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A's from Zzzz's? The Causal Effect of School Start Time on the Academic Achievement of Adolescents†

By Scott E. Carrell, Teny Maghakian, and James E. West*

Recent sleep research finds that many adolescents are sleep-deprived because of both early school start times and changing sleep patterns during the teen years. This study identifies the causal effect of school start time on academic achievement by using two policy changes in the daily schedule at the US Air Force Academy along with the randomized placement of freshman students to courses and instructors. Results show that starting the school day 50 *minutes later has a significant positive effect on student achievement, which is roughly equivalent to raising teacher quality by one standard deviation.* (*JEL* I23, J13)

Each weekday morning, most high school students are sitting in their first period class by 7:30 am.While some students may be raring to go, many are struggling to stay awake and alert. In fact, survey evidence shows that over a quarter of high school students report falling asleep in class at least once per week (National Sleep Foundation 2006). As parents and administrators look for ways to improve student academic achievement, some question whether early start times are hindering the learning process for teenagers. Sleep research supports this notion, finding that many adolescents are sleep-deprived because of both early school start times and changing sleep patterns during the teen years. Consequently, policy initiatives to delay high school start times have gained momentum across the country. At the national level, House Concurrent Resolution 176, introduced to Congress in 2007 as the "Zzz's to A's Resolution," calls for secondary schools to begin after 9:00 am. State legislatures and local school districts have also introduced similar proposals. Although some districts have adopted later start times, most were forced to maintain the status quo as a result of conflicting bussing schedules or vehement opposition from coaches and skeptical parents.

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One of the primary arguments against changing school start times is a lack of causal evidence on how start time affects student achievement, as most existing studies are correlational in nature. For instance, research has shown that early start times in high school lead to sleep deprivation among students (Amy R. Wolfson and Mary A. Carskadon 2003; Martha Hansen et al. 2005; Donn Dexter et al. 2003). Additionally, the number of hours of sleep is positively correlated with measures of academic achievement (Wolfson and Carskadon 1998; James F. Pagel, Natalie Forister, and Carol Kwiatkowki 2007; Howard Taras and William Potts-Datema 2005; Katia Fredriksen et al. 2004; Giuseppe Curcio, Michele Ferrara, and Luigi De Gennaro 2006; Arne Eliasson et al. 2002). However, in these studies, grades are not a consistent measure of student academic achievement due to heterogeneity of assignments and exams, as well as the subjectivity of assigning grades to assessments across instructors. Additionally, existing studies have been unable to take into account confounding factors, which likely bias the results. For instance, self-selection of coursework, schedules, and instructors, make it difficult to distinguish the effect of school start time from peer and teacher effects.

This paper identifies the causal effect of school start time on the academic achievement of adolescents. To do so, we use data from the United States Air Force Academy (USAFA) to take advantage of the randomized assignment of students to courses and instructors, as well as two policy changes in the school start time over a three-year period. Random assignment, mandatory attendance, along with extensive background data on students, allow us to examine how school start time affects student achievement without worrying about confounding factors or self-selection issues that bias existing estimates. USAFA's grading structure for core courses allows for a consistent measure of student achievement; faculty members teaching the same course in each semester use an identical syllabus, give the same exams during a common testing period, and assign course grades jointly with other instructors, allowing for standardized grades within a course-semester.

Despite our use of university-level data, we believe our findings are applicable to the high school student population more generally because we consider only freshmen students in their first semester at USAFA. Like high school seniors, first semester college freshman are still adolescents and have the same biological sleep patterns and preferences as those in their earlier teens. However, we recognize that USAFA students are not the average teen; they were high-achievers in high school and chose to attend a military service academy. Although we do not know for certain if school start times affect high-achievers or military-types differently than teenagers in the general population, we have no reason to believe that the students in our sample would be *more* adversely affected by early start times. Because the students in our study self-selected into a regimented lifestyle, if anything, we believe our estimates may be a lower-bound of the effect for the *average* adolescent.

Our results show that starting the school day later in the morning has a significant positive effect on student academic achievement. We find that when a student is randomly assigned to a first period course starting prior to 8 AM, they perform significantly worse in all their courses taken on that day compared to students who are not assigned to a first period course. Importantly, we find that this negative effect diminishes the later the school day begins. We verify that the negative start time effect is not solely driven by worse performance in the first period class. Hence, our results show that student achievement suffers from earlier start times in not only courses taken during the early morning hours, but also throughout the entire day.

With schools aiming to improve student achievement while simultaneously facing large budget cuts, determining the impact of school start time has important implications for education policy. Our findings suggest that pushing back the time at which the school day starts would likely result in significant achievement gains for adolescents.

I. Background

Although school start time has not been widely studied in the economics literature, the subject of adolescent sleep behavior and its effect on academic performance has been explored extensively in the medical, education, psychology, and child development literatures. These studies focus on understanding how adolescent sleep preferences shift as a result of changing biological rhythms, how sleep deprivation from early start times affects the learning process, and how later school start times affect sleep patterns.

A. *The Circadian Rhythm*

To fully understand how school start time can influence academic achievement, it is important to first have a basic understanding of the biology of sleep and wakefulness. The biological rhythm that governs our sleep-wake cycles is called the circadian rhythm, a hard-wired "clock" in the brain that controls the production of the sleep-inducing hormone melatonin. During adolescence, there are major changes in one's circadian rhythm. More adult-like patterns of REM sleep develop, there are increases in daytime sleepiness, and there is a shift in the circadian pattern toward a more owl-like tendency for later bed and wake-up times (Daniel P. Cardinali 2008; Stephanie J. Crowley, Christine Acebo, and Carskadon 2007; Carskadon, Cecilia Vieira, and Acebo 1993; Wolfson and Carskadon 1998). The adolescent body does not begin producing melatonin until around 11 PM and continues in peak production until about 7 AM, then stops at about 8 AM. In contrast, adult melatonin levels peak at 4 AM. Therefore, waking up a teenager at 7 AM is equivalent to waking up an adult at 4 AM.

