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HOW THE TIME OF DAY AFFECTS PRODUCTIVITY: EVIDENCE FROM SCHOOL SCHEDULES

Nolan G. Pope*

Abstract—Increasing the efficiency of the school system is a primary focus of policymakers. I analyze how the time of day affects students' productivity and if efficiency gains can be obtained by rearranging the order of tasks they perform throughout the school day. Using a panel data set of nearly 2 million sixth- through eleventh-grade students in Los Angeles County, I perform within-teacher, class type, and student estimation of the time-of-day effect on students' learning as measured by GPA and state test scores. I find that given a school start time, students learn more in the morning than later in the school day. Having a morning instead of afternoon math or English class increases a student's GPA by 0.072 (0.006) and 0.032 (0.006), respectively. A morning math class increases state test scores by an amount equivalent to increasing teacher quality by one-fourth standard deviation or half of the gender gap. Rearranging school schedules can lead to increased academic performance.

I. Introduction

COMPANIES, schools, hospitals, and other organizations are always looking for innovations that increase productivity with little to no increase in inputs. History has proven that simple innovations such as assembly lines, crop rotation, washing hands, changes in incentive structures, and other simple managerial practices have been successful at increasing efficiency. By using such methods, companies increase their profits, hospitals improve patient outcomes, and schools produce more academically prepared students.

In this paper, I propose a simple innovation that schools can use to improve student performance: rearranging schedules to take advantage of time-of-day effects. I use detailed, student-level panel data from the Los Angeles Unified School District for 1.8 million student-year observations. The data include the complete class schedule, grades, and California Standards Test (CST) scores for all sixth- through eleventh-grade students from 2003 to 2009.

The fundamental challenge in estimating time-of-day effects is that class assignments are not random. Certain teachers or subjects might selectively be placed at certain times of day. The panel nature of the data allows me to control for individual characteristics, and the main results are estimated within teacher, class type, and student. The data allow previous years' GPA and test scores to be used as clear falsification tests. These falsification tests, with the notable exception of English GPA, also support a causal interpretation of the results.

I find that having math in the first two periods of the school day instead of the last two periods increases the math GPA of students by 0.072 (0.006) and increases math CST scores by 0.021 (0.003) standard deviations. These effect sizes are equivalent to increasing teacher quality by one-fourth standard deviation or half of the gender gap (Rockoff, 2004; Hyde et al., 2008). Similarly, having English in the morning increases the English GPA of students by 0.032 (0.006); however, there is no increase in their English CST score. There are no clear systematic differences in the time-of-day effect between boys and girls, older and younger students, students with high- and low-educated parents, or low- and high-performing students. The time-of-day effect may be caused by changes in teachers' teaching quality, changes in students' learning ability, or differential student attendance. The time-of-day effect may be interpreted as differential productivity during different parts of the day due to the circadian rhythm; stamina effects, with decreasing productivity the longer a student is at school; or school structure effects such as lower productivity after a lunch break.

The finding that productivity is higher in the morning than the afternoon allows for efficiency gains to be obtained. There are two dimensions in which students and schools can move along to create efficiency gains. The first is by moving tasks and classes that are more affected by the time of day to the morning and moving other tasks and classes to the afternoon. The results show that moving some math classes to the morning and other classes, like English, to the afternoon could increase students' GPA and test scores. The second dimension to create efficiency gains is by moving classes believed to be more important by individuals or schools to the morning. Constraints on the supply of teachers in a given subject limit how much middle schools and high schools can move along both of these dimensions. These constraints are less binding for elementary schools.

This paper contributes to three distinct literatures. The first literature focuses on workplace productivity. Despite the substantial research on productivity variation due to health, workplace environment, and compensation (Stewart et al., 2003; Fisk, 2000; Lazear, 2000), little research looks at how productivity varies throughout the workday. This work has mostly focused on changes in productivity and safety between

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* University of Chicago.

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day and night shifts (Levin, Oler, & Whiteside, 1985; Wharf, 1995). Folkard & Tucker (2003) find that productivity and safety decline during the night shift. Smith, Folkard, and Poole (1994) find a 23% increase in injuries at night. Many studies have found that sleep deprivation in medical residents decreases performance (Philibert, 2005; Weinger and Ancoli-Israel 2002, and Veasey et al., 2002). However, little research has looked at how productivity varies within a given shift.

My study is also related to the school start time literature. Research has indicated that due to changing sleep patterns during adolescence, academic gains can be achieved by starting school later. Carrel, Maghakian, and West (2011) use random assignment of college classes and find that having one hour earlier start times decreases students' GPA by 0.031 to 0.076 standard deviations. Similarly, Dills and Hernandez-Julian (2008) find that even when controlling for course and student characteristics, students perform worse in earlier classes. Edwards (2012) uses variation in school start times produced by staggered busing schedules and finds that starting school an hour later increases test scores by 2 percentage points.

Some have interpreted the finding that later school start times increase students' academic performance as implying that given a school start time, students perform better in the afternoon than in the morning (Carrel et al., 2011; Dills & Hernandez-Julian, 2008). However, this hypothesis has not been tested empirically. The common conclusion is that later start times increase students' achievement because students are less sleep deprived. However, this says nothing about how teaching and learning ability change throughout the day. School start times affect the average learning in a day but not differential learning throughout the day. Therefore, the results of this paper and the school start time literature estimate slightly different effects.

