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Jeffrey A. Groen
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Jeffrey A. Groen
U.S. Bureau of Labor Statistics

Sabrina Wulff Pabilonia
U.S. Bureau of Labor Statistics and IZA

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IZA – Institute of Labor Economics

Schaumburg-Lippe-Straße 5–9
53113 Bonn, Germany

Phone: +49-228-3894-0
Email: publications@iza.org

www.iza.org

ABSTRACT

Snooze or Lose: High School Start Times and Academic Achievement*

Many U.S. high schools start classes before 8:00 A.M., yet research on circadian rhythms suggests that students' biological clocks shift to later in the day as they enter adolescence. Some school districts have moved to later start times for high schools based on the prospect that this would increase students' sleep and academic achievement. This paper examines the effect of high school start times on student learning. We use longitudinal data from the Child Development Supplement to the Panel Study of Income Dynamics (PSID-CDS) to conduct the first study of this relationship using a nationally-representative sample of students. We also use the CDS time diaries to explore the effects of high school start times on students' time allocation. Results indicate that female students who attend schools with later start times get more sleep and score higher on reading tests. Male students do not get more sleep when their schools start later and their test scores do not change.

JEL Classification: I12, I20, J22

Keywords: academic achievement, school start times, sleep, time allocation

Corresponding author:
Sabrina Wulff Pabilonia
U.S. Bureau of Labor Statistics
2 Massachusetts Ave. NE, Rm. 2180
Washington, DC 20212
USA
E-mail: Pabilonia.Sabrina@bls.gov

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I. Introduction

Over the past decade, many U.S. school districts have pushed their high school start times later in response to surveys suggesting that teens are not getting enough sleep and evidence from sleep scientists suggesting that children's circadian rhythms shift to later in the day as they enter adolescence.[1] Poor or inadequate sleep is correlated with higher rates of obesity, lower cognitive performance, and higher rates of depression (Pilcher and Hufcutt 1996; Roenneberg 2013). Therefore, shifting to later start times has the promise of increasing both sleep and academic achievement. At the same time, shifting to later start times often occurs with much disruption to local communities' schedules and can potentially raise busing costs.[2] For example, changing high school start times would require employers who provide teenagers with after-school jobs and providers of extracurricular activities to make scheduling adjustments (Shapiro 2015; Wahlstrom 1999).

The link between school start times and achievement has received much attention in the popular press, by the health community, and even by Congress. House Concurrent Resolution 176, introduced to Congress in 2007 as the "Zzz's to A's Resolution" but not passed, called for secondary schools nationwide to begin the school day after 9:00 A.M. More recently, the American Academy of Pediatrics (2014) recommended that "in most districts, middle and high schools should aim for a starting time of no earlier than 8:30 A.M." If delaying start times causes students to get more sleep, students may experience increases in positive health outcomes

[1] Some of these changes in school start times have been documented by Start School Later, Inc. (2015).

[2] Many school districts originally set early schedules for high schools to implement less-expensive multiple-tiered busing schedules. One way for high schools to start later without affecting younger students' schedules would be to add buses. An alternative that does not add to transportation costs would be to switch the bell schedules of high schools with those of either middle schools or elementary schools.

and cognitive performance—and ultimately academic achievement. Early start times, however, may not be detrimental to learning if students are able to adapt to waking up early or if teachers are more productive with early schedules. Some recent papers (Carrell, Maghakian, and West 2011; Edwards 2012; Heissel and Norris 2017; Hinrichs 2010; Luong, Lusher, and Yasenov 2017; Wong 2011) have examined whether changing school start times results in a positive effect on measurable academic outcomes, with mixed results.

The goals of this paper are twofold: 1) to examine whether school start times affect student learning, and 2) to examine the effects of school start times on students' time allocation, especially sleep time, in order to more fully understand the mechanisms through which changing start time affects student learning. This paper contributes to the extant literature on the effects of school start times in two ways: 1) we use longitudinal data from a nationally-representative sample of high school students aged 13-18 (the Child Development Supplement to the Panel Study of Income Dynamics [PSID-CDS]) whereas prior studies examined the effects of school start times on student learning at a school, within a state or metropolitan area, or at the high-school level, and 2) we use time diaries to explore the effects of high school start times on students' time allocation, which could help to explain any observed effects on academic achievement beyond a disturbance in natural sleep cycles. Time diaries are believed to produce more-accurate estimates of time spent doing activities than surveys asking about usual time spent on activities (Juster, Ono, and Stafford 2003). Our time-diary estimates suggest that students actually sleep about an hour more than reported in studies asking about usual sleep on a school night.

Results indicate that female students who attend schools with later start times get more sleep and score higher on reading tests, but not on math tests. We find that shifting start time one hour later results in an increase in reading test scores by 0.15 standard deviations. Male students, however, do not get more sleep with a later start time and we do not observe any effects of school start times on their test scores. We also find that girls with a later start time are more likely to be on a sports team, though they spend less time on other schooling activities (such as SAT prep). Male students with a later start time spend less time on computer games and less time with their parents, but spend more time on personal care activities.

II. Background and Literature Review

A. Sleep Patterns and Sleep Science

A sleep-laboratory study among adolescents given a 10-hour sleep opportunity suggested that adolescents need on average 9.2 hours of sleep each night (Carskadon et al. 1980). Recently, the National Sleep Foundation recommended that teenagers (ages 14-17) sleep between 8 and 10 hours each night (Hirshkowitz et al. 2015). However, a national survey of adolescents found that adolescents in high school reported sleeping on average only 7.2 hours on the typical school night (National Sleep Foundation 2006).[3] About 45 percent of U.S. public high schools started the school day before 8:00 A.M. in 2015-2016, and about 86 percent started before 8:30 A.M. (Taie and Goldring 2017). Advocates of later bell times argue that delaying bell times would allow students to get more sleep, which would promote cognitive functioning during the school day and improve academic achievement (e.g., Jacob and Rockoff 2011; National Sleep Foundation 2013).

[3] Estimates from time diaries suggest that adolescents actually sleep slightly longer than estimates from surveys about usual hours (e.g., Kalenkoski and Pabilonia 2012). The time-diary estimates from the PSID-CDS and ATUS both fall close to the lower bound of the appropriate sleep-duration range for adolescents as specified in the National Sleep Foundation's recommendations (Hirshkowitz et al. 2015).

These claims have a basis in sleep science. Sleep scientists postulate that sleep/wake behavior in humans is coordinated by two processes: a circadian timing system and a homeostatic system (Borbely 1982). The circadian system is associated with the hormone melatonin, is influenced by light and darkness, and tends to make humans tired during the nighttime hours. The homeostatic system provides sleep pressure that increases the longer a person is awake and decreases with sleep. There is some evidence that the circadian system of humans undergoes a phase shift in adolescence (associated with puberty) toward later bedtimes and later wake-up times (Carskadon, Vieira, and Acebo 1993). A later sleep/wake cycle may also be promoted by a slower accumulation of homeostatic sleep pressure, allowing adolescents to stay awake longer (Crowley, Acebo, and Carskadon 2007).

In addition to biological factors, environmental factors appear to contribute to the later sleep/wake cycle of adolescents. These factors include reduced parental influence on bedtimes, increased homework, and extracurricular activities such as sports, music, and part-time employment (Carskadon 1990). In short, the evidence from sleep science argues that early start times are in conflict with the desired sleep patterns of adolescents. Environmental influences and changes in biological systems may limit the ability of students to make adequate adjustments to early start times.

