deprivation surveyed in Section 2, we might expect negative health effects from such sleeping habits.

In Table 3, we report the summary statistics for the employed and urban sample comparing late sunset areas with early sunset areas. Individuals living in late sunset areas tend to sleep significantly less than those in early sunset areas, and have poorer cognitive outcomes. There is also evidence of a marginal difference in age as individuals living in early sunset areas tend to be slightly older than those living in late sunset areas. However, most of the other individual covariates are balanced across the two samples.

4 Main Results

4.1 First-Stage: Sunset and Sleep

We first show that the average sunset time is a strong predictor of sleeping behavior. Second, we show that, consistent with our conjecture, the effects are driven by employed people in urban areas whose schedules are less flexible than those of the unemployed or less responsive to the daily solar cycle than

[13] By restricting our sample to areas located in UTC+7, UTC+8, and UTC+9, we dropped 106 and 102 individuals in 2011 and 2013, respectively.

[14] http://www.who.int/countries/chn/en/)

[15] However, these restriction do not significantly affect our results. Furthermore, restricting to individuals below age 60 yields very similar results (available upon request).

those of individuals living in rural areas. Table 4 presents estimates of the effect of the average sunset time on sleep duration using different model specifications. In Model A, we include among our controls a large set of individual socio-economic characteristics (education, i.e. no formal education or illiterate, at most completed elementary school, completed middle school, completed at least high school or vocational school, age and its quadratic term, gender, marital status, employment status, subjective poverty status, the logarithm of household consumption, urban/rural area of residence) and interview characteristics (survey wave and month fixed effects). Model B adds to Model A regional fixed effects (see Section 3 and Figure 4). Model C includes socio-economic characteristics of the respondent's city (the logarithm of population and GDP, type of main landscape and degree of industrial pollution). Standard errors are clustered at the city level. The table clearly shows that the average sunset time is a strong predictor of respondents' self-reported sleep duration. A one hour increase in average sunset time is associated with a 20 minutes reduction in reported sleep duration (Model A). The estimated effect substantially increases (in absolute terms) to 31 minutes when we include socio-economic controls at city level (Model C). This result is particularly relevant to our analysis for two main reasons. First, it shows that the sunset time is a strong and significant predictor of sleep duration, in particular if we consider that the average sleep duration is roughly 6.5 hours. This is also relevant from a medical perspective because the experimental evidence on sleep deprivation finds the presence of sizeable negative health effects when people are constrained to sleep less than seven hours per night. Second, we show that if we do not account for the level of economic activity (the controls included directly or indirectly in Model B and C), we introduce a downward bias in the estimated effect of the average sunset time. More specifically, along the eastern coast, where the level of economic activities is higher, the sunset occurs at a earlier nominal hour than in western cities. Work pressures as well as the digitalization of life (and bedroom), often blamed as important factors of sleep deprivation, are likely to delay individual bedtime, mitigating the sunset effect (Xiang et al., 2008).

In Table 5, we analyze the effect on other subgroups of the population. In particular, we estimate Model C in six different subsamples: rural, urban, employed, not-employed, rural and employed, and again our main sample urban and employed. Overall, our results show that while the coefficient is always negative, it is only statistically significant for respondents living in urban areas and among the employed. Indeed, the largest effect is observed in our main sample. In particular, column 1 shows that in urban areas an hour difference in the average sunset time is associated with an average reduction of 12 minutes in average sleep duration (column 1). The coefficient is smaller and not statistically significant in rural areas (column

2). Instead, the point-estimate more than doubles when we focus on the employed population (column 3). The coefficient is again small and non-significant when analyzing the non-employed population (column 4). While we find no significant effects in rural areas where the population is largely comprised by farmers, we do observe a larger point-estimate (column 5) when focusing on individuals employed in other (non-farming) occupations.

