Snooze or Lose: High School Start Times and Academic Achievement

Jeffrey A. Groen
U.S. Bureau of Labor Statistics
2 Massachusetts Ave. NE, Rm. 4945
Washington, DC 20212
E-mail: Groen.Jeffrey@bls.gov

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

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Abstract

Many U.S. high schools start classes before 8:00 A.M., yet sleep science suggests that students' circadian rhythms 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 time on student learning using a nationally-representative sample of students. We also use time diaries to examine the effects of start time on students' time allocation in order to explore the mechanisms through which changing start time affects learning. Results indicate that female students who attend schools with later start times get more sleep and score higher on reading tests. Male students get more nighttime sleep when schools start later, but their daily sleep is unchanged due to a decrease in napping; their test scores do not change.

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

JEL codes: I12, I20, J22

1. 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 (Carskadon, Vieira, & Acebo, 1993). Poor or inadequate sleep is correlated with higher rates of obesity, higher rates of depression, higher motor-vehicle crash rates, and lower cognitive performance (Bostwick, 2018; Pilcher & Huffcutt, 1996; Roenneberg, 2013).[1] Proponents of later start times argue that the lack of sleep resulting from early start times harms students' mental and physical health (Wahlstrom, 2002). Therefore, shifting to later start times has the promise of increasing sleep, academic achievement, and health (e.g., Jacob & Rockoff, 2011; National Sleep Foundation, 2013).

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 likely require employers who provide teenagers with after-school jobs and providers of extracurricular activities to make scheduling adjustments (Shapiro, 2015; Wahlstrom, 1999). It is also often argued by opponents of later school start times that moving the high school day later (both start and end times) would mean that sports teams could not practice after school or would have to shorten their practices due to less daylight (National Sleep Foundation, 2005). If students end up spending less time on these activities, later start times

[1] Bostwick (2018) found that earlier start times are associated with a greater rate of late-night car accidents involving teen drivers, which she attributes to long-run sleep deprivation.
[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, or to move the bell schedules of all schools later.

could diminish the human capital acquisition that usually results from students' participating in these activities (Hinrichs, 2011).

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 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 papers have examined whether changing school start times results in a positive effect on measurable academic outcomes, with mixed results (Carrell, Maghakian, & West, 2011; Edwards, 2012; Heissel & Norris, 2018; Hinrichs, 2011; Luong, Lusher, & Yasenov, 2017; Wong, 2011).

The goals of this paper are twofold: 1) to examine whether school start times affect high school student learning, and 2) to examine the effects of school start times on students' time allocation (especially sleep time) and health in order to understand the mechanisms through which changing start time affects student learning. This paper contributes to the literature on the effects of school start time in two ways: 1) we use longitudinal data from a nationally-representative sample of high school students aged 13–18 attending grades 9–12 (the Child Development Supplement to the Panel Study of Income Dynamics [PSID-CDS]), whereas prior studies examined the effects of high school start time on student learning and health at a school, within a state or metropolitan area, or at the school level, and 2) we use time diaries to explore the effects of high school start time on students' time allocation, which could help to explain any observed effects on academic achievement beyond a shift in sleep timing. To the best of our knowledge, we are the first to use time diaries to address the policy debate on the effects of school start time on after-school activities, including sports, homework, and part-time jobs. We are also the first to use diaries for a nationally-representative sample of students to examine the effect of school start time on sleep. Time diaries are believed to produce estimates of time spent doing activities that are more accurate than surveys asking about usual time spent on activities (Juster, Ono, & Stafford, 2003). Our time-diary estimates suggest that students actually sleep about an hour more than reported in surveys asking about usual sleep on a school night.

In our econometric analysis, our objective is to identify the causal effect of start time on academic achievement. When we estimate the effect of school start time on math and reading test scores, we include a rich set of controls for individual (including lagged test scores), family, high school, and community characteristics. However, because we are unable to control for unobservable characteristics (such as teacher quality) that may be correlated with both start times and test scores, we also use an econometric technique developed by Oster (2017) that relates selection on observables to selection on unobservables in order to estimate bounds on the true causal effect.

Our results inform the policy debate on the effects of changing school start times for high school students. For female students, we find that those who attend schools with later start times get more sleep and score higher on reading tests, though not on math tests. We find that shifting start time one hour later increases reading test scores by 0.16 to 0.28 standard deviations. Male students get more nighttime sleep with later start times; however, they do not get more daily sleep due to an offsetting decrease in napping, and we do not observe any effects of start time on their test scores. We also find that female students whose school starts later are more likely to be on a sports team, though they spend less time on other schooling activities (such as SAT prep) and leisure activities. Male students with a later start time spend less time watching TV and playing computer games. Lastly, we find no deleterious effects of changing start time on student employment or health.

2. Literature Review on Start Times, Academic Achievement, and Sleep

2.1 Start Times and Academic Achievement

A small number of papers have investigated the relationship between start times in high school and academic achievement, and the evidence is mixed. Early research in this area examined the Minneapolis–St. Paul metropolitan area, where Minneapolis and several suburban districts shifted to later bell times for their high schools but St. Paul and other suburban districts maintained early schedules. Wahlstrom (2002) examined Minneapolis high schools before and after the change and found that grades improved slightly. However, Hinrichs (2011) found no effect of start time on ACT test scores using data from schools in the area that changed schedules and those that did not change schedules. Hinrichs (2011) obtained similar results using school-level data on start times and scores on statewide standardized tests from Kansas and Virginia.

In contrast to Hinrichs (2011), Wong (2011) found positive effects of later school start time on school-level student performance on state standardized tests using a national sample of high schools from the Schools and Staffing Survey (SASS) combined with standardized tests from 27 states. (Using alternative independent-variable measures, Wong also found that average sunlight before 8 A.M. and average sunlight before school have positive effects on exam performance.)

Several papers found positive effects for younger students and college students. For example, Edwards (2012) found positive effects of start time on standardized test scores in math and reading for middle school students in Wake County, North Carolina. Using administrative data from Florida and observing students aged 8–15 moving across the time-zone boundary, Heissel and Norris (2018) found that increasing sunlight before school increased standardized test scores in math and reading, especially math scores for the older children.

Carrell et al. (2011) and Luong et al. (2017) provide evidence that suggests a positive effect of later start times for older teenagers. Carrell et al. (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 et al. (2017) found that freshman college students at a large university in Vietnam saw a small boost in their class grade from starting later, but only for morning classes.