School schedules affect adolescent sleep patterns by imposing earlier rise times that are asynchronous with the circadian rhythm. That is, adolescents are forced to wake up and be alert and focused at a time at which their body wants to be asleep. Although adolescents know they have to wake up early, they are unable to adjust their bedtime accordingly because they naturally become more alert during the night hours. Physically, they won't become sleepy until melatonin production begins later in the night. Because the circadian system can't adapt easily to advances in the sleep-wake schedule (i.e., it is easier to stay awake when one is tired than it is to go to sleep when one is not tired), students cannot force themselves to fall asleep at a time early enough to get an adequate night's rest. Although there are many factors that contribute to later bedtimes, sleep researchers have found that adolescents stay awake later largely for biological, not social, reasons

(Crowley, Acebo, and Carskadon 2007; Carskadon, Vieira, and Acebo 1993). The amount of sleep deprivation for teens during the school year is sizable. Compared to the summer months (when adolescents presumably obtain their optimal amount of sleep), Hansen et al. (2005) find that students lose as much as 120 minutes of sleep per school night.

In addition to the amount of sleep students obtain, research indicates academic achievement may also be affected by the asynchrony between the preferred time of day and the time at which courses are taught. That is, the cognitive functioning of adolescents is likely to be at its peak more toward the afternoon than in the morning. Using college-level data from Clemson University, Angela K. Dills and Rey Hernandez-Julian (2008) find that even when controlling for student and course characteristics, students perform better in classes that meet later in the day. David Goldstein et al. (2007) find that scores on intelligence tests are significantly lower during the early morning hours.

B. *The Link Between Sleep and Academic Achievement*

Recent scientific research has strengthened the notion that sleep may play an important role in learning and memory, with several studies finding an inverse relationship between sleep and academic performance at both the secondary and post-secondary level (Curcio, Ferrara, and Gennaro 2006; Wolfson and Carskadon 1998; Mickey T. Trockel, Michael D. Barnes, and Dennis L. Egget 2000). Correlational studies comparing sleep-wake patterns and academic performance for early versus late starting schools find that students attending later starting schools self-report more hours slept, less daytime fatigue, and less depressive feelings (Wolfson and Carskadon 2003; R. Epstein, N. Chillag, and P. Lavie 1998; Kyla Wahistrom 2002). Interestingly, daytime fatigue and difficulty staying awake in class were not associated with the total hours of sleep, implying that these are consequences of earlier wake times that disrupt natural adolescent circadian rhythms. A recent study at an American high school found that a 30-minute delay in start time led to significant decreases in daytime sleepiness, fatigue, and depressed mood (Judith A. Owens, Katherine Belon, and Patricia Moss 2010). However, there are several acknowledged methodological weaknesses in this literature. Although studies find a correlation between sleep and grades, they cannot establish a causal relationship. Additionally, much of the existing literature relies on surveys and self-reports, which are both retrospective and subjective. Differences in academic achievement measures across studies make cross-study comparisons difficult and many suffer from small sample size.

Only a handful of studies have investigated how the school schedule affects academic achievement, and all of these studies face identification challenges stemming from students' ability to choose their courses and schedule. Minneapolis Public School District was one of the first school districts to change the start times of their high schools. In 1997, start times changed from 7:15 AM to 8:40 AM. Wahistrom (2002) examines this policy change and finds that the later start time had a positive effect on attendance and an insignificant improvement on grades. However, because of record-keeping issues, subjectivity of grading, and differences in courses across teachers and schools, Wahistrom (2002) questioned the strength of her own findings. Peter Hinrichs (2011) also studies the effect of start time using data from Minneapolis Public School District. While high schools in Minneapolis moved back their start time, schools in St. Paul (Minneapolis' twin city) did not. He uses ACT test score data on all individuals from public high schools in the Twin Cities metropolitan area who took the ACT between 1993 and 2002 to estimate the effects of school starting times on ACT scores. Hinrichs (2011) broadens his analysis by estimating the effects of start time on achievement using statewide standardized test scores from Kansas and Virginia. His results suggest no effect of school start time on academic achievement.

II. Data

Data for this study come from the United States Air Force Academy (USAFA). USAFA is a fully-accredited post-secondary institution with annual enrollment of approximately 4,500 students, offering 32 majors within the humanities, social sciences, basic sciences, and engineering. Students are required to graduate within four years and typically serve a minimum five-year commitment as a commissioned officer in the United States Air Force following graduation. Despite its military setting, USAFA is comparable to other selective colleges and universities in the United States. Like other selective post-secondary schools, USAFA faculty hold graduate degrees from high quality programs in their fields. Approximately 40 percent of classroom instructors have terminal degrees, similar to large universities where introductory courses are taught by graduate students. However, class size at USAFA is rarely larger than 25 students, and students are encouraged to interact with faculty members in and outside of the classroom. Therefore, the learning environment at USAFA is similar to that of small liberal arts colleges. Students at USAFA are high achievers, with average math and verbal SAT scores at the 88th and 85th percentiles of the nationwide SAT distribution, respectively. Only 14 percent of applicants were admitted to USAFA in 2007. Students are drawn from each Congressional district in the US by a highly competitive admission process that ensures geographic diversity.

The school day at USAFA is highly structured, which is atypical of most universities, but very similar to a high school setting. There are four 53-minute class periods each morning and three each afternoon. All students are required to attend mandatory breakfast 25 minutes before first period.[1] In this study, we exploit five important features of the school day structure at USAFA. First, students in their freshman year at USAFA are required to take a series of core courses in which attendance in their assigned section is mandatory. Second, students are randomly assigned to course sections and cannot choose which periods they take their classes.[2] Third, not every student is assigned to a first period course. Fourth, we exploit the fact that USAFA runs

[1] Even students without a first period class must attend the breakfast. However, many students take naps after breakfast if they do not have a first period class.

[2] The USAFA Registrar employs a stratified random assignment algorithm to place students into sections within each course and semester. The algorithm first assigns all female students evenly throughout all offered sections, then places male recruited athletes, and then assigns all remaining students. Within each group (female, male athlete, and male non-athlete), assignments are random.

TABLE 1—CLASS SCHEDULE AT THE US AIR FORCE ACADEMY

Period	AY1996–AY2005	AY2006	AY2007–AY2009
1	7:30	7:00	7:50
2	8:30	8:05	8:50
3	9:30	9:10	9:50
4	10:30	10:15	10:50
5	13:00	13:00	13:30
6	14:00	14:05	14:30
7	15:00	15:10	15:30

on an M/T schedule. On M Days, students have one set of classes and on T Days they have a different set of classes. The M/T schedule runs every other day. Thus, some students may have first period classes on both M and T days, others may only have a first period class on one of the schedule days, and some may not have any first period classes. Finally, we exploit two distinct policy changes in the USAFA class schedule. Prior to academic year 2006–2007 (AY 2006), the academic day started at 7:30 AM. In AY 2006 the school day was moved 30 minutes earlier, starting at 7 AM. In AY 2007, the start time was moved to 7:50 AM. Table 1 shows the academic day schedule across the years of our sample. These unique features of our dataset enable us to cleanly identify the causal average treatment effect of school start time using both within-student and across-student/cohort variation. Importantly, we are able to identify both the effect of being assigned to a first period course (e.g., a wake-up effect), but also how this effect changes as the time in which the school day begins.