Our findings are consistent with the idea that farmers are less affected by time zone settings and more likely to follow the natural light in their daily activities. Consistent with this conjecture, recent evidence shows that farmers in China have longer sleep duration and better sleep quality than Chinese employed as blue collar workers or civil servants (Sun et al., 2015). We also find no evidence of significant effects among self-employed (see Section 4.4) who are likely to be more flexible than employed individuals with respect to their work schedules. In Section 4.4, we show that our findings are robust to alternative non-linear measures of sleep duration.

4.2 Reduced-Form Analysis: Sunset and Cognitive Skills

Table 6 analyzes the reduced-form relationship between sunset time, a battery of cognitive outcomes and a depression test (CES-D). Each set of rows reports the estimated reduced-form effect on a specific cognitive outcome (along with the number of observations and the R-squared), starting from the mental skills test. The last row reports the estimated effect on the despression test (CES-D). Again, we group the results by urban/rural and employment status.

With the exception of the effect on memorial test for a few subgroups, our point-estimates show that a later sunset time is always negatively associated with the average test score. Consistent with our first-stage results, point-estimates are larger (in both relative and absolute terms) for the employed respondents in urban areas. For this subgroup, an hour increase in the average sunset time is significantly associated with a 0.36 points reduction in mental abilities (9% reduction with respect to the mean), 0.59 points reduction in numerical skills (17% reduction with respect to the mean), and a one point reduction in the average TICS score (12% reduction with respect to the mean). Negative but not significant effects are also found for the memorial and draw test and for the CES-D test for depression.[16]

It is worth noting that, unlike our first-stage results, we found evidence of a significant effect of the average sunset time also among retired people (not-employed). As discussed in Section 2.2, this result

[16] The higher CES-D score, the more severe the depression is.

should not represent a concern since the estimated reduced-form effect might also capture long term effects of previous sleep deprivation on cognitive abilities. Therefore, we are not surprised to find evidence of an association among retired people, as they used to be exposed to different sunset time when they were employed. However, it is reassuring that the largest effects are found among employed respondents (column 3), especially in urban areas (column 6).

Finally, in the last set of rows we show that a later sunset is associated with a higher depression score among the employed population in urban areas. an hour increase in average sunset time increases the depression score by 23% with respect to the mean observed in the sample. Note that this is also reassuring that the exposure to daylight is not confounding our analysis through its possible effects on depression symptoms. Indeed, we find, that if anything, an earlier sunset has positive effects on depression (lower CES-D score).

4.3 2SLS Estimates: Sleep Duration and Cognitive Skills

Having shown the effect of the average sunset time on sleep duration and its reduced-form effect on cognition and mental depression, it is natural to show the 2SLS estimates to provide an estimate of the average effect of one hour of sleep on cognitive abilities and depression symptoms. However, as already discussed throughout the paper, these estimates must be interpreted with caution as they represent the effect of both short and long term effect of sleep deprivation.

Table 7 reports 2SLS estimates for the effects of sleep duration on cognitive skills and depression symptoms in our main sample. Focusing on employed individuals in urban areas mitigates the concerns regarding weak instrument problems (see the F-test at the bottom of Table).

Our 2SLS estimates show that an increase in average sleep duration increases cognitive abilities and lowers the depression symptoms score. Excluding the draw and the memorial test, the estimated effect is always statistically significant at least at the 10% level. In particular, an hour increase in average sleep duration would increase numerical skills by 33%, the mental test by 18% and the TICS test by 25% with respect to the mean of each dependent variable.[17] Note that an hour increase in sleeping corresponds to approximately 15% of the average sleep duration (approximately six hours). To gauge a sense of the magnitude, Huang and Zhou (2013) estimate that concluding primary education increases cognition scores by

[17] Using an overall measure of respondents' cognitive function (0-21) which sums the scored obtained in TICS test, the word recall test, and the draw test, we find that an hour increase in sleep duration would increase the overall cognitive score by 30% with respect to the mean of the dependent variable (results are available upon request).

20%.

Finally, we find evidence of a two points reduction in the CES-D score corresponding to a 35% reduction with respect to the average CES-D score in the sample. This is an economically important effect. Again, to gauge a sense of the magnitude, Lei et al. (2014) show that having completed junior school is associated with a 20% lower depressive symptom score.