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 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. Hansen, Janssen, Schiff, Zee, and Dubocovich (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 had higher grades if their math or English class met in the morning than later in the school day, controlling for school start times. Lusher and Yasenov (2018) found effects could vary by gender: males received a boost in performance relative to females when school started in the afternoon rather than the morning. Using data from a single large university, both Dills and Hernandez-Julian

(2008) and Cotti, Gordanier, and Ozturk (2018) found that college students earned higher grades in a class if it met later in the day. Using data from a small liberal-arts college where students were randomly assigned to different course sections, Diette and Raghav (2017) found that grades were lower for classes scheduled in the morning, particularly those meeting at 8 A.M. and 9 A.M. They also found that male students were particularly negatively affected by early start times.

2.2 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. A national survey of adolescents found that adolescents in high school reported sleeping on average 7.2 hours on the typical school night (National Sleep Foundation, 2006), less than the 8–10 hours each night recommended by the National Sleep Foundation (Hirshkowitz, Whiton, Albert, Alessi, Bruni, DonCarlos et al., 2015).[3] 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, & Carskadon, 2007; Hansen et al., 2005; Stewart, 2014). Moreover, surveys have found that students who start school earlier in the day obtain less sleep on school nights (Carskadon, Wolfson, Acebo, Tzischinsky & Seifer, 1998; Knutson & Lauderdale, 2009; Nahmod, Lee, Buxton, Change & Hale, 2017; Stewart, 2014; Wolfson & Carskadon, 1998; Wolfson, Spaulding, Dandrow & Baroni, 2007).[4] In addition, most prior research suggests that wake-up times change more than bedtimes in response

[3] Estimates from time diaries suggest that adolescents actually sleep slightly longer than estimates from surveys about usual hours (Kalenkoski & Pabilonia, 2012). The time-diary estimates from the PSID-CDS and American Time Use Survey (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).
[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.

to changes in school start times (e.g., Knutson & Lauderdale, 2009; Minges & Redeker, 2016; Nahmod et al., 2017; Stewart, 2014).

In addition to the evidence that later start times are associated with more sleep, studies have linked sleep and achievement. Evidence from laboratory studies indicates that sleep deprivation impairs cognitive performance (Pilcher & Huffcutt, 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 & Showalter, 2012; Wolfson & Carskadon, 2003). Sabia, Wang, and Cesur (2017) found that longer sleep was beneficial for success in the classroom and increased the probability of high school graduation and college attendance.

Beyond nighttime 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 nap after school, receive extra support from their parents (or tutors) with their homework, or use stimulants to promote alertness for their morning classes. Start times may also affect the amount of time that students spend in part-time work, sports, and other extracurricular activities. They may also affect school attendance and tardy rates, which would reduce students' time for learning.[5] Even though adolescents may work better later in the day, teachers may prefer earlier start times; as a result,

[5] Wahlstrom (2002) found that attendance rates increased when Minneapolis high schools started later. Dunster, de la Iglesia, Ben-Hamo, Nave, Fleischer, Panda, and de la Iglesia (2018) found that attendance rates increased and tardy rates decreased when Seattle high schools started later.

teachers may be less productive with later start times.[6] Each of these things has its own influence on academic achievement.[7]

3. Data

3.1 Data Sets Used

Our data come primarily from the PSID-CDS, which 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).[8]

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.[9] 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 Common Core of Data (U.S. Department of Education, 2015) using school identifiers from the restricted-use version of the PSID (2014).

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[6] 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.

[7] For example, Light (2001) reviewed the benefits of student employment; Lipscomb (2007) found that participation in sports and other extracurricular activities increased students' math and science scores; Crispin (2017) found that extracurricular participation reduced the probability that students dropped out of high school; and Stevenson (2010) found that increases in state-level female sports participation following Title IX resulted in increases in female college-attendance rates.

[8] The CDS-IV was fielded in 2014 but not used in this study.

[9] 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.

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; Start School Later, Inc. (2015); the restricted-use versions of the 2007-08 and 2011-12 SASS (U.S. Department of Education, 2014); and data provided by Mary Carskadon and Peter Hinrichs. In most cases, schools do not change their start times from year to year. When we have two sources of bell times for a school in the same year, the sources usually concur. As shown in Appendix Table A.1, 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.[10] 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.[11] Thus, our data set contains greater variation in school start times than those used in most prior studies. 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. The variable for day length is created by taking the difference between the school end time and start time. Day length ranges from 5.5 to 8.75 hours per day, with an average day length of 6.99 hours per day.

[10] 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.
[11] 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 weight the SASS school-level data by student enrollment in order to provide a proper comparison to the CDS student-level data.)

3.2 Sample Construction

We examine a subsample of CDS respondents aged 13–18 who were enrolled in grades 9–12 in a public high school in either CDS-II (2002-03) or CDS-III (2007-08). Appendix Table A.2 details our sample construction. Our main analysis sample includes 1,200 respondents —600 females and 600 males—who attended 790 unique high schools.[12] 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 (the latter being a sign of poor diary quality). 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, & Kuziemko, 2006; Jacob, 2002; Kalenkoski & Pabilonia, 2017). There is also some evidence that males and females have different circadian rhythms, which would make it more difficult for males to cope with early school start times (Adan & Natale, 2002).

3.3 Academic Outcomes

Our main dependent variables are two test scores: the broad-reading and applied-problems standardized test scores (age-adjusted) 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-problems test score is considered a general measure of mathematics reasoning achievement. We standardize the test scores by survey year so that the scores have a mean of zero and standard deviation of one. Table 1 includes overall sample means for the test scores as well as their means in three categories defined by school start time. Scores are higher for students in the earliest start-time category (7:00–7:44 A.M.) than in the two later periods (7:45–

[12] Observation counts are rounded to the nearest ten in accordance with National Center for Education Statistics (NCES) disclosure requirements.

8:14 A.M. and 8:15–9:15 A.M.); however, the differences are not statistically significant, with the exception of the applied-problems scores in the earliest category being higher than those in the middle category for the pooled sample. Male students scored higher than female students on the applied-problems test, a result consistent with the literature on the gender gap in math test scores (Niederle & Vesterlund, 2010), but lower on the broad-reading test.

3.4 Intermediate Outcomes

In addition to the academic outcomes, we examine numerous intermediate outcomes, each of which could be affected by start time. Some of these outcomes are created using the time diaries, while others are from general survey questions. We consider the effects of school start time on students' activities across the day as well as on annual sports participation, current employment, and health outcomes. See Appendix Table A.3 for the 12 activity categories that we use to classify students' time allocation across the day.

All measures of time spent on a primary activity on the diary day are reported in hours per day.[13] We calculate school-day measures (Monday through Thursday), weekday measures, and all-day measures. The latter are calculated by taking a weighted average of the weekday and weekend-day activity times.[14] We argue that measures of time spent on an activity that are aggregated from time-use diaries are preferable to survey measures of usual time spent because they are less subject to both aggregation bias and social-desirability bias (Juster et al., 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.