The Dataset.—Our dataset consists of 6,165 first-year students from the entering classes of 2004 to 2008. For each student we have pre-treatment demographic data and measures of their academic, athletic, and leadership aptitude. Academic aptitude is measured through SAT verbal and math scores and an academic composite computed by the USAFA admissions office, which is a weighted average of an individual's high school GPA, class rank, and the quality of the high school they attended. The measure of pre-treatment athletic aptitude is a score on a fitness test required by all applicants prior to entrance. The measure of pre-treatment leadership aptitude is a leadership composite computed by the USAFA admissions office, which is a weighted average of high school and community activities. Other individual-level controls include indicators for students who are black, Hispanic, Asian, female, recruited athlete, attended a military preparatory school, and the number of courses students have on that schedule day.

Table 2 shows summary statistics for our entire sample and separately for students enrolled in first period, second through seventh periods, athletes, and non-athletes. Each observation is a student-class. Approximately 17 percent of the students in our entire sample are female, four percent are black, seven percent are Hispanic, and eight percent are Asian. Twenty-two percent of students are recruited as athletes and seventeen percent attended a military preparatory school. To uphold the validity of our results, we want to ensure that students who are enrolled in a first period course are similar to those enrolled in the other periods. These students appear to be very similar in all background characteristics except for recruited athlete. This anomaly

Table 2—Summary Statistics

	Full sample mean	First period mean	Periods 2–7 mean	Non-athletes mean	Athletes mean
Normalized grade	0.00	−0.12	0.02	0.06	−0.25
	[1.00]	[1.00]	[0.99]	[0.99]	[0.97]
Credit hours	8.20	8.04	8.24	8.31	7.79
	[2.23]	[2.28]	[2.22]	[2.27]	[2.02]
SAT math	6.63	6.56	6.64	6.70	6.38
	[0.63]	[0.65]	[0.63]	[0.61]	[0.64]
SAT verbal	6.36	6.28	6.38	6.45	6.02
	[0.66]	[0.66]	[0.65]	[0.63]	[0.63]
Academic composite	13.04	12.93	13.06	13.20	12.47
	[2.04]	[2.10]	[2.03]	[1.97]	[2.20]
Fitness score	4.14	4.20	4.13	4.08	4.40
	[0.94]	[0.96]	[0.93]	[0.91]	[1.00]
Leadership composite	17.35	17.34	17.36	17.37	17.27
	[1.76]	[1.78]	[1.80]	[1.80]	[1.79]
Black	0.04	0.05	0.04	0.03	0.08
	[0.20]	[0.23]	[0.20]	[0.18]	[0.27]
Hispanic	0.07	0.06	0.07	0.08	0.04
	[0.26]	[0.25]	[0.26]	[0.27]	[0.20]
Asian	0.08	0.07	0.09	0.10	0.04
	[0.28]	[0.26]	[0.28]	[0.29]	[0.20]
Female	0.19	0.21	0.19	0.19	0.21
	[0.39]	[0.40]	[0.39]	[0.39]	[.40]
Recruited athlete	0.22	0.35	0.19	0.00	1.00
	[0.41]	[0.48]	[0.39]	[0.00]	[0.00]
Military preparatory school	0.17	0.18	0.17	0.16	0.19
	[0.37]	[0.38]	[0.37]	[0.37]	[0.39]

Notes: Standard deviation in brackets. The full sample included 20,680 observations, of which 3,977 are during first period and 16,703 are during periods 2–7. Of the observations, 4,512 are for recruited athletes and 16,168 are for non-athletes. SAT math, SAT verbal, academic composite, fitness score, and leadership composite were divided by 100. Credit hours is the total number of credit hours enrolled in by schedule day.

is explained by the fact that athletes at USAFA are not assigned to afternoon classes, since they have athletic practices at that time. Thus, they are more likely to be randomly assigned a first period class.[3] Athletes and non-athletes also differ slightly in their pre-treatment characteristics. Athletes, on average, have lower SAT math and verbal scores as well as a lower academic composite score. They are more likely to be black, and less likely to be Hispanic or Asian. To account for differences in peer quality across course sections, we control for the average classroom-level peer characteristics in all of our specifications.

Figure 1 plots the distributions of pre-treatment academic variables by start-time cohorts. We refer to the students who started before AY 2006 as the middle cohort, as their first period began at 7:30 AM. The cohort starting first period at 7:00 AM in AY 2004 and 2005 is referred to as the early cohort, and the late cohort started first period at 7:50 in AY 2007 and 2008. The distributions of SAT math scores are fairly even across cohorts as are SAT verbal scores for the early and late cohorts.

[3] We exclude athletes in our main specifications, but we show in our robustness checks that our results are not sensitive to this restriction.