4.4 Robustness Checks

In this section, we report the results of a set of tests that we implement to verify the robustness of our estimates and the validity of our identification strategy. We start from Table 8 where we analyze alternative non-linear measures of sleep, such as sleeping no more than six hours, sleeping at least eight hours and between seven and nine hours. These metrics have been often used in the medical literature analyzing sleep deprivation (Cappuccio et al., 2010).

The results are fully consistent with those reported in Table 5. Regardless of the metric considered, a later sunset time has a negative effect on sleeping, in particular if we focus on employed people living in urban areas. More specifically, for employed people living in urban areas, one hour increase in sunset time increases the probability of sleeping less than 6 hours by 14 percentage points (column 1), or decreases the probability of sleeping at least eight hours by 17 percentage points (column 2).

We also indirectly test our identification assumption by verifying whether the average sunset is significantly associated with other predetermined characteristics that should not be affected by a different sunset time. In Table 9, we test the association of the average sunset time with the length of the knee and self-reported poor health during childhood. We use the same specification we used to analyze the effect of the average sunset time on sleep duration. The results clearly show that there is no evidence of any significant effect of the average sunset time on these two variables. This is reassuring because a significant correlation with predetermined characteristics would cast doubts on our identification strategy.

As mentioned above, we also test whether sleeping behavior and cognitive abilities of self-employed are affected by variation in sunset time. Table 10 shows that, even if we focus on self-employed in urban areas, we do not find evidence of significant effect on both sleeping and cognitive abilities. Given the low sample size and the rather large standard errors we cannot conclude that this group is not affected at all. However, point-estimates are far smaller than those found among employed people, suggesting that self-employed have more flexible schedules, so that they can, at least partially, compensate the effect of the large differences in sunset time across Chinese cities.

Our results are not driven by one particular province. When we replicate all our estimates by leaving out one province at a time, the results hold and remain consistent with those reported in the main text (available upon request). Finally, using the retrospective questions of the survey we are able to recover individual's migration history. Our findings are substantially unchanged if we exclude individuals who were born in a different province or individuals who reported working in a different province. This is not surprising as we focus on individuals aged over 45. Internal migration was long restricted by the Hukou system which began to loosen only in the mid 80's in response to the demands of both the market and rural residents wishing to seek greater economic opportunity in cities (Au and Henderson, 2006).

5 Conclusions

Economists have largely ignored the effects of sleep on health and human capital. The medical literature provides extensive evidence of the association between sleep deprivation and health. However, most of these studies do not attempt to analyze the causal relationship between sleep duration and health outcomes. Furthermore, we know relatively little about the effects of sleep duration on cognitive skills in developing contexts. However, in many low- and middle-income countries sleep deprivation is becoming increasingly recognized as a public health challenge, particularly because of its effects on the elderly population.

In this paper we analyze the effects of sleep duration on the cognitive skills of older workers in China. We show that sleep duration has non-trivial effects on cognitive and mental skills. To identify the effects of sleep on cognitive skills, we use an instrumental variable that exploits the relationship between sunset time, circadian rhythms, and average sleep duration. Our findings indicate that an hour increase in average sleep duration increases old age cognitive skills (TICS) by 25%, mental skills by 18%, numerical skills by 33%, and reduces the depression score by 35% with respect to the mean. We find no evidence of significant effects on memorial and drawing skills. The effects are larger among employed individuals in urban areas and robust to the use of non-linear metrics of sleep duration. Importantly, a later sunset does not have significant effects on outcomes that are not affected by sleep duration.

Our results suggest that increasing the awareness of the negative effects of sleep deprivation is crucial for the design of policies aimed at reducing the cognitive decline associated with ageing. Increasing the attention on the importance of sleep quality may have non-trivial effects on both cognitive skills and mental health of older workers. Interventions in this direction may be particularly beneficial in countries that are undergoing epidemiological transitions and rapid economic transformations and are now facing the public health challenges associated with economic development. Finally, the heterogeneity of our results by occupational and demographic characteristics suggests that many individuals suffer from a misalignment between social and biological time (Wittmann et al., 2006). While working schedules and other social constructs affecting the timing of our daily activities (e.g., school start times) respond to economic incentives and returns to coordination, their costs in terms of negative effects on health and human capital should not be underestimated.