[13] Although we only examine effects on primary activities, note that students often report doing homework as a secondary activity (Kalenkoski & Pabilonia, 2017; Pabilonia, 2015).

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

We examine four measures of sleep on weekdays—all diary sleep (including napping), nighttime diary sleep, usual night sleep, and napping—in order to observe whether we see tradeoffs between sleep and start times. The first two diary-sleep measures are intended to measure sleep on school days. We exclude Fridays from the school-day measures 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. Napping includes any time recorded as napping or resting.

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).[15] 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 report only 7.35 hours of usual night sleep. Male students sleep slightly more—on average 8.33 hours per night on their weekday diary day and 7.54 hours of usual night sleep. These diary-based sleep measures closely match those obtained from the ATUS (Appendix Table A.4). Thus, we conclude that usual night sleep measures are biased. We also find that male students nap after

[15] One criticism of the diary measure that should not affect our estimates of the effect of school start time is that night sleep can include sleeplessness (Eide & Showalter, 2012). In Appendix Table A.4, we present separate estimates of diary night sleep and sleeplessness on school nights from the 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.

school (0.34 hours on average) for longer periods 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 time on sleep time, we consider how start time affects students' wake-up times and bedtimes. Wake-up time is defined as the end time of the last night-sleep episode occurring before 1:00 P.M. on Monday through Thursday diary days.[16] 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.[17] 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 all 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.

Because we have time diaries that record the start and end time of all activities, we can compare the time students report starting their class time with the official school start times to create a measure of tardiness. Our tardy-to-school variable is an indicator variable equal to one if the student was ten or more minutes late for school, and zero otherwise. We find that female students are more likely than male students to be tardy to school (18 percent versus 13 percent).

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

From the child-interview portion of the CDS, we can determine whether the student participates in an athletic or sports team at school during that academic year. On average, male students are much more likely than female students to participate in a sports team (39 percent versus 28 percent). We also examine the number of hours that the student spends on sports and other extracurricular activities on the diary day. Male students spend more time on the average day on these after-school activities than female students do (1.25 hours versus 0.96 hours).

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, on both the extensive and intensive margins.

We examine three health-outcome indicators. The first is an indicator for whether the student's overall health was reported as fair or poor. Female students are slightly more likely than male students to report worse overall health (9 percent versus 7 percent). The second, a measure of depressive symptoms, is an indicator for whether the student scored a two or greater out of a total of 20 possible on the short form of the Children's Depression Inventory (CDI), a standard diagnostic instrument with good psychometric properties (Sitarenios & Stein, 2004). The CDI asks students about their emotional and functional problems. 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 depressive symptoms (59 percent versus 50 percent). The third is an indicator for a student being overweight or obese, using the student's age and gender-specific BMI percentile (a BMI equal to 85 or greater is considered overweight or obese, according to the CDC). Male students are more likely than female students to be considered overweight or obese (36 percent versus 30 percent).

4. Econometric Analyses

4.1 Methodology

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

$$Y = b_0 + b_1S + b_2D + b_3X + u \qquad (1)$$

where the dependent variable, Y, is the test-score outcome, time-use outcome, or health outcome; S denotes school start time; D denotes the school day length; X is the vector of control variables; b_0, b_1, b_2, and b_3 are the coefficients to be estimated; and u is a stochastic disturbance term.[18] The subscripts indicating observation and outcome are suppressed. School day length is included because we are interested in the effect of changing the school start time without changing the day length.[19] The regressions and means are weighted using the CDS child weights. Standard errors are adjusted for clustering by school.

In estimating these equations, we are interested in the causal effects of start time on achievement, time use, and health. 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 directly 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.[20] 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 broad-reading and applied-problems standardized test scores (age-adjusted) from the WJ-R

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

[19] Day length was also included in specifications used by Hinrichs (2011) and Wong (2011). When schools change their start times, they typically also move the end time later, so day length remains the same. Our results without the day-length control are qualitatively similar.

[20] See Appendix Table A.5 for means of these control variables by school start-time category.

that were given during the CDS child interview occurring about five years prior to the CDS high school observation.[21] We include these lagged test scores (which we standardize to have a mean of zero and standard deviation of one) to control for prior achievement and ability.

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 members (the omitted category is 'lives with two biological parents'); the number of other children under 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.

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 these 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 pupil, and median household income. The county variable is the population density.

[21] 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 by survey year using the mean score.

The results, shown in Table 4, indicate that the most important determinants of start time are Census region (schools in the Northeast start earlier), urbanicity (suburban schools start earlier), school size (larger schools start earlier), and sunrise (schools with later sunrise start later). 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 average sunrise over the school year (September 1, 2007, to May 31, 2008).[22] The estimated effects suggest that school districts appear to take account of morning sunlight when setting starting times; however, a one-hour later average sunrise is associated with only a ten-minute later start time. Overall, there are differences in school start times based upon school characteristics, some of which may be correlated with achievement.

4.2 Main Results: Effects on Achievement

Using our student-level data from the PSID-CDS, we estimate several specifications for achievement using equation (1) where we add controls sequentially. Results are presented in Table 5 for the female and male samples as well as a pooled sample where we fully interact the male dummy with start time and the control variables. 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, with the exception of a positive relationship between school start time and broad-reading test scores for males. However, all the coefficients are not significant. For female students, when we add controls for lagged test scores in specification 2, the sign of the coefficient flips in the broad-reading regressions. The coefficients on both of the lagged test scores are positive and highly significant, and the R-squared value increases

[22] Sunrise for each day was computed for each high school location using data on latitude, longitude, time zone, and daylight saving time and a formula from the National Oceanic and Atmospheric Administration (2018).

substantially. When we add individual and family controls, there is a further increase in R-squared and an increase in the effect of school start time on the broad-reading score for females.

In specification 4, our preferred specification, we add school-level, district-level, county-level, and state-level controls. For females, we find a large 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 broad-reading test scores of 0.16 standard deviations). The effect of school start time on the applied-problems test score is not significant. For male students, we find no statistically significant effects of school start time on test scores.[23]

Although we are primarily interested in the total effects of start time on achievement and time allocation (as in specification 4), in specification 5 we add a control for average sunrise. In this case, b_1 is the partial effect of start time that operates through clock time, holding average sunrise time constant. For females, the effect of school start time on the broad-reading test score falls, but only somewhat (a one-hour later start time results in an increase in broad-reading test scores of 0.13 standard deviations). Thus, a large portion of the total effect results from a later clock time.