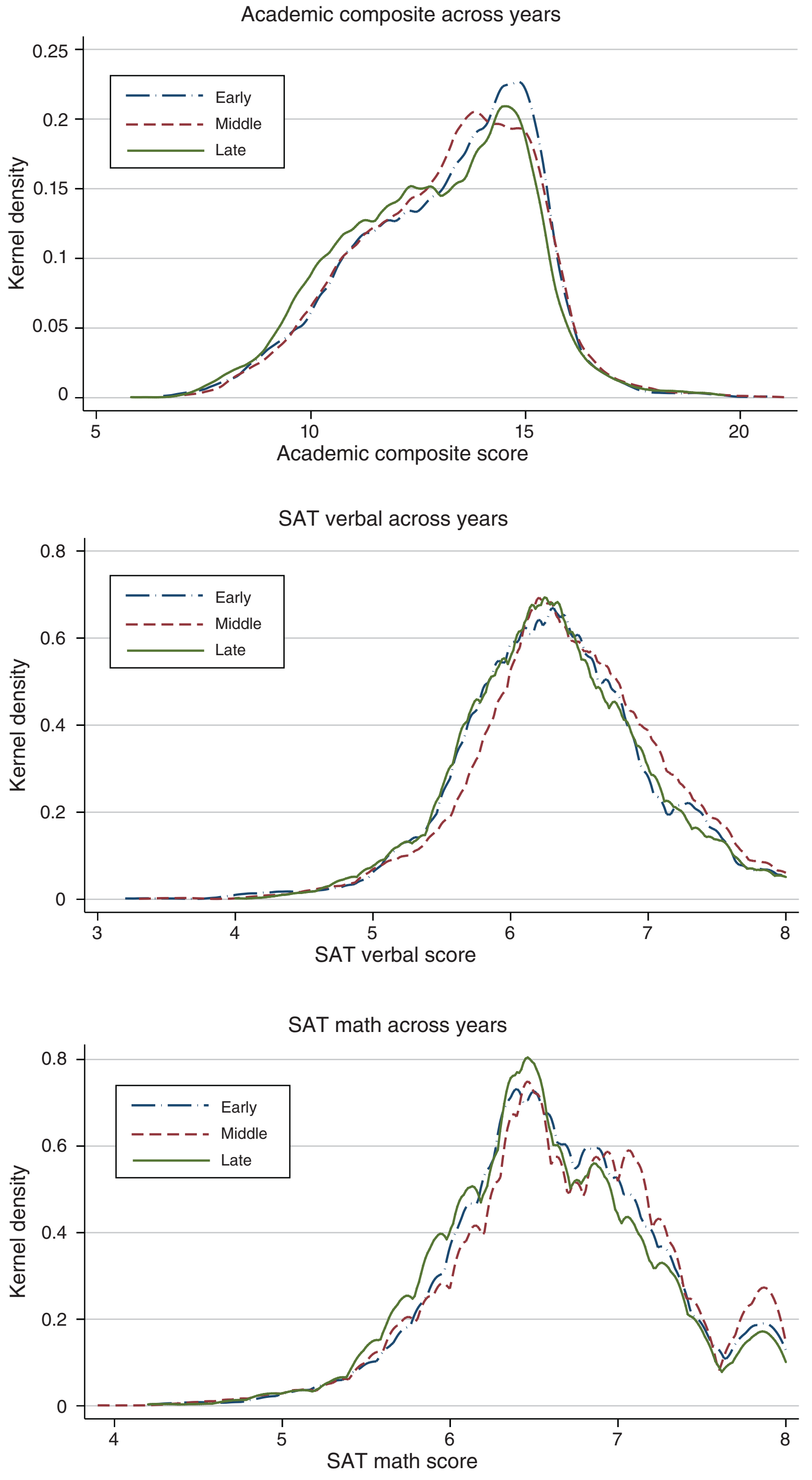

Figure 1. Distribution of Student Pre-treatment Characteristics by Start Time Cohort

Note: Recruited athletes are excluded in all figures.

Students from the middle cohort appear to have slightly higher SAT verbal scores. The distributions of high school academic composite scores show some differences across cohorts. The late cohort has slightly lower academic composite scores and the Early cohort has slightly higher scores. Even if small differences between cohorts exist, we do not expect them to affect our results as we make within course by year comparisons and control for all observable background characteristics as well as classroom peer characteristics.

We measure academic performance using students' final percentage score earned in a course. To account for differences in course difficulty or grading across years, we normalize all scores to a mean of zero and a variance of one within a course-semester.[4] We refer to this measure as the student's normalized grade. Students at USAFA are required to take a core set of approximately 30 courses in mathematics, basic sciences, social sciences, humanities, and engineering. In this study, we focus primarily on the mandatory introductory courses in mathematics, chemistry, engineering, and computer science taken during the fall semester of the freshman year. Because grades in humanities courses (English and history) are mostly determined by papers and assignments done outside the classroom, we believe that achievement measures in math and science courses, wherein grades are based on performance on common exams, better capture the level of learning that occurred during the class. However, our results are robust to the inclusion of humanities courses.

Prior to the start of the freshman year, students take placement exams in mathematics, chemistry, and select foreign languages. Scores on these exams are used to place students into the appropriate starting courses (e.g., remedial math, Calculus I, Calculus II, etc.). Conditional on course placement, athlete status, and gender, the USAFA registrar randomly assigns students to core course sections. Thus, students have no ability to choose the class period or their professors in the required core courses. Professors teaching the same course in each semester use an identical syllabus and give the same exams during a common testing period. These unique institutional characteristics assure there is no self-selection of students into (or out of) courses, towards particular class periods, or toward certain professors. Additionally, since the start time changes were not announced long before their implementation, incoming students could not have foreseen the time changes to select into or out of USAFA based on their time preferences.

We formally test whether first period assignment is random with respect to student characteristics by regressing first period enrollment on student characteristics for each course. Table 3 shows the results from these regressions. Only two of the 80 coefficients are significant at the one percent level, and three are significant at the five percent level. The coefficients are only jointly significant for one of the courses, Chemistry 141.[5] Because of this, we exclude Chem 141 in one of our robustness specifications. We also control for classroom-level peer characteristics to address differences in peers across classes. Carrell and West (2010) show that student

[4] We find qualitatively similar results when using raw scores.

[5] Chem 141 is a lab course that spans two periods; thus, it is only offered first, third, and fifth periods. Because athletes are not assigned afternoon courses, they are far more likely to be assigned a first period Chem 141 class. Additionally, in 2004–2006 the 92 lowest ability students were grouped into four Chem 141 sections—pairing the worst students with the best professors.