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Table 1: Population and GDP, by UCT Time Zones in 2013

Time zone:	UTC +5 and +6	UTC +7	UTC +8	UTC +9
GDP	1.91%	30.57%	65.41%	2.11%
Population	2.61%	38.36%	56.62%	2.42%

Notes - GDP and population data at province level are drawn from China Statistical Yearbook (2014), excluding Hong Kong SAR, Macao SAR and Taiwan. Although most provinces lie within a single geographical time zones, there are 10 out of 31 provinces that are divided into two time zones. Therefore, the aggregated GDP and population by time zone are calculated by authors roughly according to the proportion of territory located in each time zone. The details are as follows: Jilin and Heilongjiang are split equally between UTC+8 and UTC+9; Shanxi, Inner Mongolia, Henan, Hubei, and Guangdong are split equally between UTC+7 and UTC+8; Qinghai is split equally between UTC+6 and UTC+7; two-third of Hunan is counted in UTC+7 and the rest in UTC+8; one-fourth of Gansu is counted in UTC+6 and the rest in UTC+7.

Table 2: Summary Statistics

	All			Urban, employed Aged 45–70 Time zone 7-9		
	N	mean	SD	N	mean	SD
Sleep hours	35,960	6.285	1.786	3,169	6.523	1.443
Sleep $\leq$ 6 hours	35,960	0.502	0.500	3,169	0.422	0.494
Sleep $\geq$ 8 hours	35,960	0.247	0.431	3,169	0.232	0.422
7 $\leq$ Sleep $\leq$ 9 hours	35,960	0.399	0.490	3,169	0.451	0.498
Average sunset time	36,310	18.520	0.465	3,300	18.383	0.417
Mental ability: date	35,210	3.413	1.733	3,069	3.958	1.723
Numerical ability	35,210	2.934	1.994	3,069	3.486	1.894
TICS	35,210	6.347	3.324	3,069	7.444	3.334
Memorial ability	35,210	3.082	2.046	3,069	3.710	2.259
Drawing ability	32,185	0.642	0.479	2,653	0.848	0.359
CES-D scale for depression measurement	30,686	8.117	6.077	2,599	5.666	4.774
Male	36,310	0.432	0.495	3,300	0.535	0.499
Age	36,208	59.516	10.216	3,300	53.059	5.785
Ever married	36,310	0.873	0.333	3,300	0.945	0.229
Employed	35,903	0.173	0.378	3,120	1.000	0.000
Living in urban area	36,310	0.404	0.491	3,300	1.000	0.000
Survey year 2013	36,310	0.512	0.500	3,300	0.507	0.500
Subjective poverty status	33,079	0.195	0.396	2,853	0.240	0.427
Household consumption	35,815	30,188	73,813	3,120	40,421	58,423
Population of the residential community	36,216	3343	3738	3,269	5786	5037
GDP of the residential city	36,310	2,123	2,732	3,300	3,216	3,592
Educational attainment:						
No formal education illiterate	36,285	0.266	0.442	3,299	0.055	0.228
Elementary school	36,285	0.395	0.489	3,299	0.266	0.442
Middel school	36,285	0.208	0.406	3,299	0.298	0.457
High school and above	36,285	0.129	0.335	3,299	0.379	0.485
Type of main landscape:						
Plain	36,310	0.421	0.494	3,300	0.618	0.486
Hill	36,310	0.296	0.457	3,300	0.219	0.414
Mountainous region	36,310	0.207	0.405	3,300	0.110	0.313
Plateau	36,310	0.046	0.210	3,300	0.027	0.163
Basin	36,310	0.027	0.163	3,300	0.026	0.158
Degree of industrial pollution:						
Poor	36,310	0.029	0.168	3,300	0.049	0.215
Fair	36,310	0.119	0.324	3,300	0.174	0.379
Good	36,310	0.190	0.393	3,300	0.273	0.446
Very good	36,310	0.662	0.473	3,300	0.505	0.500

Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013) except GDP of the residential city that are draw from Statistical Yearbook of each provinces (2011, 2013). The summary statistics are not weighted by individual weights.