The third strand of literature deals with the circadian rhythm, a biological process that governs the production of the sleep-inducing hormone melatonin and therefore controls individuals' sleep-wake cycles. For the average adult, the secretion of melatonin starts around 9:00 p.m., peaks between 2:00 and 4:00 a.m., and stops around 7:30 a.m. In adolescents this time schedule is typically shifted two hours later in the day (Cardinali, 2008; Carskadon, Vieira, & Acebo, 1993). The circadian rhythm literature indicates that adolescents' activity level is higher in the afternoon than the morning (Crowley, Acebo, & Carskadon, 2007; Wolfson and Carskadon, 1998). Biologists have long been interested in the effect of the circadian rhythm on simple tasks (Gates, 1916; Laird, 1925; Kleitman, 1963; Lavie, 1980). However, the time-of-day effect on the performance of laboratory and field tasks varies drastically, even for similar tasks (Folkard, 1975; Blake, 1967; Folkard et al., 1976). Folkard (1983) summarizes this confusion: "Perhaps the main conclusion to be drawn from studies on the effects of time of day on performance is that the best time to perform a particular task depends on the nature of that task" (p. 266).

II. Data and Methodology

A. Data Description

This analysis uses student-level panel data of students in sixth to eleventh grade from the Los Angeles Unified School District (LAUSD). The data contain 1.8 million student-year observations from 2003 to 2009. In the LAUSD, 72% of students are Hispanic. The data contain students' gender, grade, parents' education, English Language Learner (ELL) status, teacher, course name, and course period to be used as control variables. In addition, California Standards Test (CST) English Language Achievement scores, CST math scores, and individual course GPA are available as academic outcome measures.

The CST is a high-stakes statewide multiple-choice test given to all California students in grades 2 through 11. The test is administered each spring to all students at the same time of the day as determined by individual schools. The English and math portions consist of two 90-minute parts. Students are given a grade of A, B, C, D, or F for each class every semester. I normalize both English and math CST scores and report all effects in standard deviation units. The GPA is measured on a 0 to 4 scale (e.g., A = 4.0, B = 3.0).

Summary statistics are presented in table 1. The difference column shows the difference in the variables' means. The raw data show that math and English GPA are about 0.1 GPA points higher in the first two periods than the last two periods. Similarly, math and English CST scores are 0.073 and 0.061 standard deviations higher for students in morning classes.

B. Background

The majority of middle schools and high schools in the LAUSD have a six-period class schedule. I restrict the sample to schools with this schedule and students who registered for full school days. The typical school starts around 8:00 a.m. and follows the pattern of periods 1 and 2, a nutrition break, periods 3 and 4, lunch, and then periods 5 and 6. Each school' period length ranges from 50 to 60 minutes, and schools often have a 20 to 30 minute home room at the beginning or end of the school day—for example, period 1: 8:00 to 8:55 a.m.; period 2: 9:00 to 9:55 a.m.; nutrition: 9:55 to 10:15 a.m.; period 3: 10:20 to 11:15 a.m.; period 4: 11:20 a.m. to 12:15 p.m.; lunch: 12:15 to 12:45 p.m.; period 5: 12:50 to 1:45 p.m.; period 6: 1:50 to 2:45 p.m.; and homeroom: 2:50 to 3:10 p.m. A small minority of six-period-schedule schools have a block schedule with the following pattern: period 1 or 2: 8:00 to 9:50 a.m.; nutrition: 9:50 to 10:10 a.m.; period 3 or 4: 10:20 a.m. to 12:10 p.m.; lunch: 12:10 to 12:40 p.m.; period 5 or 6: 12:50 to 2:40 p.m.; and homeroom: 2:50 to 3:10 p.m.

In the LAUSD, students in sixth through eighth grade are required to take a math and English class each year. High school students are required to take four years of English and two years of math in order to graduate. I restrict the math

TABLE 1.—SUMMARY STATISTICS

Variable	Periods 1 and 2 Mean	Periods 1 and 2 SD	Periods 5 and 6 Mean	Periods 5 and 6 SD	Difference
Math GPA	2.02	1.23	1.91	1.24	0.11
Math CST Score	309.76	61.80	304.49	59.50	5.27
English GPA	2.30	1.20	2.20	1.22	0.10
English CST Score	334.32	53.19	331.04	52.59	3.28
Female	0.51	0.50	0.51	0.50	0.00
Less than HS	0.19	0.40	0.20	0.40	−0.01
HS Grad	0.15	0.36	0.15	0.35	0.00
Some College	0.10	0.30	0.09	0.29	0.01
College Grad	0.09	0.28	0.08	0.28	0.01
College Plus	0.03	0.18	0.03	0.17	0.00
No Educ Response	0.29	0.46	0.30	0.46	−0.01
ELL	0.21	0.41	0.23	0.42	−0.01
Number of individuals	519,960		450,513		

class sample to students who are enrolled in only one math class. Since the school year is broken into two semesters, that sample is also restricted to students whose one math class is taught by the same teacher in the same period over the two semesters. The English class sample is analogously restricted.

C. *Methodology*

Due to the richness of the data, a simple analysis can reveal much about how having a class in a given period affects academic outcomes. The baseline analysis uses the following model:

$$S_{i,t} = \alpha + \beta Morning_{i,0} + \delta P_{i,t-1} + \pi X_{i,t} + \eta G_{i,t} + \gamma TC_{i,t} + \mu_t + \varepsilon_{i,t}, \tag{1}$$

where $S_{i,t}$ is the academic outcome of interest, math GPA, math CST score, English GPA, or English CST score, of individual i in year t. $Morning_{i,0}$ is a binary variable that is equal to 1 if individual i in year $t = 0$ has the relevant math or English class in period 1 or 2, and equal to 0 if in period 5 or 6. Students with the relevant class in period 3 or 4 are omitted from this analysis. Therefore, the coefficient on $Morning_{i,0}$ compares the academic outcome of interest for students with the relevant class in period 1 or 2 to students with the relevant class in period 5 or 6. The choice of comparing periods 1 and 2 to period 5 and 6 emphasizes the difference between morning and afternoon classes and consolidates the time-of-day effect into a single estimate that is simple to interpret. However, this choice is somewhat arbitrary, and figure 2 will show the results for each individual period. The vector $P_{i,t-1}$ contains individual controls for the previous year's CST scores and relevant subject GPA. The vector $X_{i,t}$ contains demographic controls including gender parental education level, and ELL status. The vectors $G_{i,t}$, $TC_{i,t}$, and μ_t allow for grade, teacher by class type (e.g., Mr. John Smith by Geometry), and year fixed effects. Finally, $\varepsilon_{i,t}$ is a random error term. When performing all analyses, the variable $Morning_{i,0}$ is always in year $t = 0$ (the year in which the student has a morning or afternoon class). To begin the analysis, the academic outcome variable $S_{i,t}$ will also be in the year $t = 0$; however, later I allow $t < 0$ and $t > 0$ to perform falsification tests and to look at the persistence of the effects.