Table 3— Randomization Checks

Course	Math 141 (1)	Math 152 (2)	Chem 100 (3)	Chem 141 (4)	Engr 100 (5)	ComSci 110 (6)	English 111 (7)	History 101 (8)
Attended preparatory school	−0.005	0.023	−0.016	−0.008	−0.011	0.026	−0.010	0.020
	(0.017)	(0.022)	(0.055)	(0.028)	(0.034)	(0.022)	(0.023)	(0.020)
Black	0.031	−0.001	0.144*	−0.040	0.026	0.087*	0.015	−0.028
	(0.038)	(0.047)	(0.080)	(0.040)	(0.036)	(0.050)	(0.036)	(0.023)
Asian	0.022	−0.004	0.010	−0.034	−0.060**	−0.012	0.010	−0.028
	(0.017)	(0.023)	(0.058)	(0.028)	(0.028)	(0.024)	(0.019)	(0.021)
Hispanic	−0.016	−0.013	−0.067	0.021	0.002	−0.015	−0.018	−0.023
	(0.013)	(0.032)	(0.053)	(0.037)	(0.021)	(0.024)	(0.023)	(0.019)
Academic composite	0.002	−0.005	0.007	−0.013*	0.002	−0.004	−0.001	0.001
	(0.003)	(0.006)	(0.012)	(0.007)	(0.004)	(0.004)	(0.003)	(0.003)
Leadership score	0.002	0.009	−0.004	0.000	−0.009*	0.000	−0.001	−0.002
	(0.003)	(0.006)	(0.010)	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)
SAT verbal	−0.023*	−0.041**	0.025	0.023	−0.01	−0.004	−0.016	0.000
	(0.012)	(0.017)	(0.024)	(0.015)	(0.014)	(0.012)	(0.012)	(0.009)
SAT math	−0.002	0.011	0.022	−0.081***	−0.009	0.021	−0.015	−0.004
	(0.011)	(0.015)	(0.025)	(0.022)	(0.015)	(0.016)	(0.016)	(0.011)
Fitness score	0.004	−0.009	0.015	0.018**	0.000	0.008	0.007	−0.001
	(0.007)	(0.010)	(0.020)	(0.008)	(0.012)	(0.009)	(0.009)	(0.006)
Female	−0.003	0.005	−0.034	0.067***	0.037	0.034*	−0.013	−0.012
	(0.012)	(0.023)	(0.026)	(0.019)	(0.025)	(0.020)	(0.016)	(0.011)
Observations	3,690	1,493	1,132	3,377	2,531	2,851	2,712	2,801
p-value: joint significance of all individual covariates	0.041	0.037	0.023	0.090	0.032	0.020	0.037	0.062

Notes: Each specification represents results for a regression where the dependent variable is an indicator for first period. The SAT verbal, SAT math, and academic composite, fitness score, and leadership composite variables were divided by 100 prior to running the regressions. All specifications include year indicators and an idicator for recruited athlete. Robust standard errors are clustered at the section by year level.

assignment to core courses at USAFA is random with respect to peer characteristics and professor experience, academic rank, and terminal degree status. Carrell, Marianne E. Page, and West (2010) find no correlation between student characteristics and professor gender.

To visualize how academic achievement changed across start time cohorts, we look at the distribution of achievement measures across cohorts in Figure 2. The distribution of scores in all class periods and first period courses shifts to the right with later start times. To assure us that the difference in scores across start time cohorts is not a result of differences in course difficulty across years, we look at the distribution of normalized grades as well. The same pattern holds for the normalized grade, wherein the later-start cohorts have a higher distribution of grades in all class periods and an even higher distribution of grades in first period courses compared to the earlier-start cohorts.

III. Methods and Results

The unique institutional characteristics of USAFA and the two policy changes in start time allow us to cleanly identify the causal effect of start time on academic

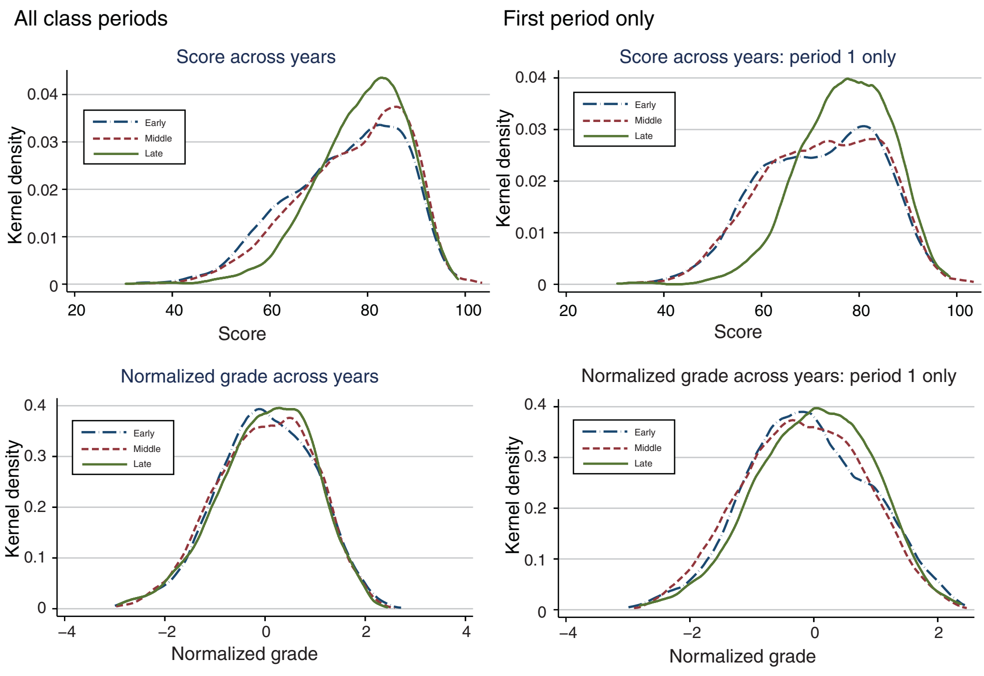

Figure 2. Distribution of Academic Outcomes by Start-Time Cohort

achievement. Importantly, the opposite direction of changes in the start of the academic day at USAFA over consecutive years helps assure that we are identifying the effects of start time versus trends in grading or course difficulty. We begin by examining whether being randomly assigned to a first period course affects overall academic achievement for students throughout the entire day. This analysis measures differences in achievement in all courses taken on the same schedule day as a first period class compared to achievement in courses taken on a schedule day without a first period class. We examine how this effect differs across the various start times in our sample (7:00, 7:30, and 7:50 AM). Since not all students are randomly assigned to a first period course on a given schedule day, we are able to identify these effects using variation both across and within individuals. When including individual fixed effects, we take advantage of the fact that with randomization some students are assigned a first period on one schedule day, but not the other. Finally, we extend this model to determine if the effects we find are driven by early morning courses or performance throughout the entire day.