B. Start Times and Academic Achievement

Our paper investigates the relationship between starting times in high school and academic achievement. A small number of papers have investigated this relationship, and the evidence is mixed. The earliest research in this area used data from the Minneapolis–St. Paul metropolitan area, where Minneapolis and several suburban districts shifted to later bell times for their high schools (starting in 1997-98) but St. Paul and other suburban districts maintained early schedules. Wahlstrom (2002) examined Minneapolis high schools before and after the change and found that attendance rates increased and grades improved slightly. However, Hinrichs (2010) found no effect of starting times on achievement in an analysis that involved data from both schools that changed schedules and those that did not change schedules. Using individual-level ACT test-score data for students in the region who took the test for several years before and after the policy change, Hinrichs found that students who attended high schools with later start times did no better on the ACT than students who attended high schools with earlier start times. Hinrichs obtained similar results using school-level data on starting times and scores on statewide standardized tests from Kansas and Virginia.

In contrast, Wong (2011) found positive effects of later school start times on school-level student performance on state standardized tests using a nationally representative cross-sectional sample of high schools from the National Center for Education Statistics (NCES) 2007-08 Schools and Staffing Survey (SASS) combined with standardized tests obtained from 27 state departments of education. He also found that average sunlight before 8 A.M., which is tied to regulating circadian rhythms, has a positive effect on exam performance. Edwards (2012) also found positive effects of starting times on standardized tests in math and reading for middle school students in Wake County, North Carolina. Recently, using administrative data from Florida and observing students aged 8–15 moving across the Central-Eastern time-zone boundary, Heissel and Norris (2017) found that moving school start times later relative to the sunrise increased standardized test scores in both math and reading, though especially math scores for the older children. Carrell, Maghakian, and West (2011) and Luong, Lusher, and Yasenov (2017) also provide evidence that suggests a positive effect of later start times, at least for older teenagers. Carrell, Maghakian, and West (2011) found that freshman college students at the U.S. Air Force Academy who began the school day later in the morning performed better in all of their courses taken that day compared with students who began the day earlier in the morning. Luong, Lusher, and Yasenov (2017) found that freshman college students at a large university in Vietnam saw a very small boost in their class grade from starting later, but only for morning classes. Both Edwards (2012) and Carrell, Maghakian, and West (2011) found that effects were stronger for students in the lower end of the achievement distribution.

Related literature addresses whether the time of day that students attend a class affects their performance. Cortes, Bricker, and Rohlfs (2012) found that high school students in Chicago Public Schools received lower grades and were more likely to be absent from a class when it met in first period than when it met later in the day. Dills and Hernandez-Julian (2008) found that college students at Clemson University received higher grades in a class if it met later in the day. Hansen et al. (2005) found that high school students performed better on cognitive tests given in the afternoon than in the morning. However, Pope (2016) found that high school students in Los Angeles County Schools have higher grades if their math or English class is in the morning than later in the school day, controlling for school start times.

C. Mechanisms

According to several strands of literature, the primary mechanism connecting high school start time and academic achievement is sleep. There is general evidence that school attendance is associated with sleep loss. Students sleep less on weekdays during the school year than during the summer, and during the school year they sleep less on school nights than on non-school nights (Crowley, Acebo, and Carskadon 2007; Hansen et al. 2005; Stewart 2014). Moreover, surveys have found that students of all ages who start school earlier in the day obtained less total sleep on school nights (Carskadon et al. 1998; Knutson and Lauderdale 2009; Stewart 2014;

Wolfson and Carskadon 1998; Wolfson et al. 2007).[4] When a large school district delayed its start time for high school by 60 minutes, average hours of sleep on school nights increased and "catch-up" sleep on weekend nights decreased (Danner and Phillips 2008). In addition, most prior research suggests that wake-up times change more than bedtimes in response to changes in school start times (e.g., Knutson and Lauderdale 2009; Minges and Redeker 2016; Stewart 2014). Epstein, Chillas, and Lavie. (1998) found that early start times increased sleepiness in fifth graders regardless of the amount of sleep the children got. Thus, disrupting natural sleep cycles could also negatively affect academic achievement.

In addition to the evidence that later start times are associated with more sleep, studies have related sleep and achievement. Evidence from laboratory studies indicates that sleep deprivation impairs cognitive performance (Pilcher and Hufcutt 1996). Many studies document that students who obtain more sleep perform better in school and on standardized tests, although these correlations do not establish a causal relationship (Eide and Showalter 2012; Wolfson and Carskadon 2003). Recently, using a fixed-effects strategy, Sabia, Wang, and Cesur (2017) found that longer sleep was beneficial for success in the classroom as well as increased the probability of high school graduation and college attendance. They identified 8.5 hours per night as the ideal amount of sleep for academic success.

Beyond sleep, there are several other potential mechanisms that may mediate the link between school starting times and academic achievement. Although students with early start times may get less sleep on school nights, they may be able to make other lifestyle changes so that their achievement is not affected. For instance, they could use stimulants to promote

[4] The range of estimates in the literature for a 60-minute delay in start time is additional sleep of 20 minutes to 60 minutes.

alertness for their morning classes, they could receive extra support from their parents (or tutors) with their homework, or they could nap in class (which we don't capture with the time diaries). Starting times may also affect the amount of time that students spend in part-time work, sports, and other extracurricular activities. In addition, starting times may affect parental employment or the amount of time that students spend with their parents if they cannot synchronize their work and school schedules. The latter is of particular interest because parental supervision can potentially decrease risky behaviors or increase homework time (Aizer 2004). Even though adolescents may work better later in the day, teachers may prefer earlier start times; as a result, teachers may be less productive with later start times.[5] Each of these things has its own influence on academic achievement and labor-market outcomes.[6]

Given the existing literature on starting times, sleep, and student achievement, it seems likely that other mechanisms are relevant. Specifically, the partial effect of a later starting time on achievement that operates through sleep is likely positive because a later start time should increase sleep and more sleep should improve achievement. If the total effect of a later starting time on achievement is smaller than the partial effect, other mechanisms would appear to be responsible. For example, later start times may reduce participation in extracurricular activities, thereby reducing the achievement gains associated with increased sleep.

[5] Wahlstrom (1999) reported that some urban high school teachers were negatively impacted by later school start times. Teachers reported less down time, increased rush-hour traffic, and less time spent on second jobs.

[6] For example, Light (2001) reviewed the positive benefits of student employment; Lipscomb (2007) found that participation in sports and other extracurricular activities increased students' math and science scores; and Stevenson (2010) found that increases in state-level female sports participation following Title IX resulted in increases in female college-attendance rates.

III. Data

A. Data Sets Used

Our data come primarily from the Child Development Supplement to the Panel Study of Income Dynamics (PSID-CDS). The PSID-CDS began in 1997 (referred to henceforth as CDS-I) with children aged 0-12 and is nationally representative. Up to two children in a family were interviewed. These children were then reinterviewed in 2002-03 (CDS-II) and again in 2007-08 (CDS-III). After a child reached the age of 18 and was no longer attending high school, his/her participation in the CDS ended, but he/she was eligible for a follow-up Transition to Adulthood (TA) survey or the main PSID.