I also perform the analysis by first differencing the academic outcome variable of interest to explicitly control for individual effects. This model is as follows:

$$\Delta S_{i,t} = \alpha + \beta Morning_{i,0} + \delta P_{i,t-1} + \pi X_{i,t} + \eta G_{i,t} + \gamma TC_{i,t} + \mu_t + \varepsilon_{i,t}, \tag{2}$$

where $\Delta S_{i,t} = S_{i,t} - S_{i,t-1}$. All independent variables are identical to equation (1) except $P_{i,t-1}$, which excludes the prior year's academic variable being used as the dependent variable. Using this model removes any individual component and therefore corrects for any selection of higher-achieving students into either morning or afternoon classes. It also allows for trends by demographic characteristics. This model is used instead of a student fixed-effect model because if the morning effect is persistent, then the student fixed-effect model will be biased downward. The student fixed-effect model estimates are noticeably smaller (see table 6).

III. Results

D. *Main Results*

The results section is organized as follows. First, I estimate the effect of morning versus afternoon classes on GPA and CST scores using equations (1) and (2). Second, I plot estimates of equation (1) from three years before to four years after the $t = 0$ year. Next, I analyze within the $t = 0$ year and map out productivity throughout a school day. I then look at how the time-of-day effect differs by gender, age, parental education level, and ability level of the student. Finally, I use robustness checks and falsification tests to verify the results.

Table 2 shows the estimates of equations (1) and (2) for math GPA and CST scores. Columns 1 and 6 show the difference in the mean math GPA and math CST scores between students with math in periods 1 and 2 and those in periods 5

TABLE 2.—EFFECT OF MORNING VERSUS AFTERNOON MATH CLASSES

	Math GPA					Math CST Score				
Variables	(1)	(2)	(3)	(4)	(5) $\Delta MathGPA_{i,t}$	(6)	(7)	(8)	(9)	(10) $\Delta MathCST_{i,t}$
Morning Class	0.114***	0.057***	0.060***	0.068***	0.072***	0.071***	0.016***	0.023***	0.024***	0.021***
	[0.008]	[0.007]	[0.007]	[0.005]	[0.006]	[0.008]	[0.004]	[0.004]	[0.003]	[0.003]
Prior Math CST Score		0.316***	0.315***	0.426***	0.019***		0.624***	0.542***	0.458***	
		[0.004]	[0.004]	[0.003]	[0.004]		[0.003]	[0.003]	[0.002]	
Prior English CST Score		0.112***	0.116***	0.155***	0.102***		0.109***	0.166***	0.143***	−0.070***
		[0.003]	[0.003]	[0.003]	[0.003]		[0.002]	[0.002]	[0.001]	[0.002]
Prior Math GPA		0.440***	0.432***	0.425***			0.048***	0.051***	0.078***	−0.020***
		[0.002]	[0.002]	[0.002]			[0.001]	[0.001]	[0.001]	[0.001]
Female			0.112***	0.123***	−0.032***			−0.054***	−0.058***	0.023***
			[0.003]	[0.003]	[0.004]			[0.002]	[0.002]	[0.002]
Less than HS			−0.009*	−0.021***	−0.021***			−0.008***	−0.008***	−0.008***
			[0.005]	[0.004]	[0.005]			[0.003]	[0.002]	[0.002]
HS Grad			−0.011*	−0.016***	−0.016***			−0.002	−0.010***	−0.007**
			[0.006]	[0.005]	[0.006]			[0.003]	[0.002]	[0.003]
Some College			−0.001	0.008	0.016**			0.017***	−0.008***	−0.002
			[0.006]	[0.005]	[0.006]			[0.003]	[0.003]	[0.003]
College Grad			0.053***	0.079***	0.045***			0.083***	0.021***	0.011***
			[0.007]	[0.006]	[0.007]			[0.004]	[0.003]	[0.004]
College Plus			0.062***	0.082***	0.061***			0.118***	0.033***	0.017***
			[0.009]	[0.008]	[0.009]			[0.006]	[0.005]	[0.005]
ELL			0.038***	0.011**	0.015**			0.015***	−0.007***	0.009***
			[0.007]	[0.005]	[0.006]			[0.003]	[0.002]	[0.003]
Grade FE			X	X	X			X	X	X
Year FE			X	X	X			X	X	X
Course by Teacher FE				X	X				X	X
Number of observations	651,836	410,903	410,903	410,903	411,257	640,893	404,632	404,632	404,632	404,632
R^2	0.002	0.391	0.398	0.524	0.197	0.002	0.604	0.632	0.708	0.177

Columns 1 to 4, and 6 to 9, use the model in equation (1) for math GPA and math CST scores, respectively. Columns 5 and 10 use the model in equation (2). Morning class is a binary variable equal to 1 if the individual's math class is in period 1 or 2 and 0 if in period 5 or 6. The excluded parental education binary variable is no response. Standard errors clustered at the classroom level are in brackets. Statistical significance is shown by $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