Table 3: Balancing Test, Individual Characteristics

	Early sunset		Late sunset		t-test
	N	Mean	N	Mean	
Sleep hours	1,739	6.613	1,381	6.410	-3.514
Sleep $\leq$ 6 hours	1,739	0.396	1,381	0.456	3.041
Sleep $\geq$8 hours	1,739	0.255	1,381	0.201	-5.210
7 $\leq$ Sleep $\leq$ 9 hours	1,739	0.485	1,381	0.404	-2.455
Average sunset time	1,739	18.088	1,381	18.749	9.133
Mental ability: date	1,670	4.069	1,319	3.965	0.967
Numerical ability	1,670	3.623	1,319	3.471	-1.655
TICS	1,670	7.692	1,319	7.436	-0.558
Memorial ability	1,670	3.857	1,319	3.694	0.341
Drawing ability	1,475	0.858	1,158	0.837	-0.457
CES-D scale for depression measurement	1,440	5.342	1,138	6.077	-0.686
Male	1,739	0.542	1,381	0.555	-0.054
Age	1,739	53.072	1,381	52.708	-2.163
Educational attainment	1,739	3.014	1,381	3.012	0.367
Ever married	1,739	0.945	1,381	0.959	-0.717
Subjective poverty status	1,526	0.261	1,238	0.200	0.363
Household consumption	1,728	40,263.629	1,370	40,695.200	0.845

Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013). The sample is restricted to employed individuals living in the urban area of time zone 7, 8 or 9, between 45 and 70 years old (inclusive), and weighted by individual weights.T-test: the estimates include survey wave and regional fixed effects. Standard errors are clustered at city level. Late sunset: sunset time of a city is above the median of all cities' sunset time.

Table 4: First Stage: Sunset Time and Sleep Duration for Employed People in Urban Areas (Models Comparison)

	(1)	(2)	(3)
Dependent Variable:	Sleep hours	Sleep hours	Sleep hours
Model:	A	B	C
Average sunset time	-0.330***	-0.472***	-0.525***
	(0.097)	(0.158)	(0.174)
Individual controls	Yes	Yes	Yes
Region F.E.	No	Yes	Yes
City characteristics	No	No	Yes
Observations	2,641	2,641	2,641
R-squared	0.041	0.043	0.049
Mean of Dep. Var.	6.536	6.536	6.536
Std.Err. of Dep. Var.	1.425	1.425	1.425

Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013). Model A include individual controls for education (no formal education or illiterate, at most completed elementary school, completed middle school, completed at least high school or vocational school), age and its quadratic term, gender, marital status, employment status, subjective poverty status, the logarithm of household consumption, living in urban or rural area, and interview characteristics (survey wave and month fixed effects). Model B adds to model A regional fixed effects. Model C adds to model B some city characteristics namely the logarithm of GDP and population, type of main landscape (plain, hill, mountain, plateau, basin), degree of industrial pollution (poor, fair, good, very good). The sample is restricted to employed individuals living in the urban area of time zone 7, 8 or 9, between 45 and 70 years old (inclusive). The estimation sample is weighted by individual weights. Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are clustered at the city level.