For our study, the CDS-I provides background information on the child's race, and the main PSID interviews provide information on the respondent's family structure and mother's education.[7] A unique aspect of the PSID-CDS is the collection of two 24-hour time diaries – one for a randomly-assigned weekday and another for a randomly-assigned weekend day. Each diary contains start and stop times of students' primary and secondary activities occurring from midnight to midnight on the diary day as well as where each activity took place and who was with them in the room (or who accompanied them on an activity, if they were not at home). We control for high school-level and school district-level variables by matching our sample to the NCES Common Core of Data (CCD) using school identifiers from the restricted-use version of the Panel Study of Income Dynamics (2014).

We obtain school start and end times from several sources, including current (2014-16) school websites and older school websites archived in the Internet Archive's Wayback Machine;

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[7] We use the main PSID interview in 2003 for CDS-II high school respondents and the main PSID interview in 2007 for CDS-III high school respondents.

Start School Later, Inc. (2015); the 2007 and 2011 restricted-use versions of the NCES Schools and Staffing Survey (SASS); and data provided by Mary Carskadon and Peter Hinrichs. In most cases, schools do not change their start times from year to year. Usually when we have two sources of bell times for a school in the same year, the sources concurred. As shown in Appendix Table A1, our primary source of bell times is school websites.

Our main independent variable is the school start time. School start time is the time of the first official school bell and is measured in hours since midnight.[8] It is reported in decimal form and thus indicates hours and a fraction of an hour. In our CDS sample, start times ranged from 7:00 A.M. to 9:15 A.M., with a majority of students (79 percent) starting school between 7:30 A.M. and 8:29 A.M. and an average start time of 7:53 A.M.[9] Thus, our data set contains greater variation and range in school start times than those used in most prior studies, with the exception of Wong (2011). In our regressions, we control for the length of the school day so that our estimates are the effects of starting the school day later without changing its length (as in Hinrichs 2010). The length of the school day is created by taking the difference between the school end time and start time. The length of the school day ranged from 5.5 to 8.75 hours per day, with an average day length of 7 hours per day.

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[8] Some schools have "zero period" classes, which meet before first period. Because these classes are limited in enrollment and usually considered optional, we measure the school start time based on the beginning of first period.

[9] Specifically, 12.8 percent started before 7:30 A.M., 41.5 percent started between 7:30 A.M. and 7:59 A.M., 37.3 percent started between 8:00 A.M. and 8:29 A.M., and 8.4 percent started at 8:30 A.M. or later. Notably, the distribution of start times in our CDS sample is similar to the distribution of start times for public high schools in the 2007-08 SASS: 15.9 percent started before 7:30 A.M., 38.1 percent started between 7:30 A.M. and 7:59 A.M., 35.2 percent started between 8:00 A.M. and 8:29 A.M., and 10.9 percent started at 8:30 A.M. or later. The average start time in the SASS is also 7:53 A.M. (For these calculations, we weighted the SASS school-level data by student enrollment in order to provide a proper comparison to the CDS student-level data.)

B. Sample Construction

We examine a subsample of CDS respondents aged 13-18 who were enrolled in grades 9-12 in a full-time public high school in either CDS-II (2002-03) or CDS-III (2007-08). Appendix Table A2 details our sample construction. Our main analysis sample includes 1,200 respondents – 600 females and 600 males – who attended 790 unique high schools.[10] For our time-use analyses, we further restrict the sample to those who had two time diaries and were not missing more than 180 minutes on a diary day. This resulted in a time-use sample of 1,110 respondents. We conduct separate analyses by gender because of the huge differences in schooling achievement and time use between males and females (Goldin, Katz, and Kuziemko 2006; Jacob 2002; Kalenkoski and Pabilonia 2017).[11] There is also some evidence that males and females have different circadian rhythms, with males having more difficulty coping with sleep deprivation. A recent paper by Lusher and Yasenov (2017) found that males received a boost in performance relative to females when school started in the afternoon rather than the morning.

C. Academic Outcomes

Our main dependent variables are two test scores: the broad-reading and applied-problem standardized test scores on the Woodcock Johnson Revised Tests of Basic Achievement (WJ-R) that were administered at the time of the high school CDS child interview. The broad-reading test score is considered a general measure of reading achievement while the applied-problem test score is considered a general measure of mathematics reasoning achievement. Table 1 includes overall sample means for the test scores as well as their means in three categories defined by school start times. Scores are higher for students in the earliest school start-time category (7:00–

[10] Observation counts are rounded to the nearest ten in accordance with NCES disclosure requirements.
[11] Pooled results are available upon request for our main results.

7:44 A.M.) than in the two later periods (7:45– 8:14 A.M. and 8:15– 9:15 A.M.); however, the differences are not statistically significant. Male students scored slightly higher than female students on the WJ-R applied-problems test, a result consistent with the literature on the gender gap in math test scores (Niederle and Vesterlund 2010). In our econometric analyses below in Section IV, we examine the relationship between test scores and school start time with a rich set of controls for individual, family, school, and community characteristics.

D. Intermediate Outcomes

In addition to the academic outcomes, we examine numerous intermediate outcomes, each of which could be affected by start times. Some of these outcomes are created using the time diaries, while others are from general survey questions. All measures of time spent on an activity are reported in hours per day. We calculate school-day measures (Monday through Thursday), weekday measures, and all-day measures. The latter is calculated by taking a weighted average of the weekday and weekend-day activity times.[12] We argue that measures of time spent on an activity that are aggregated from time-use diaries are preferable to measures of "usual" time spent because they are less subject to both aggregation bias and social desirability bias (Juster, Ono, and Stafford 2003). For example, if a society places a high value on hard work at the expense of sleep, individuals may overestimate their usual hours worked and underestimate their usual hours of sleep. We consider the effects of school start time on students' activities across the day as well as on annual sports participation, daily time spent with parents, employment, weight, and mood. See Appendix Table A3 for the 15 activity categories that we use to classify students' time allocation across the day.

[12] Specifically, we calculate all-day hours measures as (5/7)*(weekday hours) + (2/7)*(weekend day hours).

Sleep

We examine four measures of sleep on weekdays – all diary sleep (including naps), nighttime diary sleep, usual night sleep, and naps – in order to observe whether we see tradeoffs between sleep and start times as observed by previous researchers. The first two diary-sleep measures are intended to measure sleep on school days. We initially exclude Fridays because Friday bedtime corresponds to a weekend schedule. Usual night sleep is obtained from the child-interview portion of the CDS rather than the time diary. We assume that the usual night sleep reported by students is for a weeknight, because the questionnaire asked "What time do you usually go to bed on weeknights?" just prior to asking about a usual night's sleep. Naps include any time recorded as napping or resting. Later, we also consider sleep on all days to determine whether students who go to school earlier are able to "catch-up" on sleep on weekend days.[13]

As shown in Table 2, there is little difference in the sample means between all diary sleep and night diary sleep (a difference of 0.21 and 0.34 of an hour for females and males, respectively).[14] In most cases, night sleep includes parts of two sleep episodes: the first episode is the latter part of the sleep cycle begun the day prior to the diary, and the second episode is the first part of the sleep cycle begun on the day of the diary. Using the weekday-night sleep-diary measure, we find that female high school students sleep on average 8.29 hours per night but

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[13] Research by Kim et al. (2011) suggests that weekend catch-up sleep is negatively related to performance on tasks.