TABLE 3.—EFFECT OF MORNING VERSUS AFTERNOON ENGLISH CLASSES

	English GPA					English CST Score				
Variables	(1)	(2)	(3)	(4)	(5) $\Delta EngGPA_{i,t}$	(6)	(7)	(8)	(9)	(10) $\Delta EngCST_{i,t}$
Morning Class	0.103***	0.035***	0.037***	0.044***	0.032***	0.061***	0.006*	0.008***	0.003	−0.001
	[0.008]	[0.007]	[0.007]	[0.005]	[0.006]	[0.008]	[0.003]	[0.003]	[0.002]	[0.002]
Prior Math CST Score		0.118***	0.162***	0.199***	0.049***		0.214***	0.195***	0.176***	−0.027***
		[0.004]	[0.003]	[0.003]	[0.003]		[0.002]	[0.002]	[0.002]	[0.002]
Prior English CST Score		0.252***	0.215***	0.264***	0.109***		0.694***	0.687***	0.634***	
		[0.003]	[0.003]	[0.003]	[0.003]		[0.002]	[0.002]	[0.002]	
Prior English GPA		0.483***	0.455***	0.437***			0.057***	0.050***	0.050***	0.011***
		[0.002]	[0.002]	[0.002]			[0.001]	[0.001]	[0.001]	[0.001]
Female			0.227***	0.239***	0.009**			0.048***	0.040***	0.006***
			[0.004]	[0.003]	[0.004]			[0.002]	[0.002]	[0.002]
Less than HS			−0.007	−0.013***	−0.012**			−0.015***	−0.007***	−0.001
			[0.006]	[0.005]	[0.005]			[0.003]	[0.003]	[0.003]
HS Grad			0.014**	0.015***	0.013**			0.002	0.001	−0.001
			[0.006]	[0.005]	[0.006]			[0.003]	[0.003]	[0.003]
Some College			0.020***	0.034***	0.032***			0.025***	0.014***	−0.001
			[0.006]	[0.005]	[0.006]			[0.003]	[0.003]	[0.004]
College Grad			0.091***	0.113***	0.045***			0.063***	0.037***	0.009**
			[0.007]	[0.006]	[0.007]			[0.004]	[0.004]	[0.004]
College Plus			0.106***	0.132***	0.064***			0.090***	0.053***	0.010*
			[0.009]	[0.008]	[0.009]			[0.005]	[0.005]	[0.006]
ELL			−0.021***	−0.055***	0.001			−0.144***	−0.139***	0.023***
			[0.008]	[0.006]	[0.007]			[0.003]	[0.003]	[0.003]
Grade FE			X	X	X			X	X	X
Year FE			X	X	X			X	X	X
Course by Teacher FE				X	X				X	X
Number of observations	550,446	367,574	367,574	367,574	367,952	547,402	366,000	366,000	366,000	366,000
R^2	0.002	0.37	0.389	0.518	0.192	0.001	0.686	0.701	0.726	0.104

Columns 1 to 4, and 6 to 9, use the model in equation (1) for English GPA and English CST scores, respectively. Columns 5 and 10 use the model in equation (2). Morning class is a binary variable equal to 1 if the individual's English class is in period 1 or 2 and 0 if in period 5 or 6. The excluded parental education binary variable is no response. Standard errors clustered at the classroom level are in brackets. Statistical significance is shown by $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

and 6. When the prior year's English and math CST scores and math GPA are added as controls in columns 2 and 7, the estimates shrink substantially, which shows some selection of higher-performing students into morning math and English classes. This decrease in the estimates between columns 1 and 6 and columns 2 and 7 may come from how advanced math and English classes are scheduled. Students with an Advanced Placement (AP) class are 2.82 times more likely to have their AP math or English class in period 1 or 2 than in period 5 or 6, compared to 1.13 times for students with other math and English classes. This class scheduling fact, combined with the fact that students with AP courses have higher GPAs and test scores, may be the cause of this substantial decrease in the estimates.

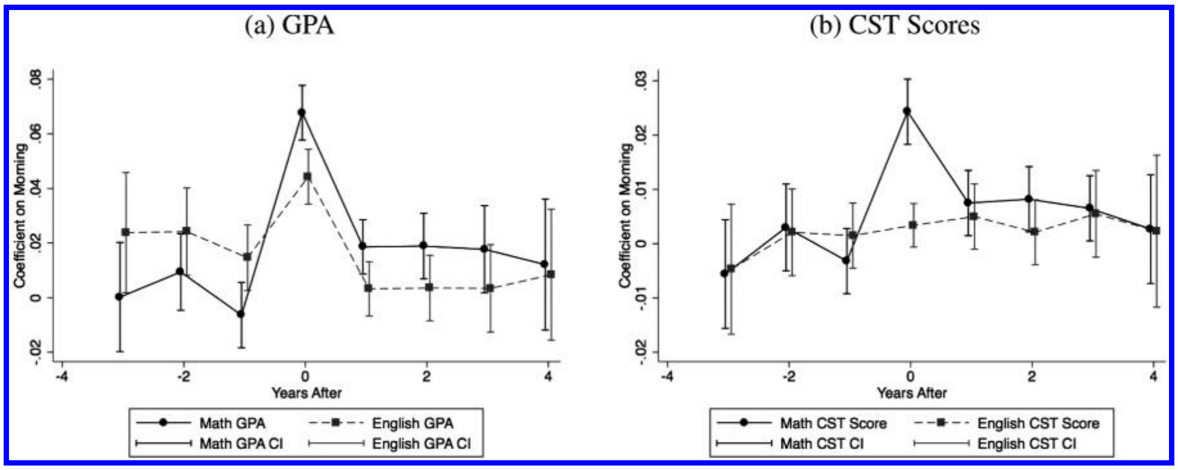
When gender, parental education, ELL status, grade fixed effects, year fixed effects, and teacher-course fixed effects are added in columns 3 to 4 and 8 to 9, the estimates move a reasonable amount. With the full set of controls, the estimate of having a morning instead of an afternoon class increases a student's math GPA by 0.068 (0.005) points and CST scores by 0.024 (0.003) standard deviations. These effect sizes are roughly equivalent to half of the gender gap in math (Hyde et al., 2008). Additionally, a 0.024 standard deviation increase in math CST scores is equivalent to the increase in standardized test scores associated with increasing a student's teacher quality by a quarter of a standard deviation (Rockoff, 2004). Using the estimates from Carrel et al. (2011), moving a student's math class from the afternoon to the morning increases the student's math GPA by the same amount as moving the student's school start time back one hour.