Table 5: First Stage: Sunset Time and Sleep Duration by Urban Area and Employment Status

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	Sleep hours	Sleep hours	Sleep hours	Sleep hours	Sleep hours	Sleep hours
Sample:	Urban	Rural	Employed	Not-employed	Rural & emp.	Urban & emp.
Average sunset time	-0.218**	-0.052	-0.398***	-0.125	-0.245	-0.525***
	(0.095)	(0.110)	(0.132)	(0.095)	(0.179)	(0.174)
Observations	10,126	16,168	5,071	21,223	2,430	2,641
R-squared	0.041	0.033	0.043	0.027	0.054	0.049
Mean of Dep. Var.	6.336	6.289	6.541	6.251	6.546	6.536
Std.Err. of Dep. Var.	1.625	1.808	1.423	1.803	1.421	1.425

Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013). All estimates include the same controls as in Model C of Table 4. The sample is restricted to individuals living in time zone 7, 8 or 9, between 45 and 70 years old (inclusive). The estimated sample is weighted by individual weights. Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are clustered at the city level.

Table 6: Reduced-Form Analysis: Sunset Time and Cognitive Skills

	(1)	(2)	(3)	(4)	(5)	(6)
Sample:	Urban	Rural	Employed	Not-employed	Rural & emp.	Urban & emp.
Dependent variable:						
Mental	-0.186	-0.167	-0.173	-0.173	0.090	-0.360**
	(0.130)	(0.158)	(0.193)	(0.126)	(0.307)	(0.164)
Observations	9,915	15,909	4,881	20,943	2,346	2,535
R-squared	0.131	0.154	0.115	0.196	0.113	0.089
Dependent variable:						
Numerical	-0.266**	-0.240**	-0.490***	-0.245***	-0.336	-0.596***
	(0.110)	(0.108)	(0.148)	(0.081)	(0.307)	(0.120)
Observations	9,915	15,909	4,881	20,943	2,346	2,535
R-squared	0.136	0.221	0.106	0.224	0.119	0.110
Dependent variable:						
TICS	-0.452**	-0.407*	-0.663**	-0.418***	-0.246	-0.955***
	(0.190)	(0.236)	(0.321)	(0.154)	(0.578)	(0.255)
Observations	9,915	15,909	4,881	20,943	2,346	2,535
R-squared	0.158	0.237	0.115	0.267	0.13	0.096
Dependent variable:						
Memorial	0.246	0.023	-0.139	0.149	-0.401	-0.090
	(0.172)	(0.155)	(0.202)	(0.124)	(0.369)	(0.213)
Observations	9,915	15,909	4,881	20,943	2,346	2,535
R-squared	0.127	0.105	0.131	0.122	0.102	0.143
Dependent variable:						
Draw	-0.010	-0.044	-0.015	-0.041	0.067	-0.049
	(0.032)	(0.032)	(0.029)	(0.027)	(0.047)	(0.035)
Observations	9,236	14,899	4,177	19,958	1,925	2,252
R-squared	0.181	0.223	0.172	0.226	0.172	0.178
Dependent variable:						
CES-D	0.133	0.605	0.798	0.638	0.464	1.116
	(0.669)	(0.437)	(0.616)	(0.475)	(0.978)	(0.719)
Observations	8,976	14,243	4,061	19,158	1,858	2,203
R-squared	0.127	0.121	0.136	0.107	0.133	0.134

Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013). All estimates include the same controls as in Model C of Table 4. The sample is restricted to individuals living in time zone 7, 8 or 9, between 45 and 70 years old (inclusive). The estimated sample is weighted by individual weights. Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are clustered at the city level.

Table 7: 2SLS: Sleeping Time and Cognitive Skills (Urban and Employed)

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	Mental	Numerical	TICS	Memorial	Draw	CES-D
Sleep hours	0.713*	1.181**	1.894**	0.178	0.086	-2.010*
	(0.428)	(0.488)	(0.869)	(0.42)	(0.061)	(1.300)
Observations	2,535	2,535	2,535	2,535	2,252	2,203
F-test	9.28	9.28	9.66	9.28	9.66	8.54
Mean of Dep. Var.	4.056	3.591	7.647	3.797	0.844	5.625
Std.Err. of Dep. Var.	1.634	1.828	3.165	2.210	0.363	4.783

Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013). All estimates include the same controls as in Model C of Table 4. The sample is restricted to employed individuals living in the urban area of time zone 7, 8 or 9, between 45 and 70 years old (inclusive). The estimated sample is weighted by individual weights. Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are clustered at the city level.