[14] One criticism of the diary measure that should not affect our estimates of the effect of school start times is that night sleep can include sleeplessness (Eide and Showalter 2012). In Appendix Table A4, we present separate estimates of diary night sleep and sleeplessness on school nights from the American Time Use Survey (ATUS) for a sample of high school students aged 15-18. In the ATUS, we find little reporting on sleeplessness, and teens' night sleep is actually slightly longer than that reported in the CDS. Even though the ATUS diary runs from 4 A.M. on one day to 4 A.M. on the next day, the duration of the last activity (usually sleep) is obtained. Therefore, the ATUS measures a complete night-sleep episode.

report sleeping only 7.35 hours on a "usual" night. Male students sleep slightly more – on average 8.33 hours per night on their weekday diary day and 7.54 hours on a "usual" night. These diary-based sleep measures closely match those obtained from ATUS (Appendix Table A4). Thus, we conclude that "usual" night sleep measures are very biased. We also find that male students nap (0.34 hours on average) for longer periods on average than do female students (0.21 hours on average), suggesting more daytime sleepiness, which would be consistent with males having more difficulty coping with sleep deprivation.

In addition to examining the effect of start times on sleep time, we consider how start times affect students' wake-up times and bedtimes. Wake-up time is defined as the end time of last night-sleep episode occurring before 1:00 P.M. on Monday through Thursday diary days.[15] Bedtime is defined as either the start time of the last recorded night-sleep episode (if beginning after noon on the diary day) or the start time of the first night episode that begins at or after midnight but before noon (if the former episode does not exist) on Monday through Thursday diary days.[16] On average, female and male students wake up at 6:44 A.M. on school-day mornings and go to sleep at 10:23 P.M. on school nights. In Table 3, we report the average hours per day spent on activities on both weekdays (Monday through Friday) and all days. Over all days, female students sleep 9.05 hours per day on average while male students sleep 9.07 hours per day on average, suggesting that students do try to catch-up on sleep on the weekend and are likely suffering from sleep deprivation during the week.

[15] Some students report starting several night-sleep episodes in the early-morning hours, with other short spells of another activity in between periods of sleep. Although Friday diary days could also be used to examine wake-up times, we do not include them so that our estimated effects on night sleep, bedtime, and wake-up time are for the same sample.

[16] Bedtime is measured in hours. For bedtimes after midnight, we add 24 hours so that they occur after bedtimes before midnight.

Other intermediate outcomes

It is often argued by opponents of later start times that moving the high school day later would mean that sports teams cannot practice or would have to shorten their practices due to less daylight after school (National Sleep Foundation 2005a). Opponents also argue that students' afterschool employment would be negatively affected (National Sleep Foundation 2005b). We examine two measures of sports participation. One, from the child-interview portion of the CDS, is whether the student participates in an athletic or sports team at school during that academic year. The other is the number of hours the student participates in sports on the diary day. On average, male students are much more likely to participate in a sports team than female students (39 percent versus 28 percent). We examine two measures of employment. One is whether the student is currently employed. The second is the number of hours worked on the diary day. Male and female students have roughly the same employment participation.

Proponents of later start times argue that students would be less tired if they started school later and thus be more efficient at doing their homework; however, they may also be more rested and thus able to do more homework, resulting in better grades. Indeed, Edwards (2012) found that middle school students spent more time doing homework when schools started later. We examine only homework time that was recorded as a primary activity.[17]

School start times may also affect the amount of time that students spend with their parents on weekdays, due to the degree of synchronization between school schedules and parents' work schedules. We measure time with parents as the sum of all hours on activities where the student reported being in the same room with a parent while at home or accompanying

[17] Students often report doing homework as a secondary activity (Kalenkoski and Pabilonia 2017; Pabilonia 2015).

a parent while away from the home. We measure a student's being overweight using an indicator for whether the student's age and gender-specific BMI percentile was equal to 85 or greater (i.e., being considered overweight or obese according to the CDC). Male students are more likely than female students to be considered overweight (36 percent versus 30 percent). Proponents of later start times argue that the lack of sleep resulting from early start times contributes to students' mood problems (Wahlstrom 2002). We measure students' mood with an indicator for whether the student was "many times" or "always" sad in the last two weeks. Consistent with other surveys (e.g., Youth Behavior Risk Survey [Department of Health and Human Services 2008]), female students are more likely than male students to report being sad (24 percent versus 10 percent).

IV. Econometric Analyses

To examine the effect of start times on student learning and time allocation, we estimate linear models using Ordinary Least Squares (OLS)[18]:

$$Y = b_0 + b_1 S + b_2 D + b_3 X + u \qquad (1)$$

where the dependent variable, Y, is the test score outcome or time use outcome; S denotes school start time; D denotes the length of the school day; X is the vector of control variables; b_0, b_1, b_2, and b_3 are the coefficients to be estimated; and u~N(0,1). The subscripts indicating observation and outcome are suppressed. Length of school day (D) is included because we are interested in the effect of changing the school start time without changing the length of the school day. The regressions and means are weighted using the CDS child weights. Standard errors are adjusted for clustering by school.

[18] In cases where the outcome variable is an indicator variable, we still estimate a linear probability model; estimates using a probit model yield similar results, but in some instances some controls perfectly predicted the outcome and had to be dropped from the specifications.

In estimating these equations, we are interested in the causal effect of start time on achievement and time use. A potential concern with our approach is that students and schools with different start times may be different in ways related to achievement. Two aspects of our approach attempt to deal with concerns about omitted variables bias. First, we include a rich set of controls for individual, family, high school, school-district, county, and state characteristics.[19] Second, our individual controls include lagged versions of the test scores that are the dependent variables in our achievement regressions. Specifically, the lagged test scores are age-adjusted broad-reading and applied-problems standardized-test scores from the Woodcock-Johnson Revised Tests of Basic Achievement (WJ-R) that were given during the CDS child interview occurring about five years prior to the CDS high school observation.[20] We include these lagged test scores to control for prior achievement and ability. Tests taken at that time are more likely to measure inherent ability than tests taken during high school.

In addition to the lagged test scores, our individual controls include indicators for race and Hispanic ethnicity, Census region, grade in school, and interview year and month. We also control for whether the student was ever classified by a school as needing special education for learning disabilities or language problems. We control for several family characteristics, including whether the student lives with a single parent, a stepmother, a stepfather or with other family (the omitted category is 'lives with two biological parents'), the number of other children under the age 19 in the family unit, whether the mother has a college degree, whether the father has a college degree, and whether the student received a free or reduced-price lunch (FRL) at school.

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[19] See Appendix Table A5 for means of these control variables by school start time category.
[20] Approximately 17 percent of the sample is missing one of these scores. We include an indicator for missing scores and impute a score for these students using the average score.

Although we are primarily interested in the total effects of start time on achievement and time allocation, we also estimate a specification where we include controls for sunlight. In this case, b_1 is the partial effect of start time that operates through clock time, holding morning sunlight (or sunrise time) constant.

To motivate our choice of school, school-district, and county controls, we estimate a series of regressions using the high-school-level data in the 2007-08 SASS. Our intent is to control for school or community factors that might be correlated with both achievement and start times. The dependent variable in the regressions is school start time (coded in hours since midnight), and each regression has a different set of controls. The school controls are Census region, urbanicity, number of students, student-teacher ratio, percent of students by race, percent eligible for FRL, and an indicator for magnet or charter school. The district variables are the number of students, expenditure per student, and median household income. The county variable is the population density.