Columns 5 and 10 explicitly control for individual selection into morning classes by first differencing the outcome variable. The estimates in columns 5 and 10 change some from the full model estimates. The coefficient on $Morning_{i,0}$ from equation (2) is 0.072 (0.006) for math GPA and 0.021 (0.003) for math CST scores. It is noticeable that although all the estimates are statistically significant for each of the specifications, the magnitudes do vary substantially.

Analogous to table 2, table 3 shows the estimates of equations (1) and (2) for English. Estimates of the effect of having a morning rather than afternoon English class on English GPA for equations (1) and (2) are 0.044 (0.005) and 0.032 (0.006), respectively. These estimates are about half the size of the effect on math GPA. The models from equations (1) and (2) find no effect of morning versus afternoon class on English CST scores. The English GPA estimates are somewhat volatile, but all are statistically significant.

To better understand the effect of morning versus afternoon classes on academic outcomes, I now allow the year t on the variables $S_{i,t}$ and $\Delta S_{i,t}$ to vary from 0. The variable $Morning_{i,0}$ is still always in year $t = 0$ (the year in which the student has a morning or afternoon class), but the academic outcome variables will have three cases: $t = 0, t > 0$, and $t < 0$. The $t = 0$ case, used previously, answers the basic question of

FIGURE 1.—DYNAMIC EFFECT OF MORNING VERSUS AFTERNOON CLASSES



Both panels display estimates of the effect of morning versus afternoon classes in the year $t = 0$ on outcome variables in the year relative to $t = 0$. All estimates use equation (1), shown in columns 4 and 9 in tables 2 and 3, and classroom-level clustered standard errors. The $t < 0$ years are falsification tests. The $t = 0$ year is the effect of morning versus afternoon classes. The $t > 0$ years are the persistence of the effect. Morning is a binary variable equal to 1 if the individual's pertinent math or English class is in period 1 or 2 and 0 if in period 5 or 6.

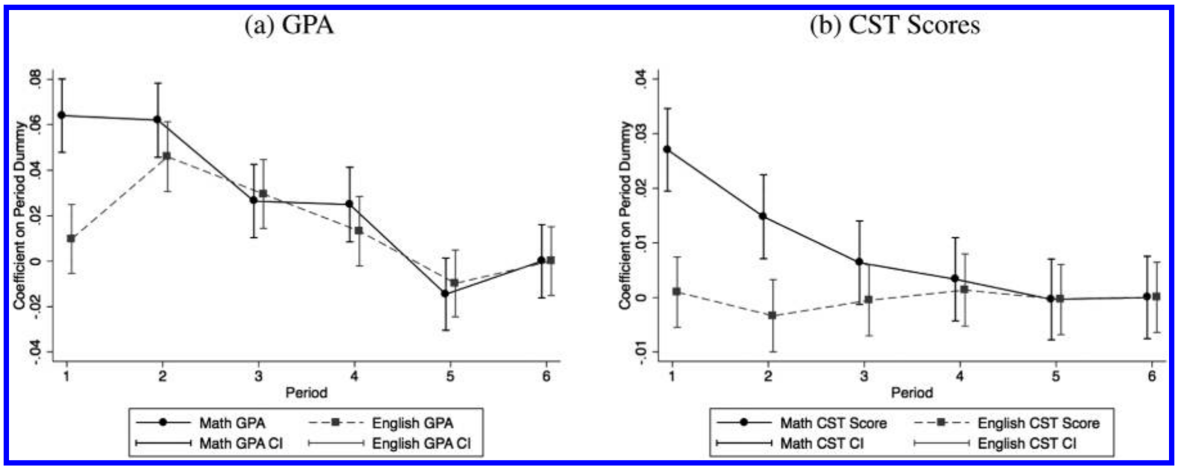
interest of how having a class in a morning versus afternoon periods affects contemporaneous academic outcomes. When $t > 0$, the analysis tests if the effect from the $t = 0$ case persists up to year t. When $t < 0$, the analysis determines the effect of having a future morning class on current academic outcomes. Therefore, when $t < 0$, there should be no effect unless there is selection of better students into either morning or afternoon classes. The case of $t < 0$ provides falsification tests for the $t = 0$ case. If the $t < 0$ and $t = 0$ cases give similar results, then any effect in the $t = 0$ case is being driven by selection. If the estimate on $Morning_{i,0}$ in the $t = 0$ case is different than the estimates in the $t < 0$ cases, from selection bias is less likely to be a problem.