Table 8: First Stage: Sunset Time and Other Sleep Measures

	(1)	(2)	(3)
Dependent variable:	Sleep $\leq$ 6 hours	Sleep $\geq$ 8 hours	7 $\leq$ Sleep $\leq$ 9 hours
Average sunset time	0.140**	-0.173***	-0.209***
	(0.066)	(0.042)	(0.068)
Observations	2,641	2,641	2,641
R-squared	0.053	0.044	0.064
Mean of Dep. Var.	0.420	0.232	0.456
Std.Err. of Dep. Var.	0.494	0.422	0.498

Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013). All estimates include the same controls as in Model C of Table 4. The sample is restricted to employed individuals living in the urban area of time zone 7, 8 or 9, between 45 and 70 years old (inclusive). The estimated sample is weighted by individual weights. Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are clustered at the city level.

Table 9: Unconfoundness Test: Sunset Time effect on Knee Length and Self-Reported Child Poor Health

	(1)	(2)	(3)	(4)
Dependent variable:	Knee length	Knee length	Child poor health	Child poor health
Sample:	Overall	Urban & emp.	Overall	Urban & emp.
Average sunset time	-0.413	-0.414	0.025	-0.002
	(0.340)	(0.646)	(0.031)	(0.048)
Observations	11,256	985	26,206	2,609
R-squared	0.278	0.306	0.019	0.113
Mean of Dep. Var.	47.960	48.830	0.258	0.203
Std.Err. of Dep. Var.	3.455	3.399	0.437	0.402

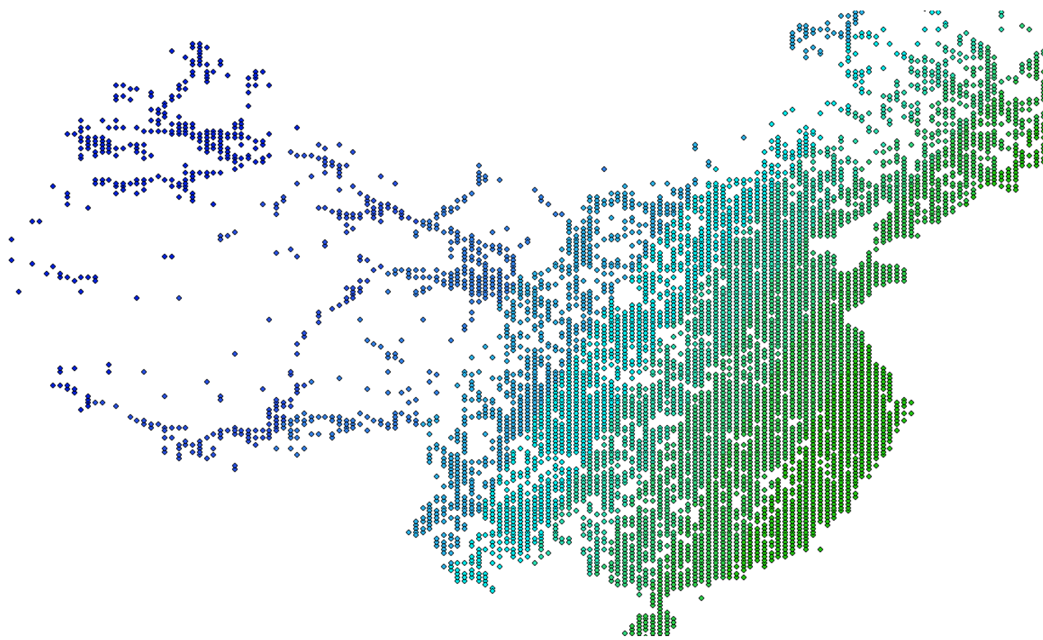
Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013). We report estimates of the effect of the average sunset time on knee length and self-reported child poor health. Knee length is available only in wave 1 by the time of writing. All estimates include the same controls as in Model C of Table 4. The overall sample is restricted to individuals living in time zone 7, 8 or 9, between 45 and 70 years old (inclusive). The other sample is further restricted to employed individuals living in the urban area of time zone 7, 8 or 9, between 45 and 70 years old (inclusive). The estimated sample is weighted by individual weights. Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are clustered at the city level.