4.3 Sensitivity Analyses

We conduct two additional analyses to address concerns that our main effects of start time on test scores may be biased due to omitted variable bias, even though we have a very rich set of controls. In the first analysis, we examine the relationship between teacher characteristics and school start time. We examine teacher characteristics because they are not included among our controls but are related to student achievement and may also be associated with school start

[23] In an alternative specification, we specified the dependent variable as the change in the test score (broad reading or applied problems) between the contemporaneous and lagged scores and regressed this on school start time and the controls. Results are broadly similar to those from specification 4.

time.[24] Although we cannot measure teacher characteristics for schools attended by students in our PSID-CDS sample, we do an analysis of teacher characteristics and start times for a separate sample of schools. Specifically, we use data on full-time high school teachers from the SASS 2007-08 survey of public-school teachers and link these data by school identifier to the SASS survey of public schools to obtain start time and day length. We also link them to our other sources of school-level data from which we obtained the school-level controls used in our main analysis. We use these data to construct a teacher-level dataset and estimate a series of linear regressions in which the dependent variable is a teacher characteristic and the independent variables are start time, day length, and (in some specifications) the school controls.

The teacher characteristics we use are some of those examined in the economics of teacher quality literature as being potentially related to student achievement: 1) an indicator for the teacher being in the first year at the school, 2) the number of years teaching full-time in any school, 3) an indicator for having a master's degree, and 4) an indicator for having a national or state certification.[25] According to the results in Table 6, the first two measures are associated with start time when the school controls are not included, but that association goes away when the school controls are included. The master's degree indicator is associated with start time in regressions with or without school controls, though adding school controls reduces the magnitude of this association substantially. The association indicates that teachers with master's degrees are less likely in schools with later start times. The certification indicator is not

[24] For example, high school teachers may prefer to work at schools with earlier start times to avoid rush-hour traffic or to be available for younger children when they return from school in the afternoon (Hinrichs, 2011). Higher-quality teachers would be more likely to be selected for their top-choice positions.

[25] Hanushek, Rivkin, and Schiman (2016) provided evidence that teacher turnover within a school leads to lower student achievement. Rivkin, Hanushek, and Kain (2005) provided evidence that overall teacher experience is not related to student achievement. Hanushek, Piopiunik, and Wiederhold (2018) showed that teachers with master's degrees have higher cognitive skills and this is related to student achievement. Clotfelter, Ladd, and Vigdor (2010) showed that teacher credentials are related to student achievement at the high school level.

associated with start time in regressions with or without school controls. Taken together, these results suggest that in our main analysis the effect of teacher characteristics is largely captured by the school controls, though some bias may exist due to teacher characteristics that are not captured by the school controls.

This possibility is examined by our second analysis to assess the robustness of our preferred results to omitted variable bias. We use methods developed by Oster (2017) that relate selection on observables with selection on unobservables to calculate bounds on the causal effect of school start time on test scores.[26] This procedure assumes that the selection bias from the observables and the selection bias from the unobservables are proportional and have the same sign, which we believe is a reasonable assumption for our analysis. In Table 5, we observe that the coefficient size increases as we add controls—showing that observables and start time are negatively correlated. In the out-of-sample teacher-level analysis presented in Table 6, we find that teachers with master's degrees are less likely in schools with later start times. Thus, unobservable teacher quality (at least by one measure) and start time are also negatively correlated, which provides further support for the assumption above. For females, we find the causal effect of start time on broad-reading test scores ranges from 0.16 to 0.28 standard deviations for a one-hour later start time (Table 7).

We examine whether our results for the effect of school start time on test scores vary by students' FRL status. We fully interact FRL status with start time and the control variables. We do this separately for the female and male samples. We find that the effect of school start time on broad-reading test scores is statistically significant for the FRL population for both females and males and the magnitude of the effect is larger than for the full population. For female FRL

[26] Specifically, we calculate these bounds on our effects of school start time using the Stata command *psacalc* (Oster, 2013).

students, we find that the effect of start time on broad-reading test scores is 0.32 standard deviations for a one-hour later start time (Table 8). For male FRL students, we find that the effect of start time on broad-reading test scores is 0.27 standard deviations for a one-hour later start time. However, the estimated effect of the interaction term between start time and FRL status is imprecise, so we cannot reject the hypothesis (at conventional significance levels) that start time has a similar effect on both FRL and non-FRL students. Our results are consistent with both Edwards (2012) and Carrell et al. (2011), who find that later start times have larger positive effects for students at the lower end of the achievement distribution.

As a final sensitivity analysis, we estimate the effects of sunlight before school on test scores. Sunlight before school is an alternative independent variable which was used by both Wong (2011) and Heissel and Norris (2018). Sunlight before school (calculated as clock time minus average sunrise) over the school year is necessarily collinear with clock time.[27] This variable measures both the pressure on circadian rhythms that comes from daylight (holding clock start time constant) and the pressure on circadian rhythms that comes from clock time (holding daylight constant). Contrary to the previous literature, we do not find significant effects of sunlight before school on test scores (see Appendix Table A.6 for results).

4.4 Effects on Sleep, Time Allocation, and Health Outcomes

In Table 9, we present the effects of school start time on both the timing and duration of sleep on school days (using the Monday through Thursday diaries) without a control for sunrise.[28] We find some different effects for female and male students. For female students, we

[27] Wong (2011) used the average sunlight before school on the 15th of each month over the calendar year, whereas we exclude the summer months. Heissel and Norris (2018) instrumented for sunlight before school with the time-zone boundary in Florida.

[28] Estimates for the sleep regressions including a sunrise control are presented in Appendix Table A.7. The estimated effects of start time increase only slightly, suggesting that a large portion of the effect results from a later clock time.

find that in response to a delay in start time of one hour, they sleep 0.636 hours (38 minutes) more on their diary day and 0.601 hours (36 minutes) more per night. If we instead use the "usual sleep" measure as our dependent variable (which we explained earlier is not our preferred measure), the effect of school start time on night sleep is significantly smaller (0.383 hours for one-hour delayed start time). For male students, the estimated effects on all three measures of sleep duration are not significantly different from zero. Overall, our heterogeneous effects of start time on sleep by gender are consistent with our different findings of the effects of start time on test scores by gender.

The pooled specification suggests some differences in the effects for males on all diary sleep and nighttime diary sleep: the diary sleep measure suggests no effect of start time on sleep over the course of the day whereas the nighttime sleep measure suggests a positive effect on nighttime sleep. (We cannot reject the hypothesis that the effect of start time on nighttime sleep is similar for males and females in the pooled model.) The contrast in these two effects can be explained by the large negative effect of start time on after-school nap time (-0.466 hours for one-hour delayed start time). Although this effect is not significant at conventional levels, we can reject the hypothesis that the effect of start time on napping is equivalent for both genders. This finding is in line with research suggesting different circadian rhythms for males and females.