The results, shown in Table 4, indicate that the most important determinants of start times are Census region (schools in the Northeast start earlier), urbanicity (suburban schools start earlier), and school size (larger schools start earlier). The variation by urbanicity and school size is consistent with the notion that high schools in large suburban districts are more likely to have earlier start times in order to reduce transportation costs. The final specification includes latitude, longitude, and time-zone indicators. The estimated effects of latitude and longitude point to the importance of the amount of sunlight in the morning to school start times. The farther east is a school (an increase in longitude), the earlier the sun rises and the earlier is the start time. The farther north is a school (an increase in latitude), the later the sun rises (in fall and winter, when most of our sample is drawn) and the later is the start time. Thus, school districts appear to take account of morning sunlight when setting starting times. Overall, there are differences in school start times based upon school characteristics, some of which may all be correlated with achievement. Our intent is to control for school or community factors that might be correlated with both achievement and start times.

Using the CDS, we estimate several specifications for achievement using equation (1) where we add controls sequentially. Results are presented in Table 5. In specification 1, we include only school start time and day length. Thus, similar to Table 1, we observe a negative relationship between school start time and test scores, but the coefficient is insignificant. When we add controls for lagged test scores in specification 2, the sign of the coefficient flips in the reading regressions for females (column 2). The coefficients on both of the lagged test scores are positive and highly significant, and the R-squared value increases substantially. In specification 3, when we add individual and family controls there is a significant increase in R-squared and the effect of school start time on the reading score increases for females (column 3). In specification 4, our preferred specification, we add school-level, district-level, county-level, and state-level controls. In addition to the before-mentioned controls, we include a control for whether the state had a compulsory-schooling law requiring attendance until age 17 or 18. The total effect of school start time on the broad-reading score is in column 4 while the total effect of school start time on the applied-problems score is in column 9. For females, we find a positive, though marginally statistically significant, effect of school start time on the broad-reading test score (a one hour later start time results in an increase in reading test scores by 0.15 standard deviations). The effects of school start time on the applied-problems test score is insignificant. For male students, we find no statistically significant effects of school start times on test scores.

In specification 5, we add sunlight controls. For females, the partial effect of school start time on the broad-reading test score is similar in magnitude, but not statistically significant at conventional levels (a one hour later start time results in an increase in reading test scores by 0.12 standard deviations). Thus, a large portion of the total effect results from a later clock time. It is not surprising that the coefficient loses significance because now the effect is identified primarily from local comparisons. For example, two schools in Maryland (in the Eastern time zone) both have an average sunrise of about 7:00 A.M., but one school starts at 7:30 A.M. while another starts at 8:00 A.M. Similarly, two schools in Michigan (also in the Eastern time zone) both have an average sunrise of about 7:30 A.M., but one school starts at 7:45 A.M. while another starts at 8:15 A.M.

In Table 6, we present the effects of school start times and school day length on both the timing and duration of sleep on school days (using the Monday through Thursday diaries) without sunlight controls.[21] We find different effects for female and male students. For female students, we find that in response to a delay in start time of one hour, they sleep 0.599 hours (36 minutes) more per night and 0.634 hours (38 minutes) more on their diary day. In response to a delay in start time by one hour, male students increase their night sleep by only 0.327 hours (20 minutes, not statistically significant). In addition, for males, the effect of delaying the start time on total diary sleep on weekdays is negative (again, not statistically significant). If we use the "usual sleep" measure, the effect of school start time on night sleep for both female and male

[21] Estimates for the other control variables are not presented here for the sake of brevity but are available from the authors upon request. Estimates for the sleep regressions including sunlight controls are presented in Appendix Table A6. The estimated effects decrease slightly suggesting that a large portion of the effect results from a later clock time but also that morning sunlight is positively correlated with start time and total sleep time.

students is smaller.[22] For male students, we do find a large negative effect of start time on nap time (-0.464 hours for one hour delayed start time), but the effect is not significant at conventional levels. This is again in line with research suggesting sleep deprivation has a large effect on males. Overall, our different findings of the effects of start times on sleep by gender are consistent with our different findings of the effects of start times on test scores by gender.

For female students, we find that the extra sleep from starting school later is a result of waking up 0.584 of an hour later in the day, with no effect on bedtime. This is consistent with prior research by Knutson and Lauderdale (2009) and Wolfson et al. (2007). For male students, we find that a delay in start time results in a later wake-up time of 0.575 of an hour (35 minutes) but also a small delay in bedtimes (0.267 of an hour, or 16 minutes), which explains why delaying the school start time does not have a significant effect on their nighttime diary sleep.[23] Broadly speaking, these effects on weekday wake-up times are consistent with the notion that early school schedules are not in sync with adolescents' circadian rhythms.

In Table 7, we present the effects of school start times on a full set of time-use activities and some other intermediate outcomes, including sports participation, time with parents, employment, and health outcomes. For female students, we find little difference in the estimated effects of weekday and all-day sleep duration, suggesting that those who must wake early during the week for an early school start do not "catch-up" on sleep over the weekend. We find that start time has a small negative effect on other schooling activities, such as SAT prep, which could potentially translate into lower test scores. Contrary to one of the common arguments put forth

[22] For female students, we find that in response to a delay in start time of one hour, they sleep 0.384 hours more per night. For male students, we find that in response to a delay in start time of one hour, they sleep 0.213 hours more per night, but the effect is not statistically significant.

[23] For male students, we also find that their bedtime is earlier with a longer school day.

by opponents of later school start times, later start times have a large positive effect on participation in sports teams for female high school students. This could lead to higher test scores given the positive link between sports participation and achievement found in the literature (Lipscomb 2007; Stevenson 2010).

For male students, we again find no effect of start time on sleep (on weekdays and on all days). We do find that they spend less time playing computer games when school starts later. They also spend less time with their parents on all days and more time on personal care. Collectively, these changes in time allocation for male students may have offsetting effects on test scores. It seems likely though that the lack of a positive relationship between school start times and academic outcomes for males is due to the lack of a large increase in sleep.

With later start times, students are not any more or less likely to hold a job or spend time at work, which is counter to the argument made by opponents of later school start times. Contrary to previous studies, we also do not find any effects of start time on time spent on homework, student mood, or the probability of being overweight.

V. Conclusion

Using longitudinal data on a nationally-representative sample of students, we find that when high school starts 60 minutes later, female students sleep 36 minutes more on school nights on average. This effect comes about entirely through a delay in wake-up time rather than a change in bedtime. We find some evidence that this increase in sleep translates into improved academic achievement. For female students, a one hour delay in high school start time results in an increase in reading test scores by 0.15 standard deviations but no change in math test scores. This effect on reading test scores is more than three times as large as found by Heissel and Norris (2017), but our students are older and more likely to have gone through puberty. The effect size is very similar to the effect of reducing class size from 22 students to 15 students in grades K-3, though the estimated costs of reducing class size exceed the estimated costs of adjusting school start time (Jacob and Rockoff 2011; Schanzenbach 2006). With regard to other changes in time allocation as a result of a delay in school start time, we find that girls are much more likely to be on a sports team, but spend slightly less time on other schooling activities, such as SAT prep.

Male students, however, do not sleep longer when their schools start later nor do we find any effects of school start times on their test scores. We do find that they spend less time playing computer games and less time with their parents when school starts later, but spend more time on personal care activities.