A. *Methods*

To measure the causal effect of early start times on academic achievement, we estimate the following equation:

$$(1) \quad Y_{icjts} = \alpha + \beta F^1_{icts} + \delta_1 X_{ict} + \delta_2 \frac{\sum_{k \neq i} X_{kcqt}}{n_{cqt} - 1} + \phi_{cts} + \gamma_{jts} + \mu_i + \epsilon_{icjts},$$

where Y_{icjts} is the normalized grade for student i in course c with professor j in year t on schedule day s. F^1_{icts} is an indicator variable equal to one if student i has a first period course on the same schedule day s as course c in year t. β is our coefficient of interest and measures the average effect of being assigned a first period class on all course grades throughout that academic day. The vector X_{ict} includes the following student characteristics: SAT math and SAT verbal test scores, academic and leadership composites, fitness score, race, gender, the number of credit hours the student has on that schedule day[6], whether the student was recruited as an athlete[7], and whether he/she attended a military preparatory school. To control for classroom peer effects, we include $\sum_{k \neq i} X_{kcqt}/(n_{cqt} - 1)$, the average pre-treatment characteristics of all other peers in section q of course c except individual i. ϕ_{cts} are course by year by M/T day fixed effects and are included in all specifications to control for unobserved mean differences in academic achievement or grading standards across courses, years, and schedule days. In robustness specifications we add professor by year by M/T day fixed effects, γ_{jts}, to control for fixed differences in instructor quality within a given year. Importantly, these fixed effects help control for potentially tired professors in years they may have been assigned to teach an early morning course. We also include individual student fixed effects, μ_i, to exploit the within-student variation in daily schedules across M/T days. Standard errors are clustered by student.

Next, we alter equation (1) slightly to examine how the effects from being assigned to a first period course changed as USAFA altered the start time of the academic day:

$$(2) \qquad Y_{icjts} = \alpha + \beta_1 F^{1,E}_{icts} + \beta_2 F^{1,M}_{icts} + \beta_3 F^{1,L}_{icts} + \delta_1 X_{ict} + \delta_2 \frac{\sum_{k \neq i} X_{kcqt}}{n_{cqt} - 1} + \phi_{cts} + \gamma_{jts} + \mu_i + \epsilon_{icjts}.$$

$F^{1,E}_{icts}$ is an indicator variable equal to one if student i was enrolled in a first period class that started at 7:00 a.m on the same schedule day s as course c in year t. $F^{1,M}_{icts}$ indicates classes starting at 7:30 AM and $F^{1,L}_{icts}$ indicates classes starting at 7:50 AM. Our coefficients of interest are β_1, β_2, and β_3, which show the effects of having a first period class on the same schedule day as course c for the different start times.

B. *Results*

We begin by graphically noting differences in academic achievement for students who were and were not randomly assigned a first period class. Figure 3 shows that the distribution of normalized grades of students with a first period class is lower than that of students who did not have a first period class on a given schedule day.

[6] On average, students assigned to a first period class take one more credit hour (equivalent to one-third of a course) on that schedule day compared to students not assigned a first period class.

[7] In our main specifications we exclude recruited athletes from the sample; however, results in column 1 of Table 6 show our results are not sensitive to this restriction.

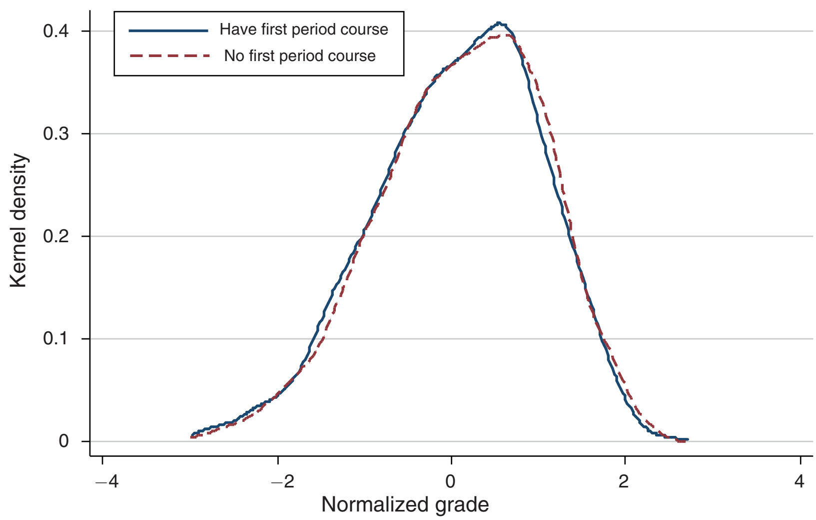

Figure 3. Distribution of Normalized Grades for all Courses by First Period Enrollment

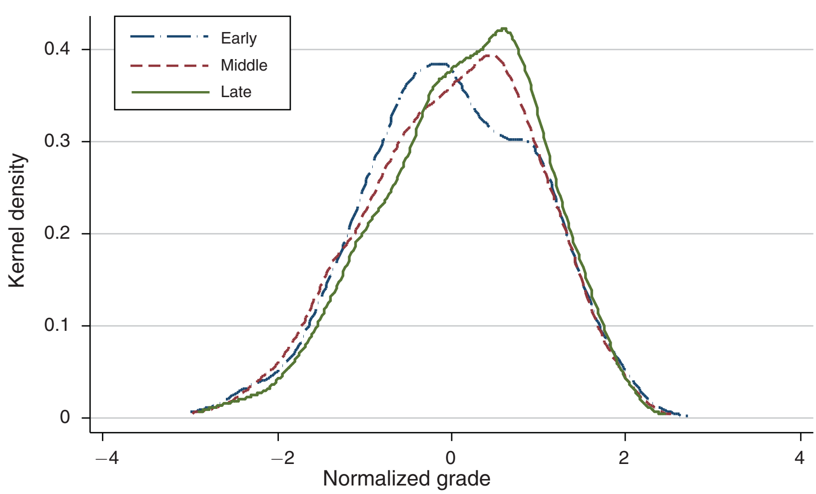

Figure 4. Distribution of Normalized Grades for all Courses by First Period Enrollment by Cohort

Figure 4 shows the distribution of grades of students with a first period class for the different start time cohorts. These figures suggest that the later first period begins, the higher the distribution of student grades.