We find that the extra nighttime diary sleep that female students receive from starting school later is a result of waking up 0.583 of an hour later in the day (35 minutes), with no effect on bedtime. Male students likewise wake later when school starts later (0.575 hours for one-hour delayed start time), with no effect on bedtime. In the pooled specification, we cannot reject that the effect of start time on wake-up time is equivalent for both genders. Broadly speaking, these effects on weekday wake-up times are consistent with prior research and the notion that early school schedules are not in sync with adolescents' circadian rhythms.

In Table 10, we present the effects of school start time on a full set of time-use activities, tardiness to school, sports participation, employment, and health outcomes—all estimated using an all-days sample.[29] Consistent with the previous results, later start time increases sleep for females (35 minutes more for one-hour later start time) and it does not appear that those who must wake early during the week for an early school start are catching up on sleep over the weekend. This large positive increase in sleep comes primarily from an offsetting decrease in leisure time (a combination of screen time and other leisure time) when school starts later (38 minutes less for one-hour delayed start time). For females, we also find that start time has a small negative effect on other schooling activities (such as SAT prep), which could translate into lower test scores.

Contrary to one of the common arguments put forth 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 (girls are 21 percentage points more likely to play per one-hour delayed start time). (The effect on the time spent on sports and other extracurricular activities is in the same direction for both males and females, although it is imprecise.) Whether this increase in sports participation for females is a mechanism by which later start times result in an increase in test scores is unclear. There is a large body of literature that finds a strong positive relationship between sports participation and school achievement (e.g., Crispin, 2017; Lipscomb, 2007; Stevenson, 2010); however, evidence using new econometric methods that relate selection on observables with selection on unobservables to bound effects suggests that some of this

[29] Appendix Table A.8 shows that using a weekdays-only sample gives results that are similar to those for the all-days sample.

relationship is due to selection rather than sports participation building skills (Ransom & Ransom, 2018).[30]

For male students, we again find no effect of start time on daily sleep. We do find that they spend less time watching TV and playing computer games (screen time) when school starts later (54 minutes less for one-hour delayed start time) but more time on personal care and unspecified missing activities (12 minutes more combined for one-hour delayed start time).[31] Algan and Fortin (2018) found a positive correlation between math test scores and computer gaming for males, which suggests that starting school later could actually lead to a decline in math test scores. 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 time and test scores for males is primarily due to the lack of a large increase in daily sleep, even though nighttime sleep increases when school starts later.

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 do not find any effects of start time on student health, time spent on homework, or tardiness.

Because we find that school start time has a large and statistically significant effect on sleep for females, we use school start time as an instrument for sleep in order to identify the causal effect of sleep on achievement. In Table 11, we present instrumental-variables (IV) estimates of the effects of sleep (both on weekdays [M–TH] and on all days) on test scores for female students. We find that an extra hour of sleep on a weekday leads to a 0.36 standard

[30] Crispin (2017) found an effect of participation in all extracurricular activities, inclusive of sports, on the high school dropout decision.
[31] The finding on the effect of start time on screen time is consistent with the finding in Kim (2018) that South Korean youth spend less time playing computer games when schools start later.

deviation increase in the broad-reading test score for female students. Overall, these results imply that the female students who are getting more sleep when schools start later are the ones who benefit in terms of higher test scores.

5. Conclusion

Using rich longitudinal data on a nationally-representative sample of students and methods relating selection on observables to selection on unobservables to bound the causal effect, we find that a one-hour delay in high school start time increases reading test scores of female students by 0.16 to 0.28 standard deviations. The lower bound on this effect is more than three times larger than the effect of sunlight before school on reading test scores found by Heissel and Norris (2018), but their effects increase with age and our students are older. Our effect is very similar in size to the effect of reducing class size from 22 students to 15 students in grades K–3, though the estimated costs of adjusting school start time are less than the estimated costs of reducing class size (Jacob & Rockoff, 2011; Schanzenbach, 2006).[32] Our results also suggest that the magnitude of the effect of school start time on test scores is larger for economically disadvantaged students.

We also examine the effects of start time on student time allocation and health to identify the mechanisms through which start times affect academic achievement. On the whole, it appears that sleep is the major mechanism through which start times affect test scores. We find that when high school starts 60 minutes later, female students sleep 36 minutes longer on school nights on average. This effect comes about entirely through a delay in wake-up time rather than a change in bedtime. Using an IV strategy, we establish a positive causal effect of sleep on achievement.

[32] A cost-benefit study by Hafner, Stepanek, and Troxel (2017) projected that having all schools start after 8:30 A.M. (compared to the current distribution of start times) would be a net positive of $83 billion for the U.S. economy over the next decade.

For male students, we find that although they sleep longer during the night time and wake up later with no change in bedtime when schools start later, they also nap less during the day time. Consequently, their daily sleep remains unchanged. This is consistent with our finding of null effects of start time on test scores for males.

With regard to other changes in time allocation as a result of a delay in school start time, we find that females are much more likely to be on a sports team but spend slightly less time on other schooling activities. In addition, both males and females spend less time on leisure activities when schools start later. For male students, the decrease in time on leisure activities is predominately from spending less time watching TV and playing computer games as opposed to other leisure activities.

Overall, our results suggest that starting school later has beneficial effects on student achievement, at least for females. 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 time, students do a similar amount of homework. Finally, changing start times does not have deleterious effects on short-run health outcomes.

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Table 1. Means of Test Scores by School Start Time (SDs)

Variables	All	7:00–7:44 A.M.	7:45–8:14 A.M.	8:15–9:15 A.M.
Females				
Broad-reading score	0.05	0.12	0.01	0.06
	(0.93)	(1.05)	(0.81)	(0.99)
Applied-problems score	-0.13	-0.03	-0.17	-0.21
	(0.96)	(1.08)	(0.87)	(0.94)
N	600	200	260	140
Males				
Broad-reading score	-0.05	-0.01	-0.09	-0.06
	(1.06)	(1.07)	(1.05)	(1.04)
Applied-problems score	0.13	0.20	0.06	0.11
	(1.02)	(0.96)	(1.09)	(0.95)
N	600	210	230	150
Pooled				
Broad-reading score	0.00	0.05	-0.04	-0.00
	(1.00)	(1.06)	(0.93)	(1.02)
Applied-problems score	0.00	0.10	-0.06*	-0.04
	(1.00)	(1.02)	(0.98)	(0.96)
N	1,200	420	500	290

Notes: CDS child weights used. Standard deviations are in parentheses.
Significance levels: * p<0.1. Significantly different from earliest start-time category.

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
Napping (hours, 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.]
Tardy to school	0.18	0.13
Participate in a sports team that year	0.28	0.39
Currently employed	0.22	0.20
Poor or fair health	0.09	0.07
Depressive symptoms	0.59	0.50
Overweight or obese	0.30	0.36
N	550	550

Notes: CDS child weights used. Means of control variables are in Appendix Table A.5. Clock time is in brackets.