Thus, overall our results suggest that starting school later has beneficial effects on student achievement, at least for girls. In addition, we do not find evidence that students lose out on extracurricular activities or employment opportunities when school starts later, contrary to the claims of opponents of later start times. We also find that regardless of start times students do a similar amount of homework.

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Table 1. Means of Test Scores by School Start Time

Variables	All	7:00–7:44 A.M.	7:45–8:14 A.M.	8:15–9:15 A.M.
Females				
WJ-R broad-reading score	103.82	105.10	102.97	103.75
	(16.70)	(18.84)	(14.51)	(17.77)
WJ-R applied-problems score	102.74	104.27	102.19	101.51
	(15.55)	(17.56)	(13.96)	(15.14)
N	600	200	260	140
Males				
WJ-R broad-reading score	101.79	102.61	101.07	101.67
	(18.76)	(18.88)	(18.72)	(17.97)
WJ-R applied-problems score	106.87	108.03	105.85	106.60
	(16.54)	(15.68)	(17.54)	(15.41)
N	600	210	230	150

Notes: CDS weights used. Standard deviations are in parentheses. Observation counts are rounded to the nearest ten in accordance with NCES disclosure requirements.

Table 2. Means of Other Variables

Variables	Females	Males
Independent Variables of Interest		
School start time (hours since midnight) [clock time]	7.89 [7:53 A.M.]	7.87 [7:52 A.M.]
School day length (hours)	6.99	6.99
N	600	600
Intermediate Outcomes		
Sleep on weekday diary (hours, M-TH)	8.50	8.67
Night sleep on weekday diary (hours, M-TH)	8.29	8.33
Usual night sleep (hours, presumed weeknight)	7.35	7.54
Naps (M-TH)	0.21	0.34
Wake-up time (hours since midnight, M-TH) [clock time]	6.74 [6:44 A.M.]	6.74 [6:44 A.M.]
Bedtime (hours since midnight, M-TH) [clock time]	22.38 [10:23 P.M.]	22.38 [10:23 P.M.]
Participate in a sports team that year	0.28	0.39
Currently employed	0.22	0.20
Time spent with parent on weekday (hours/day)	3.98	3.88
Time spent with parent on all days (hours/day)	4.70	4.63
Overweight	0.30	0.36
Sad in last two weeks	0.24	0.10
N	550	550

Notes: CDS child weights used. Means of control variables are in Appendix Table A5.

Table 3. Means of Time-use Variables (Hours per Day)

	Females		Males	
	Weekdays	All days	Weekdays	All days
Sleep	8.41	9.05	8.58	9.07
Market work	0.49	0.54	0.42	0.53
Nonmarket work	0.59	0.83	0.32	0.50
Care activities	0.20	0.24	0.10	0.15
School	6.18	4.42	6.70	4.79
Other schooling	0.25	0.20	0.18	0.15
Homework as a primary activity	0.99	0.91	0.72	0.64
Extracurricular activities	0.29	0.41	0.32	0.45
Sports	0.55	0.55	0.74	0.80
TV	1.64	1.86	1.79	2.11
Computer games	0.15	0.17	0.86	1.08
Other computer use	0.47	0.54	0.41	0.45
Personal care	1.19	1.19	0.84	0.83
Other leisure	2.51	2.98	1.96	2.38
Missing activities	0.09	0.12	0.07	0.09
N	550	550	550	550

Note: CDS child weights used. Means may not sum to 24 hours due to rounding.

Table 4. Determinants of School Start Times (N = 2,090)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Northeast	-0.254***	-0.208***	-0.219***	-0.243***	-0.264***	-0.257***
	(0.031)	(0.034)	(0.031)	(0.034)	(0.045)	(0.051)
Midwest	0.002	0.003	-0.028	-0.039	-0.053	-0.182***
	(0.029)	(0.029)	(0.028)	(0.037)	(0.039)	(0.047)
West	-0.071**	-0.051	-0.055*	-0.112*	-0.130*	-0.573***
	(0.033)	(0.035)	(0.033)	(0.062)	(0.067)	(0.165)
Suburb		-0.116**	-0.122***	-0.116***	-0.129***	-0.103**
		(0.045)	(0.046)	(0.045)	(0.046)	(0.046)
Town		0.065*	-0.000	-0.008	-0.041	-0.011
		(0.037)	(0.045)	(0.045)	(0.048)	(0.047)
Rural		0.056	-0.051	-0.058	-0.091*	-0.045
		(0.037)	(0.049)	(0.050)	(0.051)	(0.051)
Log (students)			-0.110***	-0.107**	-0.094**	-0.100**
			(0.023)	(0.042)	(0.043)	(0.043)
Magnet/charter			-0.007	0.013	0.036	0.054
			(0.085)	(0.076)	(0.080)	(0.084)
Student-teacher ratio				-0.001	0.001	0.004
				(0.009)	(0.010)	(0.010)
Percent Asian				0.001	0.001	0.003
				(0.002)	(0.002)	(0.002)
Percent Hispanic				0.001	0.001	0.002**
				(0.001)	(0.001)	(0.001)
Percent black				-0.002***	-0.002**	-0.001
				(0.001)	(0.001)	(0.001)
Percent free lunch				0.000	0.001	0.000
				(0.001)	(0.001)	(0.001)
Log (students in district)					-0.013	-0.004
					(0.015)	(0.015)
Log (expenditure per pupil)					0.049	0.052
					(0.072)	(0.079)
Log (household income)					0.038	0.019
					(0.075)	(0.073)
Log (population density)					-0.013	-0.006
					(0.013)	(0.013)
Latitude						0.018***
						(0.004)
Longitude						-0.014***
						(0.003)
Central Time						-0.114***
						(0.039)
Mountain Time						0.013
						(0.167)
Pacific Time						-0.225
						(0.195)
R-squared	0.057	0.090	0.136	0.152	0.155	0.185

Source: Authors' calculations using data from SASS (2007-08), Common Core of Data, School District Demographics System, U.S. Census Bureau, SAS time zone data.
Notes: SASS school sampling weight used. Each column reports the results of a separate regression with school start time as the dependent variable. All regressions include a constant. Students in district, expenditure per pupil, and median household income are defined at the school-district level. Population density is defined at the county level. The remaining variables are defined at the school level.
Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 5. Effects of School Start Time on Test Scores