The comparison of the $t = 0$ case to the $t < 0$ and $t > 0$ cases better illustrates the effect of morning versus afternoon classes on academic outcomes. Panel a of figure 1 graphs the coefficients on $Morning_{i,0}$ for math and English GPA, along with their 95% confidence interval for the years $t = -3$ to $t = 4$ using the specification from column 4 in tables 2 and 3. The effect of a morning math class on math GPA for all three $t < 0$ years is statistically indistinguishable from 0. This implies that after controlling for students' prior academic achievement and demographics, having a morning math class in a future year has no effect on current math GPA. This result indicates that the selection into morning classes is most likely being controlled for by prior academic achievement and other control variables. In year $t = 0$, the year a student has either a morning or afternoon math class, the effect of a morning math class is large and statistically significant. The $t > 0$ years show that about a third of the effect persists over the next three years but appears to fade away. In essence, the $t < 0$ years verify the $t = 0$ effect by performing three falsification tests, the $t = 0$ year estimate is the effect of having a morning versus afternoon class, and the $t > 0$ years show the persistence of the effect. For English GPA, the $t < 0$ years are all about 0.02 and statistically significant. The fact that these three falsification tests are above 0 is concerning for the validity of the English GPA estimate and indicates some selection is still occurring. There still appears to be a morning effect on English GPA indicated by the spike up at the $t = 0$ year; however, this estimate of 0.044 (0.005) should be smaller due to the positive estimates in the $t < 0$ years. Due to the positive English GPA falsification tests, the effects on English GPA should be viewed cautiously. The $t > 0$ years indicate no persistence of the effect.

Panel b of figure 1 is analogous to panel a but for math and English CST scores. The math CST scores have a similar dynamic pattern as math GPA. The $t < 0$ years are again statistically indistinguishable from 0, validating the measured morning effect in the $t = 0$ year. In the $t = 0$ year, there is a statistically significant spike showing the morning versus afternoon effect. The $t > 0$ years show that about a third of the effect persists for a few years and then fades away. For English CST scores, the effect of morning for all years is essentially 0. This difference in results for math and English is very similar to much of the education literature that finds larger effects in math than English (Chetty & Rockoff, 2014).

Next, I focus on just the $t = 0$ year and estimate the effect of each period during the school day instead of just comparing the first two periods of the day to the last two periods. This estimation is done by replacing $Morning_{i,0}$ in equation (2) with a vector of dummy variables for each period of the school day. The scores for period 6 are normalized to 0. Figure 2 shows the results using the model in equation (2). In panel a, math GPA is higher in the morning than the afternoon. The effect sizes are just above 0.06 GPA points in the first two periods and decrease to being statistically indistinguishable from 0 in the last two periods. English GPA follows a similar pattern to math GPA, except for period 1. It is concerning that the period 1 effect size is indistinguishable from 0. There is no clear reason for such a low effect size in period 1, and it goes against the main results of the paper. This again leads to some worry about the English GPA estimates. In panel b,

FIGURE 2.—PRODUCTIVITY THROUGHOUT THE SCHOOL DAY



This figure focuses on just the $t = 0$ year—the year in which the class period (first through sixth) is measured. Both panels display the estimates of the effect of which period a class is taken on the outcome variables. All estimates use equation (2), with Morning being replaced with a vector of binary variables indicating if the pertinent math or English class was in period 1 to 6. Period 6 estimates are excluded and therefore are normalized to 0.

TABLE 4.—MORNING EFFECTS BY GENDER AND PARENTAL EDUCATION

Variable	Math GPA	Math CST	English GPA	English CST
		A. Gender		
Morning for Females	0.060***	0.020***	0.031***	−0.005*
	[0.007]	[0.003]	[0.007]	[0.003]
Morning for Males	0.085***	0.023***	0.032***	0.003
	[0.007]	[0.003]	[0.007]	[0.003]
Difference	−0.025**	−0.003	−0.001	−0.008*
P-value	0.012	0.463	0.955	0.078
		B. Parents' Education Level		
Morning for Low Education	0.077***	0.024***	0.044***	−0.002
	[0.008]	[0.004]	[0.008]	[0.004]
Morning for High Education	0.084***	0.022***	0.023**	−0.001
	[0.010]	[0.006]	[0.009]	[0.005]
Difference	−0.007	0.002	0.022*	−0.001
P-value	0.595	0.733	0.076	0.906

Both panels use equation (2). Panel A performs separate estimation for males and females. Panel B performs separate estimation for students with parents who have a high school education for fewer and those with some college education or more. Standard errors clustered at the classroom level are in brackets. Morning class is a binary variable equal to 1 if the individual's pertinent math or English class is in period 1 or 2, and 0 if in period 5 or 6. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

the time-of-day effect on math CST scores is 0.027 (0.004) standard deviation in period 1 and 0.015 (0.004) in period 2. For the last four periods of the day, the effect sizes are statistically indistinguishable from 0. There is no time-of-day effect on English CST scores.

E. *Subgroups*

I test whether the time-of-day effect on productivity differs depending on the student's characteristics. I first look at how the time-of-day effect differs for boys and girls. I do this by splitting the sample by gender and then perform the analysis separately for each of the two subsamples. The results of this analysis are reported in panel A of table 4. The Morning for Females row is the effect of having a morning class on girls, and the Morning for Males row is the same effect on boys. For all four of the outcomes, the effect is larger on boys than girls, but it is significant only at the 10% level for two of the four outcomes.

I also split my sample for students of highly or poorly educated parents. The Morning for Low Education row in panel B of table 4 is the effect of morning classes on children of parents who have a high school diploma or less. The Morning for High Education row is the same effect for children with parents who have some college or more. The effect of morning classes is larger and marginally statistically different for students with low-education parents for English GPA. The effects are not statistically different for the other three outcomes, and for some outcomes, there is a larger effect on high-education students. There is no strong evidence of differing effect sizes for students of parents with high and low levels of education.