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

	Females		Males	
Variables	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
Class time	6.18	4.42	6.70	4.79
Other schooling	0.25	0.20	0.18	0.15
Homework	0.99	0.91	0.72	0.64
Extracurricular activities/sports	0.84	0.96	1.06	1.25
Screen time	2.26	2.57	3.06	3.63
Other leisure	2.51	2.98	1.96	2.38
Personal care	1.19	1.19	0.84	0.83
Missing activities	0.09	0.12	0.07	0.09
Number of observations	550	550	550	550

Notes: CDS child weights used. Means may not sum to 24 hours due to rounding. See Appendix Table A.3 for a description of the activity categories.

Table 4. Determinants of School Start Time

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Northeast	-0.255***	-0.209***	-0.220***	-0.244***	-0.264***	-0.216***
	(0.031)	(0.034)	(0.031)	(0.034)	(0.045)	(0.045)
Midwest	0.002	0.002	-0.029	-0.040	-0.053	-0.055
	(0.029)	(0.029)	(0.028)	(0.037)	(0.039)	(0.040)
West	-0.072**	-0.052	-0.056*	-0.113*	-0.131*	-0.097
	(0.033)	(0.035)	(0.033)	(0.062)	(0.067)	(0.065)
Suburb		-0.117***	-0.124***	-0.117***	-0.130***	-0.131***
		(0.045)	(0.046)	(0.045)	(0.047)	(0.046)
Town		0.064*	-0.001	-0.009	-0.042	-0.037
		(0.037)	(0.045)	(0.045)	(0.048)	(0.047)
Rural		0.054	-0.052	-0.059	-0.092*	-0.088*
		(0.037)	(0.049)	(0.050)	(0.051)	(0.051)
Log (students)			-0.110***	-0.107**	-0.094**	-0.094**
			(0.023)	(0.042)	(0.043)	(0.043)
Magnet/charter			-0.008	0.012	0.035	0.028
			(0.086)	(0.076)	(0.080)	(0.082)
Student-teacher ratio				-0.001	0.001	0.000
				(0.009)	(0.010)	(0.010)
Percent Asian				0.001	0.001	0.002
				(0.002)	(0.002)	(0.002)
Percent Hispanic				0.001	0.001	0.001
				(0.001)	(0.001)	(0.001)
Percent black				-0.002***	-0.002**	-0.002**
				(0.001)	(0.001)	(0.001)
Percent free lunch				0.000	0.001	0.001
				(0.001)	(0.001)	(0.001)
Log (students in district)					-0.012	-0.011
					(0.015)	(0.015)
Log (expenditure per pupil)					0.049	0.041
					(0.072)	(0.074)
Log (household income)					0.038	0.040
					(0.075)	(0.074)
Log (population density)					-0.013	-0.011
					(0.013)	(0.013)
Average sunrise						0.166***
						(0.039)
R-squared	0.057	0.090	0.136	0.152	0.155	0.166

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: N=2,090. 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 (SDs)

	Broad-reading score					Applied-problems score				
Variables	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Panel 1. Females (N = 600)										
School start time	-0.056	0.077	0.120	0.156*	0.132	-0.142	-0.050	-0.043	-0.056	-0.060
	(0.152)	(0.094)	(0.086)	(0.082)	(0.082)	(0.138)	(0.095)	(0.091)	(0.098)	(0.098)
Lagged broad-reading score		0.562***	0.442***	0.433***	0.435***		0.148**	0.037	0.032	0.037
		(0.072)	(0.064)	(0.062)	(0.061)		(0.060)	(0.059)	(0.058)	(0.058)
Lagged applied-problems score		0.157***	0.098**	0.097**	0.096**		0.509***	0.434***	0.445***	0.446***
		(0.051)	(0.049)	(0.047)	(0.047)		(0.070)	(0.067)	(0.063)	(0.063)
Individual and family controls			X	X	X			X	X	X
School, county, and state controls				X	X				X	X
Average sunrise					X					X
R-squared	0.004	0.480	0.586	0.613	0.619	0.006	0.403	0.516	0.547	0.555
Panel 2. Males (N = 600)										
School start time	0.017	0.014	-0.001	0.003	0.016	-0.041	0.020	0.013	0.049	0.042
	(0.158)	(0.096)	(0.104)	(0.097)	(0.099)	(0.131)	(0.103)	(0.096)	(0.097)	(0.098)
Lagged broad-reading score		0.634***	0.570***	0.542***	0.540***		0.109**	-0.016	-0.033	-0.032
		(0.044)	(0.050)	(0.051)	(0.050)		(0.047)	(0.052)	(0.050)	(0.050)
Lagged applied-problems score		0.159***	0.078*	0.080*	0.077*		0.578***	0.496***	0.496***	0.498***
		(0.044)	(0.046)	(0.044)	(0.044)		(0.052)	(0.060)	(0.057)	(0.058)
Individual and family controls			X	X	X			X	X	X
School, county, and state controls				X	X				X	X
Average sunrise					X					X
R-squared	0.005	0.553	0.629	0.652	0.653	0.003	0.423	0.538	0.566	0.566

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. School day length is included in all regressions. 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/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 until age 17–18, magnet/charter school, and missing school-level variable. Average sunrise is the average of the sunrise from September 1 until May 31 at each school. All regressions include a constant.
Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 5 Continued. Effects of School Start Time on Test Scores (SDs)

Variables	Broad-reading score					Applied-problems score				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Panel 3. Pooled (N=1,200)										
School start time	-0.056	0.080	0.120	0.156*	0.132	-0.142	-0.047	-0.043	-0.056	-0.060
	(0.152)	(0.094)	(0.085)	(0.082)	(0.082)	(0.138)	(0.096)	(0.091)	(0.098)	(0.098)
School start time*male	0.073	-0.054	-0.110	-0.147	-0.115	0.101	0.076	0.061	0.109	0.102
	(0.211)	(0.136)	(0.135)	(0.127)	(0.125)	(0.182)	(0.142)	(0.135)	(0.139)	(0.138)
Lagged test scores		X	X	X	X		X	X	X	X
Individual and family controls			X	X	X			X	X	X
School, county, and state controls				X	X				X	X
Average sunrise					X					X
R-squared	0.008	0.518	0.610	0.635	0.640	0.021	0.421	0.535	0.564	0.568

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. School day length is included in all regressions. 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/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 until age 17–18, magnet/charter school, and missing school-level variable. Average sunrise is the average of the sunrise from September 1 until May 31 at each school. All regressions include a constant.
Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 6. Association between Teacher Characteristics and School Start Time