	Broad-reading score					Applied-problem score				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel 1. Females (N = 600)										
School start time	-1.156	1.410	2.036	2.505*	1.921	-2.143	-0.611	-0.650	-0.947	-0.459
	(2.727)	(1.633)	(1.498)	(1.454)	(1.424)	(2.200)	(1.524)	(1.480)	(1.579)	(1.224)
Day length	-2.307	0.103	1.146	-0.094	-1.083	-2.031	-0.262	1.878	1.211	-0.727
	(1.963)	(1.463)	(1.329)	(1.461)	(1.522)	(1.974)	(1.512)	(1.246)	(1.382)	(1.145)
Lagged broad-reading score		0.656***	0.513***	0.502***	0.508***		0.122**	0.037	0.033	-0.008
		(0.087)	(0.079)	(0.075)	(0.077)		(0.060)	(0.062)	(0.060)	(0.045)
Lagged applied-problem score		0.183***	0.114**	0.113**	0.114**		0.565***	0.472***	0.484***	0.536***
		(0.058)	(0.057)	(0.054)	(0.054)		(0.065)	(0.066)	(0.061)	(0.047)
Individual and family controls			X	X	X			X	X	X
School, county, and state controls				X	X				X	X
Sunlight controls					X					X
R-squared	0.004	0.488	0.592	0.617	0.624	0.006	0.400	0.519	0.550	0.524
Panel 2. Males (N = 600)										
School start time	0.161	-0.058	-0.457	-0.321	-0.607	-0.756	0.093	0.038	0.675	0.008
	(2.736)	(1.691)	(1.841)	(1.711)	(1.865)	(2.137)	(1.690)	(1.576)	(1.586)	(1.722)
Day length	-3.852	-1.521	-0.836	-0.213	-0.334	-2.225	-1.660	-2.131	-1.866	-1.729
	(2.970)	(1.853)	(2.022)	(1.923)	(2.088)	(2.408)	(1.725)	(1.674)	(1.699)	(1.697)
Lagged broad-reading score		0.712***	0.635***	0.603***	0.610***		0.117**	-0.028	-0.044	-0.037
		(0.050)	(0.055)	(0.056)	(0.055)		(0.053)	(0.055)	(0.054)	(0.052)
Lagged applied-problem score		0.191***	0.092*	0.095*	0.087*		0.605***	0.533***	0.532***	0.536***
		(0.051)	(0.053)	(0.052)	(0.051)		(0.058)	(0.065)	(0.062)	(0.063)
Individual and family controls			X	X	X			X	X	X
School, county, and state controls				X	X				X	X
Sunlight controls					X					X
R-squared	0.006	0.539	0.618	0.641	0.646	0.003	0.411	0.538	0.566	0.572

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. Individual and family controls include the number of children in the family unit and indicators for WJ-R score missing, race, month of interview, Census region, family structure, mother college degree, mother college degree missing, father college degree, father college degree missing, free/reduced-price lunch recipient, high school grade level, cohort, and special education. School, county, and state controls include student-teacher ratio, percent black, percent white, percent Hispanic, percent Asian, percent free-or-reduced-price lunch eligible, urbanicity (suburban, town, rural), log of median household income in the school district, log of expenditure per pupil in the school district, log of number of students in the school district, log of population density in the county, state compulsory schooling, magnet/charter school, and missing school-level variable. Sunlight controls include latitude, longitude, and time zone. All regressions include a constant.
Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 6. Effects of School Start Time on Sleep

Variables	All diary sleep (M-TH)	Nighttime diary sleep	Usual night sleep	Naps (M-TH)	Wake-up time (M-TH)	Bedtime (M-TH)
Panel 1. Females						
School start time	0.634***	0.599***	0.384**	0.035	0.584***	-0.042
	(0.232)	(0.230)	(0.171)	(0.082)	(0.187)	(0.157)
Day length	-0.246	-0.237	0.046	-0.009	-0.365	-0.028
	(0.258)	(0.254)	(0.170)	(0.071)	(0.253)	(0.150)
Number of observations	450	450	550	450	450	450
R-squared	0.192	0.190	0.182	0.087	0.231	0.146
Panel 2. Males						
School start time	-0.136	0.327	0.213	-0.464	0.575***	0.267
	(0.382)	(0.228)	(0.169)	(0.282)	(0.205)	(0.192)
Day length	0.553	0.377	0.139	0.176	-0.074	-0.361*
	(0.380)	(0.231)	(0.199)	(0.286)	(0.198)	(0.185)
Number of observations	460	460	550	460	460	460
R-squared	0.244	0.244	0.215	0.242	0.248	0.205

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 for control variables. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 7. Effects of School Start Time on Time-use Activities, Weight, and Sadness

	Females		Males	
Dependent Variable	Weekdays (M-F)	All days	Weekdays (M-F)	All days
Sleep	0.722***(0.220)	0.589*** (0.175)	0.161 (0.338)	0.130 (0.250)
Market work	0.153 (0.199)	0.100 (0.192)	-0.111 (0.275)	-0.050 (0.257)
Nonmarket work	0.074 (0.131)	0.072 (0.133)	-0.085 (0.111)	-0.060 (0.123)
Care activities	0.072 (0.098)	0.0123 (0.076)	-0.040 (0.042)	-0.006 (0.042)
School	-0.271 (0.382)	-0.194 (0.273)	0.367 (0.347)	0.278 (0.247)
Other schooling	-0.127 (0.078)	-0.130** (0.066)	-0.050 (0.061)	-0.036 (0.046)
Homework	-0.176 (0.166)	-0.289 (0.139)	0.070 (0.125)	0.022 (0.107)
Extracurricular activities	-0.003 (0.118)	0.062 (0.115)	0.124 (0.129)	0.149 (0.136)
Sports	0.161 (0.153)	0.215 (0.164)	0.184 (0.178)	0.141 (0.154)
TV	-0.056 (0.258)	-0.001 (0.253)	-0.238 (0.301)	-0.3011 (0.274)
Computer games	-0.056 (0.094)	-0.087 (0.077)	-0.559*** (0.212)	-0.440** (0.203)
Other computer	-0.200 (0.137)	-0.175 (0.143)	-0.180 (0.123)	-0.146 (0.115)
Personal care	-0.023 (0.092)	0.015 (0.080)	0.123* (0.070)	0.112* (0.064)
Other leisure	-0.343 (0.247)	-0.361 (0.224)	0.157 (0.229)	0.127 (0.207)
Missing activities	0.074* (0.044)	0.060 (0.039)	0.070 (0.056)	0.090** (0.044)
Time with parents	-0.328 (0.388)	-0.126 (0.391)	-0.543 (0.367)	-0.638* (0.358)
Employed	-	-0.042 (0.063)	-	0.089(0.057)
Sports team	-	0.205** (0.081)	-	0.036 (0.063)
Overweight[1]	-	-0.025 (0.051)	-	-0.028 (0.071)
Sad in last two weeks	-	0.079 (0.050)	-	0.000 (0.042)
Number of observations	550	550	550	550

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 for control variables.
[1] The number of observations was 530 for females and 540 for males due to missing information for the overweight variable.
Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Appendix Table A1. Sources of School Start and End Times (N = 1,200)

Source	Percent
School or district website (current or archived)	73.52
Schools and Staffing Survey (SASS 2007-08 or 2011-12)	21.39
Wolfson and Carskadon (2001-2002)	2.92
Hinrichs (2000-2007)	1.84
Start School Later, Inc.	0.33

Note: Archived websites accessed via the Internet Archive's Wayback Machine.

Appendix Table A2. Sample Selection

Attend high school in CDS-II or CDS-III and primary caregiver's child file record	1,650
Drop those missing child-file interview in 2007 (no weights available)	1,590
Drop students in private high schools	1,490
Drop if no NCES high school code in geocoded PSID	1,340
Drop if attended a middle school with configuration including grade 9	1,320
Drop those who did not attend a regular high school	1,260
Drop if not able to determine a school start time	1,220
Drop if missing high school test score	1,210
Drop if missing free and reduced price lunch eligibility status	1,200
Main Analysis Sample:	**1,200**
Females	**600**
Males	**600**
Drop those without a weekday or weekend day diary	1,120
Drop if missing more than 180 minutes on diary day (low-quality diary)	1,110
Time-Use Sample:	**1,110**
Females	**550**
Males	**550**

Note: Observation counts are rounded to the nearest ten in accordance with NCES disclosure requirements.