Table 4 presents our estimates from equations (1) and (2). Columns 1–3 show the average effects from equation (1), while columns 4–6 show the effects by start time (equation (2)). Columns 2 and 5 include professor by year by M/T day fixed effects while columns 3 and 6 additionally control for student fixed effects. When including student fixed effects, the coefficients on $F^{1,\cdot}$ represent the within-student difference between average daily performance on days with a first period course, and average daily performance on days without a first period course. As noted earlier, this

Table 4—Effect of School Start Time on Academic Achievement Throughout the Day

	(1)	(2)	(3)	(4)	(5)	(6)
First period	−0.076***	−0.058**	−0.031			
	(0.021)	(0.022)	(0.027)			
7:00 AM first period				−0.139***	−0.140***	−0.116**
				(0.043)	(0.045)	(0.054)
7:30 AM first period				−0.084***	−0.052	−0.010
				(0.032)	(0.034)	(0.040)
7:50 AM first period				−0.023	−0.014	0.000
				(0.035)	(0.036)	(0.045)
Observations	11,851	11,851	11,851	11,851	11,851	11,851
R^2	0.228	0.280	0.816	0.228	0.280	0.817
Professor × year fixed effects	No	Yes	Yes	No	Yes	Yes
Student fixed effects	No	No	Yes	No	No	Yes

Notes: The dependent variable in each specification is the normalized grade in the course. First period is an indicator for whether the student had a first period class on the M/T day in which the course was taken. Robust standard errors in parentheses are clustered at the individual level. All specifications include course by year by M/T day fixed effects, peer effects controls, and individual controls. Individual-level controls include SAT verbal and math scores, academic composite, leadership composite, fitness score, the number of credit hours a student has on that M/T day, and indicators for students who are black, Hispanic, Asian, female, and attended a preparatory school. Athletes are excluded.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

analysis is made possible by the M/T Day schedules at USAFA in which a student may have a first period on one schedule day, but not have a first period on the other schedule day within the same semester.

Our estimates of β in columns 1–3 indicate that students who are randomly assigned to a first period course earn lower average grades in courses taken that day. The estimated average effect from being assigned a first period course is between $-.031$ and $-.076$ standard deviations. Results in columns 4–6 show that this negative effect is largest in absolute value the earlier first period begins. For example, estimates in column 5, when including professor fixed effects, show that students who are assigned to a first period course perform a statistically significant 0.140 standard deviations lower on average for the 7:00 AM start time, but only a statistically insignificant 0.014 standard deviations lower for the 7:50 AM start time. These effects are robust to the inclusion of individual student fixed effects in column 6.

These results reveal two important findings. First, they suggest that being assigned to a first period course has a negative and statistically significant effect on student achievement. Second, this negative effect diminishes and becomes statistically insignificant as the start time moves from 7:00 AM to 7:50 AM. These findings are consistent with the sleep literature that shows adolescent levels of melatonin production peak at 7 AM and stop at about 8 AM.

One important policy question is whether the effects we find are solely driven by poor performance in the first period course or performance throughout the entire day. The former could simply be a "wake-up" effect for students or from tired professors. Knowing this distinction is also important for determining optimal policy

Table 5— First Period versus Later Period Effects

	(1)	(2)	(3)	(4)	(5)	(6)
First period class	−0.092***	−0.071**	−0.100***			
	(0.026)	(0.034)	(0.038)			
First period × non-first period class	−0.067***	−0.054**	−0.01			
	(0.024)	(0.023)	(0.029)			
7 AM first period class				−0.150***	−0.124**	−0.159**
				(0.049)	(0.063)	(0.074)
7 AM first period × non-first period class				−0.131***	−0.147***	−0.099*
				(0.049)	(0.048)	(0.057)
7:30 AM first period class				−0.117***	−0.079	−0.128**
				(0.038)	(0.056)	(0.058)
7:30 AM first period × non-first period class				−0.063*	−0.046	0.021
				(0.035)	(0.035)	(0.042)
7:50 AM first period class				−0.012	−0.029	−0.030
				(0.043)	(0.055)	(0.064)
7:50 AM first period × non-first period class				−0.031	−0.010	0.010
				(0.038)	(0.038)	(0.047)
Observations	11,851	11,851	11,851	11,851	11,851	11,851
R^2	0.228	0.280	0.817	0.228	0.280	0.817
Professor × year fixed effects	No	Yes	Yes	No	Yes	Yes
Student fixed effects	No	No	Yes	No	No	Yes

Notes: The dependent variable in each specification is the normalized grade in the course. First period class is an indicator for whether the course was during first period. First period × non-first period class is an indicator for whether the student had a first period class on the M/T day in which that course was taken. Robust standard errors in parentheses are clustered at the individual student level. All specifications include course by year by M/T day fixed effects, peer effects controls, and individual controls. Individual-level controls include SAT verbal and math scores, academic composite, leadership composite, fitness score, the number of credit hours a student has on that M/T day, and indicators for students who are black, Hispanic, Asian, female, and attended a preparatory school. Athletes are excluded.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

responses. That is, whether schools should alter the start time of the academic day or simply offer more non-academic courses such as physical education during the early morning hours.

To help answer this question we estimate equations (1) and (2) while interacting the treatment variable (enrollment in a first period course on that schedule day) with whether or not the course was during first period or one of the other periods in that same day. Results are shown in Table 5. Across all specifications, the results suggest that the negative effects of early start times are driven by lower academic performance throughout the entire day. Students perform significantly worse in first period courses as well as non-first period courses and these effects are statistically indistinguishable in all specifications. Importantly, the evidence suggests that our results are not likely driven by tired professors who are assigned to teach during the early morning hours. That is, it seems implausible that a tired professor teaching first period in one course could negatively affect a students' later-period course performance in an unrelated subject.

Table 6—Robustness Checks

	Including athletes (1)	Females excluded (2)	Chem 141 excluded (3)	Afternoon excluded (4)	History and English included (5)	2004–2006 only (6)	2005–2007 only (7)	2006–2008 only (8)
7:00 AM first period	−0.109***	−0.127**	−0.187***	−0.173***	−0.122***	−0.139***	−0.126***	−0.140***
	(0.039)	(0.051)	(0.051)	(0.047)	(0.04)	(0.045)	(0.05)	(0.05)
7:30 AM first period	−0.049*	−0.071*	−0.057	−0.057	−0.037	−0.051	−0.026	—
	(0.029)	(0.038)	(0.037)	(0.036)	−0.03	(0.034)	(0.04)	—
7:50 AM first period	−0.018	−0.016	−0.042	−0.021	−0.038	—	−0.043	−0.014
	(0.031)	(0.041)	(0.039)	(0.039)	(0.03)	—	(0.05)	(0.04)
Observations	15,074	9,605	8,306	9,857	16,119	7,927	7,426	6,530
R^2	0.285	0.278	0.266	0.288	0.249	0.291	0.272	0.275
Professor × year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Student fixed effects	No	No	No	No	No	No	No	No

Notes: The dependent variable in each specification is the normalized grade in the course. First period is an indicator for whether the student had a first period class on the M/T day in which the course was taken. Robust standard errors in parentheses are clustered at the individual level. All specifications include course by year by M/T day fixed effects, peer effects controls, and individual controls. Athletes are excluded, except in column 1. Individual-level controls include SAT verbal and math scores, academic composite, leadership composite, fitness score, the number of credit hours a student has on that M/T day, and indicators for students who are black, Hispanic, Asian, female, and attended a preparatory school.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