Teacher characteristic	Mean	Coefficient on Start Time: Without School Controls	Coefficient on Start Time: With School Controls
First year in school	0.146	0.021*	0.009
		(0.011)	(0.010)
Years teaching full-time	13.289	0.621**	0.256
		(0.302)	(0.303)
Has master's degree	0.522	-0.096***	-0.030*
		(0.019)	(0.018)
Has national or state certification	0.899	0.011	0.013
		(0.010)	(0.010)

Source: Authors' calculations using data from SASS (2007-08) Public School Teacher Survey and Public School Survey, Common Core of Data, School District Demographics System, and U.S. Census Bureau.
Notes: N=13,410. Each row comes from a separate regression of the teacher characteristic on school start time, day length, and (in some specifications) school controls. Standard errors clustered by high school are in parentheses. SASS teacher sampling weights used. School controls are all of those shown in Table 4 with the exception of average sunrise.
Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 7. Bounded Effects of School Start Time on Test Scores (SDs)

	Females		Males	
Variables	Broad-reading score	Applied-problems score	Broad-reading score	Applied-problems score
School start time	(0.156, 0.282)	(-0.056, 0.008)	(-0.006, 0.003)	(0.049, 0.121)

Notes: CDS child weights used. Ranges calculated using Oster's psacalc.ado (Oster, 2013) assuming $R_{max} = 1$ and $\delta = 1$. See Table 5 specification 4 for control variables.
Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 8. Effects of School Start Time on Test Scores (SDs), by FRL Status

Variables	Broad-reading score	Applied-problems score
Panel 1. Females (N= 600)		
School start time	0.109	-0.077
	(0.100)	(0.126)
School start time*FRL	0.214	0.076
	(0.157)	(0.192)
[School start time + school start time*FRL]	0.323***	-0.001
	(0.121)	(0.146)
R-squared	0.657	0.609
Panel 2. Males (N= 600)		
School start time	-0.049	-0.057
	(0.131)	(0.118)
School start time*FRL	0.314	0.265
	(0.193)	(0.200)
[School start time + school start time*FRL]	0.265*	0.208
	(0.141)	(0.159)
R-squared	0.703	0.627

Notes: CDS child weights used. See Table 5 specification 4 for control variables.
Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 9. Effects of School Start Time on Sleep

Variables	All diary sleep (M–TH)	Nighttime diary sleep (M–TH)	Usual night sleep	Napping (M–TH)	Wake-up time (M–TH)	Bedtime (M–TH)
Panel 1. Females						
School start time	0.636***	0.601***	0.383**	0.036	0.583***	-0.044
	(0.232)	(0.229)	(0.171)	(0.082)	(0.187)	(0.156)
Number of observations	450	450	550	450	450	450
R-squared	0.193	0.191	0.182	0.087	0.231	0.147
Panel 2. Males						
School start time	-0.141	0.324	0.212	-0.466	0.575***	0.270
	(0.382)	(0.228)	(0.169)	(0.283)	(0.205)	(0.191)
Number of observations	460	460	550	460	460	460
R-squared	0.245	0.244	0.216	0.242	0.248	0.205
Panel 3. Pooled						
School start time	0.636***	0.601***	0.383**	0.036	0.583***	-0.044
	(0.232)	(0.229)	(0.171)	(0.082)	(0.187)	(0.156)
School start time*male	-0.777*	-0.276	-0.171	-0.501*	-0.007	0.314
	(0.449)	(0.322)	(0.243)	(0.295)	(0.278)	(0.249)
Number of observations	910	910	1,100	910	910	910
R-squared	0.225	0.218	0.204	0.209	0.239	0.178

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 specification 4 for control variables.
Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 10. Effects of School Start Time on Time-use Activities and Health (All-days Sample)

	Females	Males	Pooled	
Dependent Variable	School start time	School start time	School start time	School start time*male
Time-Diary Outcomes				
Sleep	0.591***	0.128	0.591***	-0.463
	(0.175)	(0.250)	(0.175)	(0.304)
Market work	0.097	-0.052	0.097	-0.149
	(0.193)	(0.258)	(0.193)	(0.327)
Nonmarket work	0.072	-0.058	0.072	-0.130
	(0.133)	(0.123)	(0.133)	(0.180)
Care activities	0.023	-0.007	0.023	-0.029
	(0.076)	(0.042)	(0.076)	(0.087)
Class time	-0.192	0.283	-0.192	0.475
	(0.273)	(0.246)	(0.273)	(0.359)
Other schooling	-0.128*	-0.035	-0.128*	0.094
	(0.065)	(0.046)	(0.065)	(0.079)
Homework	-0.188	0.025	-0.188	0.213
	(0.139)	(0.106)	(0.139)	(0.714)
Extracurricular activities/	0.277	0.289	0.277	0.012
sports	(0.211)	(0.188)	(0.211)	(0.269)
Screen time and other leisure	-0.628*	-0.774**	-0.628*	-0.146
	(0.335)	(0.390)	(0.335)	(0.513)
Subcategories:				
Screen time	-0.263	-0.897**	-0.263	-0.634
	(0.289)	(0.360)	(0.289)	(0.451)
Other leisure	-0.365	0.123	-0.365	0.488
	(0.224)	(0.207)	(0.224)	(0.305)
Personal care	0.015	0.111*	0.015	0.096
	(0.080)	(0.064)	(0.080)	(0.103)
Missing activities	0.061	0.090**	0.061	0.029
	(0.039)	(0.043)	(0.039)	(0.051)
Number of observations	550	550	1,100	1,100

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 specification 4 for control variables.
Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 10 Continued. Effects of School Start Time on Time-use Activities and Health (All-days Sample)

	Females	Males	Pooled	
Dependent Variable	School start time	School start time	School start time	School start time*male
Attendance and Participation Outcomes				
Tardy to school[a]	-0.073	-0.053	-0.073	0.020
	(0.064)	(0.050)	(0.064)	(0.078)
Employed	-0.043	0.089	-0.043	0.132
	(0.063)	(0.057)	(0.063)	(0.081)
Sports team	0.205**	0.035	0.205**	-0.170
	(0.081)	(0.063)	(0.081)	(0.105)
Health-Indicator Outcomes				
Fair/poor health	0.036	-0.010	0.036	-0.046
	(0.035)	(0.033)	(0.035)	(0.048)
Overweight/obese[b]	-0.025	-0.029	-0.025	-0.004
	(0.051)	(0.071)	(0.051)	(0.085)
Depressive symptoms[c]	-0.071	-0.037	-0.071	0.035
	(0.073)	(0.068)	(0.073)	(0.100)
Number of observations	550	550	1,100	1,100

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 specification 4 for control variables.