Appendix Table A3. Time-use Classifications

Classification	Examples of activities included
Sleep	Sleeping; naps
Market work	Part-time jobs; using computer at home for pay; coffee breaks while at workplace; job search
Nonmarket work	Food preparation; washing dishes; laundry; ironing; watering plants; gardening; car care; groceries; shopping for other goods
Care activities	Child care not for pay; reading to a child; helping adult household members or friends
School	Attending class; field trips; travel to school
Other schooling	Nonacademic classes; SAT prep; military training
Homework as a primary activity	Homework; using the computer for homework; being tutored; studying; reviewing homework with parent
Extracurricular activities	Volunteer work; attending church; youth group; fraternal organizations; community organizations; music lessons; playing an instrument; attending before- or after-school activities (not sports-related)
Sports	Playing sports; lessons in sports or dance; team sports; organized meets or games; exercise
TV	Watching television
Computer games	Playing computer games; playing games on a cell phone; electronic video games (Nintendo, Sony, Game Boy, Sega)
Other computer use	"Surfing the net"; downloading pictures, music; e-mail; reading media; Skype; Facebook; photo processing; learning how to use computer; financial services
Personal care	Bathing; dressing; medical care (sick or visiting doctor)
Other leisure	Attending sporting events; going to the movies; museums; zoo; visiting with others; wedding; party; reading; radio; listening to music; conversations; relaxing; hobbies; arts and crafts; playing non-electronic games; eating meals; snacking; caring for pets
Missing activities	Time gap of greater than 10 minutes

Note: Travel time associated with each activity is included in the total time spent on the activity.

Appendix Table A4. Sleep on School Nights, ATUS and PSID-CDS (Mean Hours per Day)

	ATUS (2003-2008)		PSID-CDS (2002-03/2007-08)	
Variables	Female	Male	Female	Male
Sleeplessness	0.03	0.04	-	-
Nighttime sleep	8.45	8.40	8.29	8.33
N	1,550	1,560	450	460

Notes: All estimates are weighted. ATUS includes private schools but PSID-CDS does not. ATUS includes high school students aged 15-18 whereas the PSID-CDS includes high school students aged 13-18. School nights are Sunday–Thursday in the ATUS (and include all sleep after 7 P.M.) but Monday–Thursday in the PSID-CDS.

Appendix Table A5. Means of Control Variables by School Start Time (Pooled)

Variables	7:00–7:44 A.M.	7:45–8:14 A.M.	8:15–9:15 A.M.
White or other race, non-Hispanic	0.64	0.61	0.65
Black, non-Hispanic	0.15	0.17	0.22*
Hispanic	0.11	0.16	0.09
Lived in East region in HS	0.26	0.13**	0.09**
Lived in Midwest region in HS	0.21	0.27*	0.20
Lived in South region in HS	0.28	0.24	0.61**
Lived in West region in HS	0.24	0.36**	0.10**
Grade 9	0.29	0.29	0.28
Grade 10	0.24	0.27	0.26
Grade 11	0.23	0.22	0.27
Grade 12	0.24	0.22	0.18
Interviewed in 2007-2008	0.51	0.56	0.53
WJ-R applied-problem score (before HS)	109.13	105.81*	106.23
WJ-R broad-reading score (before HS)	112.69	108.61**	109.53*
Missing a WJ-R score (before HS)	0.20	0.20	0.13*
Ever in special education	0.12	0.10	0.12
October interview	0.11	0.10	0.15
November interview	0.20	0.19	0.20
December interview	0.12	0.12	0.12
January interview	0.23	0.26	0.23
February interview	0.20	0.14*	0.11**
March interview	0.04	0.07	0.05
April/May/June interview	0.03	0.03	0.02
Family Variables			
Lives with both biological parents	0.63	0.61	0.59
Lives with step mom and biological father	0.01	0.03**	0.01
Lives with step dad and biological mother	0.11	0.07*	0.09
Lives with single parent	0.24	0.27	0.29
Lives in other family arrangement	0.01	0.03	0.03
Number of other children in family unit under age 19	1.14	1.18	1.14
Mother college degree (non-missing)	0.31	0.25	0.28
Mother education missing	0.03	0.04	0.06
Father college degree (non-missing)	0.37	0.33	0.33
Father education missing	0.23	0.26	0.29
Free or reduced-price lunch recipient	0.26	0.32	0.27
N	420	490	290

Note: CDS child weights used. Means are means of the non-missing variables.
Significance levels: ** p<0.05, * p<0.1. Significantly different from earliest start time category.

Appendix Table A5 Continued. Means of Control Variables by School Start Time (Pooled)

Variables	7:00–7:44 A.M.	7:45–8:14 A.M.	8:15–9:15 A.M.
School-level Variables			
Student-teacher ratio	18.59	18.15	15.64**
Percent white or other race	62.06	59.92	59.93
Percent black	15.93	15.50	22.13**
Percent Asian	4.83	4.77	2.64**
Percent Hispanic	16.62	18.54	12.11
Percent FRL	27.42	38.42**	32.94**
Magnet or charter school	0.07	0.04**	0.09
Urban school	0.31	0.28	0.34
Suburban school	0.46	0.22**	0.19**
Town school	0.06	0.25**	0.09
Rural school	0.16	0.26**	0.38**
Log (number of students in high school)	7.39	6.95**	7.00**
Latitude	38.41	38.52	36.74**
Longitude	-90.84	-96.97**	-90.35
Eastern Time	0.54	0.36**	0.48
Central Time	0.21	0.27*	0.43**
Mountain Time	0.07	0.06	0.01**
Pacific Time	0.18	0.30**	0.09**
District-level Variable			
Log (median household income in school district)	10.77	10.58**	10.60**
Log (number of students in district)	9.59	8.79**	9.12**
Log(district expenditures per pupil)	2.38	2.32**	2.35
County-level Variable			
Log(population density in county)	6.47	5.51**	5.71**
Missing school-level, county, or district variable	0.05	0.05	0.03
State-level Variable			
State compulsory schooling until age 17-18	0.61	0.75**	0.53
N	420	490	290

Note: CDS child weights used. Means are means of the non-missing variables.
Significance levels: ** p<0.05, * p<0.1. Significantly different from earliest start time category.

Table A6. Effects of School Start Time on Sleep Including Sunlight Controls

Variables	All diary sleep (M-TH)	Nighttime diary sleep (M-TH)	Usual night sleep	Naps (M-TH)	Wake-up time (M-TH)	Bedtime (M-TH)
Panel 1. Females						
School start time	0.584**	0.553**	0.328*	0.032	0.530***	-0.040
	(0.226)	(0.217)	(0.171)	(0.081)	(0.181)	(0.146)
Day length	-0.285	-0.261	0.084	-0.023	-0.465*	-0.096
	(0.283)	(0.281)	(0.179)	(0.076)	(0.261)	(0.148)
Number of observations	450	450	550	450	450	450
R-squared	0.197	0.196	0.198	0.095	0.247	0.176
Panel 2. Males						
School start time	-0.049	0.327	0.265	-0.463*	0.617***	0.200
	(0.388)	(0.228)	(0.174)	(0.275)	(0.231)	(0.202)
Day length	0.520	0.377	0.120	0.230	-0.069	-0.293
	(0.378)	(0.231)	(0.207)	(0.294)	(0.190)	(0.194)
Number of observations	460	460	550	460	460	460
R-squared	0.261	0.244	0.221	0.248	0.266	0.216

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 for control variables. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.