Table 5 shows the results for the differences in the time-of-day effect for low- and high-achieving students and younger and older students. The sample is split into two subsamples depending on the students' characteristics, and the analysis is performed separately for each group. The first row in panel A of table 5 estimates the coefficient on $Morning_{i,0}$ for students

TABLE 5.—MORNING EFFECTS BY PRIOR PERFORMANCE AND GRADE

Variable	Math GPA	Math CST	English GPA	English CST
A. Low and High Performance				
Morning for Low Performance	0.077***	0.013***	0.047***	0.003
	[0.007]	[0.003]	[0.007]	[0.004]
Morning for High Performance	0.061***	0.028***	0.031***	−0.004
	[0.007]	[0.004]	[0.006]	[0.003]
Difference	0.016*	−0.015***	0.016*	0.007
P-value	0.079	0.003	0.092	0.175
B. Grade				
Morning for Grades 6 to 8	0.064***	0.022***	0.042***	−0.003
	[0.008]	[0.004]	[0.008]	[0.003]
Morning for Grades 9 to 11	0.088***	0.021***	0.023***	0.001
	[0.008]	[0.004]	[0.008]	[0.003]
Difference	−0.024**	0.001	0.018	−0.004
P-value	0.036	0.883	0.104	0.413

Both panels use equation (2). Panel A performs a separate estimation for students above and below the median on prior achievement. Panel B performs separate estimation for younger and older grades. Standard errors clustered at the classroom level are in brackets. Morning class is a binary variable equal to 1 if the individual's pertinent math or English class is in period 1 or 2 and 0 if in period 5 or 6. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

performing below the median in the relevant academic variable, and the second row reports the analogous estimates for students above the median. The results are mixed, with larger effects in some outcomes for both low-achieving and high-achieving students.

For different ages, I also find no substantial evidence of differing effects. Panel B of table 5 reports these estimates. The first row shows the effect of morning classes for grades 6 to 8. The second row shows the effect of morning classes for grades 9 to 11. There is no consistent pattern in the effect by age. For all of the subsamples in tables 4 and 5, the estimates are statistically significant for math GPA, math CST scores, and English GPA. There is, however, substantial variability in the size of the effects.

F. *Robustness and Falsification Analysis*

Besides looking at how the time-of-day effect varies for students with different characteristics, the estimates in table 4 and 5 also provide a sensitivity analysis with regard to what types of students are included in the sample. Although all of the main results are still statistically significant for each of the subsamples, the magnitude of the results varies substantially. The estimates range from 0.060 to 0.088, 0.013 to 0.028, and 0.023 to 0.047 for math GPA, math CST scores, and English GPA, respectively. The results appear to be sensitive to which subsample is used. In addition to the subsample sensitivity analysis, table 6 presents robustness checks for the choice of specification. The first and second rows use the specifications from equation (1) and (2), respectively. The specification in the third row includes a fifth-degree polynomial of prior math CST scores, English CST scores, and the relevant GPA. The fourth row adds academic achievement controls from two years prior. The fifth row uses student fixed effects. One concern with the student fixed-effect specification is that if there is any persistence in the time-of-day effect (which there appears to be in figure 1), then the morning class parameter estimates from the student fixed-effects specification will be biased downward. The estimates appear to somewhat stable to specification choice except for the student fixed-effects specification. The estimates from this specification are about 30% to 40% lower than the baseline estimates. If there is little persistence in the effects and selection occurring on stable unobservable student characteristics, then the true estimates will be closer to the student fixed-effects estimates than the baseline estimates. Overall each specification tells a similar general story, but there are some differences between specifications, especially the student fixed-effects specification. It is therefore hard to know the exact size of the time-of-day effects.

The last three rows of table 6 display the estimates of the falsification tests from equation (2). The falsification tests for math GPA, math CST scores, and English CST scores are all statistically indistinguishable from 0 and show that the main results are likely not being driven by selection of certain students into morning classes. Notably, all three of the falsification tests for English GPA are positive and significant. Similar to figure 1, the fact that these three falsification tests are above 0 is concerning for the validity of the English GPA estimate and indicate that some selection is still occurring. Since the falsification tests are positive, the morning effect on English GPA should at the least be shrunk in size to the difference between the baseline effect and the previous years falsification test, 0.029.

G. *Explanations*

At least three mechanisms could be driving the difference in learning between morning and afternoon classes: changes in teachers' teaching quality, changes in students' learning ability, or differences in morning and afternoon class attendance. Regardless of which mechanism drives the results, since significant effects are observed for math CST scores

TABLE 6.—ROBUSTNESS CHECKS AND FALSIFICATION TESTS

Specification	Math GPA	Math CST	English GPA	English CST
A. Robustness Checks				
Baseline	0.068***	0.024***	0.044***	0.003
	[0.005]	[0.003]	[0.005]	[0.002]
Outcome: $\Delta S_{i,t} = S_{i,t} - S_{i,t-1}$	0.072***	0.021***	0.032***	−0.001
	[0.006]	[0.003]	[0.006]	[0.002]
Achievement Polynomial	0.068***	0.025***	0.044***	0.002
	[0.005]	[0.003]	[0.005]	[0.002]
2 Years of Prior Achievement Controls	0.076***	0.023***	0.040***	−0.002
	[0.006]	[0.003]	[0.006]	[0.003]
Student Fixed Effects	0.053***	0.016***	0.028***	−0.003
	[0.004]	[0.002]	[0.005]	[0.003]
B. Falsification Tests				
1 Year Prior	−0.006	−0.003	0.015**	0.002
	[0.006]	[0.003]	[0.006]	[0.003]
2 Years Prior	0.009	0.003	0.024***	0.002
	[0.007]	[0.004]	[0.008]	[0.004]
3 Years Prior	0.000	−0.006	0.024**	−0.005
	[0.010]	[0.005]	[0.011]	[0.006]

Row 1 uses equation (1). Row 2 uses equation (2). Row 3 uses a fifth-degree polynomial to control for prior achievement. Row 4 uses two prior years of academic achievement as controls. Row 5 uses student fixed effects. Panel B uses equation (2) with the effect of a morning versus afternoon class on outcome variables from one to three years prior to the morning or afternoon class. Standard errors clustered at the classroom level are in brackets. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

as well as GPA, it is likely that the results measure actual differences in learning instead of teachers just being more generous graders in the morning.