[a] For the tardy-to-school variable, the number of observations was 480 for females and 490 for males due to some students not attending school on their weekday diary.

[b] For the overweight/obese variable, the number of observations was 530 for females and 540 for males due to missing information.

[c] For the depressive-symptoms variable, the number of observations was 520 for males due to missing information.

Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 11. Effects of Sleep on Female Students' Broad-reading Test Scores (SDs)

	M–TH sample		All-days sample	
Variables	OLS	IV	OLS	IV
Weekday sleep	-0.029	0.355*		
	(0.024)	(0.190)		
All-day sleep			-0.018	0.248
			(0.026)	(0.157)
Number of observations	450	450	550	550
R-squared	0.609	0.241	0.611	0.480
Kleibergen-Paap F-statistic on excluded instrument		7.501		11.374

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 specification 4 for control variables. The first stage for the IV models is identical to the regressions (of sleep on start time) reported in Table 9 (M–TH sample) and Table 10 (all-days sample).

Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Appendix A

Table A.1. Sources of School Start and End Times

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

Notes: N=1,200. Archived websites accessed via the Internet Archive's Wayback Machine.

Table A.2. Sample Selection

Attend high school in CDS-II/CDS-III and Primary Caregiver 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.

Table A.3. Time-use Classifications

Classification	Examples of activities included
Sleep	Sleeping; naps and resting
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
Class time	Attending class; field trips; travel to school
Other schooling	Nonacademic classes; SAT prep; military training
Homework	Homework; using the computer for homework; being tutored; studying; reviewing homework with parent
Extracurricular activities/sports	Volunteer work; attending church; youth group; fraternal organizations; community organizations; music lessons; playing an instrument; attending before- or after-school activities (not sports-related); playing sports; lessons in sports or dance; team sports; organized meets or games; exercise
Screen time	Watching television; playing computer games; playing games on a cell phone; electronic video games (Nintendo, Sony, Game Boy, Sega); "surfing the net"; downloading pictures, music; e-mail; reading media; Skype; Facebook; photo processing; learning how to use computer; financial services
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
Personal care	Bathing; dressing; medical care (sick or visiting doctor)
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.

Table A.4. 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.

Table A.5. 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
Lives in East region	0.26	0.13**	0.09**
Lives in Midwest region	0.21	0.27*	0.20
Lives in South region	0.28	0.24	0.61**
Lives in West region	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-problems score (before HS) (SDs)	0.13	-0.07*	-0.07
WJ-R broad-reading score (before HS) (SDs)	0.16	-0.10**	-0.06*
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	0.11	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	0.31	0.25	0.28
Mother education missing	0.03	0.04	0.06
Father college degree	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

Notes: 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 A.5 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 free/reduced-price lunch	27.42	38.42**	32.94**
Magnet or charter school	0.07	0.03**	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**
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
Sunlight Variables			
Average sunlight before school	0.65	1.11**	1.50**
Average sunrise	6.82	6.83	6.97**
	[6:49 A.M.]	[6:50 A.M.]	[6:58 A.M.]
N	420	490	290

Notes: CDS child weights used. Means are means of the non-missing variables. Clock time is in brackets.

Significance levels: ** p<0.05, * p<0.1. Significantly different from earliest start-time category.

Table A.6. Effects of Sunlight before School on Test Scores (SDs)

	Females		Males		Pooled	
Variables	Broad-reading score	Applied-problems score	Broad-reading score	Applied-problems score	Broad-reading score	Applied-problems score
Sunlight before school	-0.008	-0.131	0.055	0.009	0.046	-0.037
	(0.077)	(0.101)	(0.093)	(0.085)	(0.062)	(0.072)
R-squared	0.608	0.553	0.652	0.566	0.613	0.525
Number of observations	600	600	600	600	1,200	1,200

Notes: CDS child weights used. See Table 5 specification 4 for control variables.

Table A.7. Effects of School Start Time on Sleep (Including Sunrise Control)

Variables	All diary sleep (M–TH)	Nighttime diary sleep (M–TH)	Usual night sleep	Napping (M–TH)	Wake-up time (M–TH)	Bedtime (M–TH)
Panel 1. Females						
School start time	0.643***	0.607***	0.364**	0.036	0.576***	-0.062
	(0.234)	(0.229)	(0.172)	(0.084)	(0.186)	(0.159)
Number of observations	450	450	550	450	450	450
R-squared	0.191	0.190	0.185	0.087	0.243	0.154
Panel 2. Males						
School start time	-0.035	0.427*	0.214	-0.462*	0.595***	0.182
	(0.355)	(0.234)	(0.172)	(0.252)	(0.217)	(0.185)
Number of observations	460	460	550	460	460	460
R-squared	0.253	0.257	0.216	0.242	0.249	0.222

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 specification 5 for control variables.

Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A.8. Effects of School Start Time on Time-use Activities (Weekdays Sample, Monday–Friday)

	Females	Males	Pooled	
Dependent Variable	School start time	School start time	School start time	School start time*male
Sleep	0.723***(0.220)	0.158 (0.338)	0.723***(0.220)	-0.565 (0.405)
Market work	0.151 (0.199)	-0.112 (0.275)	0.151 (0.199)	-0.263 (0.347)
Nonmarket work	0.074 (0.131)	-0.085 (0.110)	0.074 (0.131)	-0.158 (0.171)
Care activities	0.072 (0.098)	-0.040 (0.042)	0.072 (0.098)	-0.112 (0.108)
Class time	-0.268 (0.382)	0.373 (0.347)	-0.268 (0.382)	0.640 (0.503)
Other schooling	-0.126 (0.078)	-0.049 (0.061)	-0.126 (0.078)	0.077 (0.097)
Homework	-0.175 (0.166)	0.074 (0.125)	-0.175 (0.166)	0.249 (0.207)
Extracurricular activities/sports	0.158 (0.199)	0.314 (0.203)	0.158 (0.199)	0.156 (0.272)
Screen time and other leisure	-0.659*(0.386)	-0.827*(0.455)	-0.659*(0.386)	-0.168(0.585)
Subcategories:				
Screen time	-0.313 (0.312)	-0.980** (0.409)	-0.313 (0.312)	-0.667 (0.490)
Other leisure	-0.346 (0.247)	0.153 (0.229)	-0.346 (0.247)	0.499 (0.335)
Personal care	-0.024 (0.092)	0.124* (0.070)	-0.024 (0.092)	0.148 (0.114)
Missing activities	0.074* (0.044)	0.070 (0.055)	0.074* (0.044)	-0.004 (0.056)
Number of observations	550	550	1,100	1,100

Notes: CDS child weights used. Standard errors clustered by high school are in parentheses. See Table 5 specification 4 for control variables.

Significance levels: *** p<0.01, ** p<0.05, * p<0.1.