Table 10: Sunset Time, Sleep and Cognitive Skills among Self-Employed in Urban Areas

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable:	Sleep	Mental	Numerical	TICS	Memorial	Draw	CES-D
Average sunset time	-0.197	0.062	-0.366	-0.304	0.173	0.015	-0.343
	(0.212)	(0.223)	(0.278)	(0.411)	(0.256)	(0.046)	(0.745)
Observations	1,240	1,227	1,227	1,227	1,227	1,139	1,128
R-squared	0.097	0.187	0.198	0.226	0.199	0.176	0.105
Mean of Dep. Var.	6.329	4.077	3.721	7.799	3.731	0.802	6.309
Std.Err. of Dep. Var.	1.549	1.430	1.675	2.711	1.957	0.399	5.440

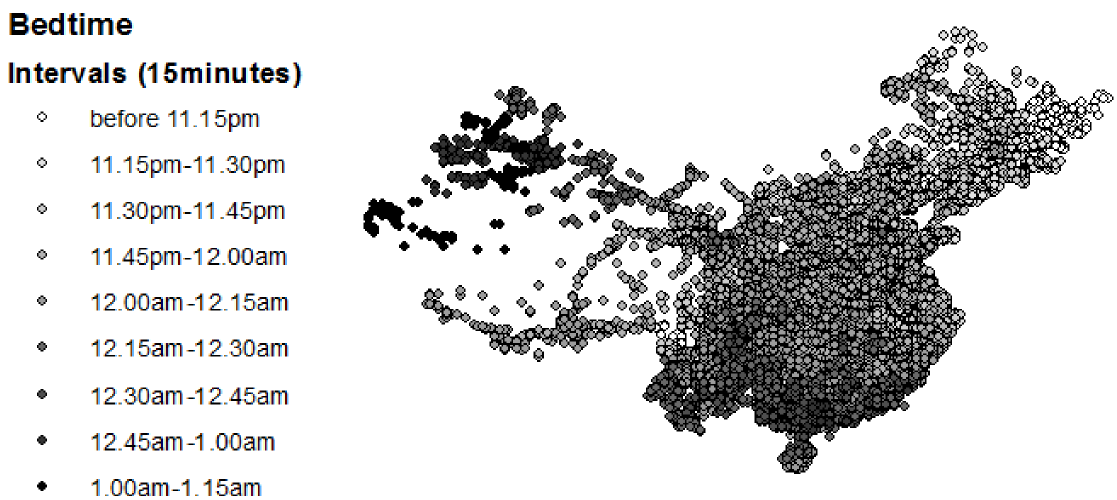
Notes - Data are drawn from the China Health and Retirement Longitudinal Study (CHARLS, 2011-2013). All estimates include the same controls as in Model C of Table 4. The sample is restricted to self-employed individuals living in the urban area of time zone 7, 8 or 9, between 45 and 70 years old (inclusive). The estimated sample is weighted by individual weights. Significance levels: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors are clustered at the city level.

Figure 1: Sunset Time in China on June 21st



Notes - Sunset time for Chinese cities was computed using the NOAA Solar Calculator. Sunset time goes from light green(early sunset) to dark blue (late sunset). The earliest sunset time in the data occurs at 18.53pm, the latest sunset in the data occurs at 22.29pm.

Figure 2: Average Bedtime Across Chinese Cities



Notes - Data were downloaded from the Jawbone blog `https://jawbone.com/blog/sleep-china/` on October 2, 2015.

Figure 3: China time zones according to the Coordinated Universal Time (UTC)

Notes - This map was downloaded from `http://www.lib.utexas.edu/maps/middle_east_and_asia/china_pol96.jpg`. The red vertical lines (elaborated by the authors) correspond to the UTC time zone areas.

Figure 4: The four economic regions of China