With the available data, I am not able to distinguish between changes due to teachers versus students. However, it is important to distinguish what may be causing changes in teaching quality or students' learning ability. There are at least three possible reasons that teaching quality or students' learning may decline throughout the day: circadian rhythms, stamina, or school scheduling structure. Much of the circadian rhythm research suggests that student performance should increase throughout the school day. Typically the cognitive function of adolescents peaks in the afternoon, not the morning, and adults' cognitive function peaks in the late morning (Goldstein et al., 2007; Cardinali, 2008; Crowley et al., 2007). Therefore, the time-of-day effect is unlikely to be due to the circadian rhythm, and in fact the circadian rhythm is likely muting the estimates.

The stamina reason seems to be more in accordance with the results. It is likely that during a given day as teachers and students are in school for a longer period of time, their teaching and learning ability decreases due to fatigue. This could be caused by physical fatigue, mental fatigue, drowsiness, or restlessness. The work-shift literature has shown that accident rates increase during overtime and for long shifts, largely due to increased fatigue (Rosa, 1995). This type of fatigue would likely increase throughout the day and result in lower levels of teaching and learning ability in the afternoon, which match the results.

School scheduling structure may also play an important role. The way schools structure their schedule may affect both teaching quality and student learning. When schools place their home room (it is usually attached to period 1 or 6) may be influential. It is also possible that classes right after a lunch break might be influenced. Each school has some flexibility over the schedule, and these choices may affect teaching and learning ability. If school scheduling structure drives the results, then the results are unlikely to translate to other domains such as the workplace.

The results may be driven by differences in morning and afternoon class attendance. If students systematically attend morning classes more than afternoon classes, then due to spending more time in morning classes than afternoon classes, they might perform better in morning classes. If students have extracurricular activities that take them out of school early or leave campus for lunch and do not return, attendance would be lower in the afternoon, and this could be driving the results. However, if due to sleeping in and traffic, it may be that students often arrive at school late and attendance is lower for morning classes. If this were the case, then the results are underestimating the actual time-of-day effect.

Data constraints do not allow a direct comparison of morning and afternoon attendance. However, the data contain the annual number of days a student is absent (a student is absent only if he or she misses all class periods). If students with few absences also tend to attend all of their classes each day, then the main analysis can be performed for the subsample of students who have few absences, and this could control for some of the possible morning and afternoon attendance difference. When the main analysis is performed on the subsamples of students with no absences, fewer than three absences, and fewer than five absences in a school year, all of the estimates for math and English GPA and test scores are statistically indistinguishable from the baseline results. Although this is far from perfect, this is the best that the limited attendance data allow and gives some weak evidence against the attendance mechanism.

It is important to understand how the results are distinct from the school start time literature. At first glance, the results appear to be in the opposite direction and contradictory to the school start time literature estimates. However, the results of this paper estimate a slightly different effect than the school start time literature does. All of the results in this paper are estimated conditional on a given school start time. Therefore, all the results hold constant items such as how much sleep students get, annual attendance rates, and annual morning tardiness, whereas changing the school start time makes these items vary. Conversely, changing school start times do not affect changes in stamina throughout the day or differences between morning and afternoon class attendance, whereas these things are affected by moving a class from the afternoon to the morning. Both moving school start times and moving a class from the afternoon to the morning affect when during the circadian rhythm, students are taking certain classes. The fact that the results are in the opposite direction likely implies that differential learning throughout the day is being driven not by circadian rhythms but by other things, such as stamina. A simple illustration of how the results are estimating different effects is to look at policy. Moving school start times later increases students' math GPA regardless of which period students take math. However, moving school start times later and moving math class from period 6 to period 1 increases students' math GPA even more.

H. *Efficiency Gains*

There are a few simple ways in which efficiency gains could be obtained in schools. These possible gains run along two dimensions. The first dimension is that some tasks performed may be more affected by the time of day than other tasks. My analysis shows that math classes are more affected by the time of day than are English classes. It is likely that other classes, such as physical education, also have small time-of-day effects. Therefore, moving math classes to the morning and other classes, like English, to the afternoon could increase students' GPA and test scores. The other dimension in which efficiency gains could be obtained is by moving classes believed to be more important by individuals or schools to the morning. For example, math and art might be equally affected by the time of day; however, schools may place a higher priority on math than art and could increase efficiency by having more math classes in the morning and more art classes in the afternoon.

Understanding how the time day affects students allows schools to change policies to increase academic outcomes. There are, however, constraints on how much schools can move along these two dimensions. The most important constraint is on the supply of teachers in a given school teaching a particular subject. For example, in middle schools and high schools, most teachers specialize in teaching one or two subjects, so there is less flexibility in when certain classes are taught. This constraint is less binding for elementary schools, where teachers teach a larger range of subjects. However, it is unclear whether these results can be extended to elementary age children.

IV. Conclusion

This paper shows that productivity is higher in the morning than the afternoon and that this variation in productivity can be exploited to increase efficiency. Despite these findings, there are areas of this paper that future work can improve on. Although all specifications find statistically significant time-of-day effects, depending on the specification used, estimates are sometimes as much as 40% smaller than the estimates from the baseline specification. Also the English GPA falsification tests are positive and statistically significant, which likely decreases the English GPA effect size. It is therefore hard to know the exact size of the time-of-day effects. In addition, the paper is unable to distinguish between the underlying mechanisms. The results seem to indicate that differential alertness due to the circadian rhythm does not drive the results. However, the paper is unable to distinguish between mechanisms such as changes in teachers' teaching quality and students' learning ability due to fatigue throughout the day or differences in morning and afternoon class attendance. Finally, it is unclear how learning in the classroom will extend to other domains. Despite these shortcomings, the results tend to show that students are more productive earlier in the school day, especially in math. These time-of-day differences in productivity along with a simple rearrangement of when tasks are performed allow for efficiency gains to be obtained in schools. These efficiency gains may also be available in other organizations.

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