C. *Robustness Checks*

We verify the robustness of our estimates to several changes in model specification with results shown in Table 6. All specifications include a full set of individual controls and professor by year by M/T day fixed effects. Column 1 shows our models with the inclusion of recruited athletes, while columns 2 and 3 sequentially exclude females and observations from Chemistry 141. Column 4 shows results when excluding afternoon courses to address concerns that the make-up of students in morning courses may be different than those in afternoon courses as a result of the stratified randomization. In column 5, our model includes the humanities courses we excluded from our main specifications because of the concern that grades in these classes are mostly determined by papers and assignments done outside the classroom. Lastly, we narrow the years that we consider. We have three specifications with narrowed years: 2004–2006, 2005–2007, and 2006–2008. Restricting our sample to 2004–2006 (column 6) shows just the effect of the first start time change from 7:30 AM to 7:00 AM 2005–2007 (column 7), restricts the sample to the years immediately surrounding the two policy changes, and 2006–2008 (column 8) isolates the second start time change from 7:00 to 7:50 AM. The estimates from our robustness specifications are qualitatively similar to those from our main specification, and provide strong evidence that our results are not driven by anomalies in the data.

IV. Discussion

While we have found a positive causal relationship between start time and academic performance for the students at USAFA, it's also important to understand why such a relationship would exist. For this, we look to evidence from sleep experts. There are two main sleep factors that affect mental performance. The first is the duration (number of hours) of sleep, known as process S. The second is the time of day one is expected to function, known as process C. Process C is related to the circadian timing; regardless of the duration of sleep, there are times of the day when a person is more and less alert. For adolescents, alertness begins in the late morning, drops off mid-afternoon, and peaks again in the early evening.

It's clear to see the role process C plays in poor academic performance in early classes. However, understanding the role process S plays in our study is more difficult, as USAFA does not collect data on students' hours of sleep. Thus, we have no statistical evidence of sleep time differences between students with and without first period classes. Instead, we draw from related studies and anecdotal evidence to understand what differences might exist. Sleep research has been done at the US Military Academy in West Point, NY, where the daily schedule is very similar to that of USAFA during the 7:30 AM start time regime. These studies find that first year students sleep an average of 5.5 hours per night, far less than the 8.5–9.5 hours of sleep most adolescents need (Nita Lewis Miller et al. 2008, Aileen Kenney and Daniel Thomas Neverosky 2004). This was also three hours less than the average amount of sleep the students reported getting before the start of cadet basic training, which implies that the students were sleep deprived. We anticipate that sleep patterns are similar at USAFA, but that there may be differences in hours of sleep for students with and without a first period class.

All students at USAFA are required to attend breakfast 25 minutes before first period begins, thus we speculate that all students wake up at approximately the same time. After breakfast, some students go straight to class while those who start classes later in the day spend their time studying or napping, even though napping is prohibited at USAFA. The fact that some students nap is important for two reasons. First, the extra sleep will make the students better rested, which may benefit them throughout the day. Second, the desire and ability to nap (even when it's against the rules) reflects the students' need for sleep and likely sleep deprivation. Although we do not know what time students go to sleep, it is possible that students with a first period may be staying up later to complete assignments due during first period, whereas, students without first period wait and complete these assignments in the morning. This evidence implies that there may also be a difference in the total hours of sleep that students with and without a first period course obtain. However, this fact is unverifiable in our data.

Academic performance for all students is affected by both processes S (duration of sleep) and C (timing of activities). Students with a first period class are disadvantaged for two reasons. First, they are in class at a time that their body wants to be asleep, which both makes it difficult to learn and fatigues the brain. Second, they may be getting less sleep than their peers who napped during first period. Thus, the positive effect of later start times we find is reflective of the synchronization of learning to optimal times of day and possibly also increased amounts of sleep. An important aspect of this study is that grades at USAFA are standardized within a course-semester. That is, a student's grade in a course is determined by the scores of everyone taking the course, regardless of which period they are taking it. Our measures of the effect of start time are determined by how students who start the day at first period perform in their courses relative to those who start later and have improved timing of learning and potentially more sleep. Because not all students at USAFA begin class at the same time, we cannot determine the effect of all students having an earlier or later start time. In contrast, Wahistrom's (2002) analysis of the Minneapolis start time change examines the effect of all students beginning school later in the morning. To do so, she compares the letter grades earned by a student before and after the start time change. Changes in student performance across start time regimes in that study would be a result of improvements in sleep amounts and timing of learning (process S and C). However, because all students face the same improvements, relative performance across all students may not change. The students who earn Bs may still earn Bs even through they've learned more, because their peers have also improved.[8] Thus, it would appear as if start time had little or no effect on achievement.

V. Conclusion

Across the country, debates about school start time are surfacing. While sleep researchers find that later start times are beneficial for adolescent learning, many argue there is not enough evidence on the benefits of later start time to warrant making such a change. Researchers have attempted to answer the question of how start time affects student achievement; however, to this point determining the causal effects of start time on student achievement has been difficult due to issues related to self-selection and measurement error.

This study identifies the causal effect of school start time on student academic achievement using data from the USAFA to take advantage of the randomized assignment of students to courses and instructors as well as two policy changes in the school start time over a three-year period. Random assignment, mandatory attendance, along with extensive background data on students, allows us to examine how school start time affects student achievement without worrying about confounding factors or self-selection issues that bias existing estimates. USAFA's grading structure for core courses allows for a consistent measure of student achievement; faculty members teaching the same course in each semester use an identical syllabus and give the same exams during a common testing period, allowing for standardized grades within a course-semester.

We find that early school start times negatively affect student achievement—students randomly assigned to a first period course earn lower overall grades in their classes on the same schedule day compared to students who are not assigned a first period class on that day. We verify that this negative effect is not solely a result of

[8] We mention other issues with grading methods in these studies earlier in the paper.

poor performance during first period courses. Although students perform worse in first period classes compared to other periods, those with first period classes also perform worse in their subsequent classes on that schedule day. These estimates are robust to professor by year by M/T day fixed effects and individual student fixed effects.

Our findings have important implications for education policy; administrators aiming to improve student achievement should consider the potential benefits of delaying school start time. A later start time of 50 minutes in our sample has the equivalent benefit as raising teacher quality by roughly one standard deviation. Hence, later start times may be a cost-effective way to improve student outcomes for adolescents.

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