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Shinsuke Asakawa

Fumio Ohtake

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Graduate School of Economics
Osaka University, Toyonaka, Osaka 560-0043, JAPAN

Impact of Temporary School Closure Due to COVID-19 on the Academic Achievement of Elementary School Students[1]

Shinsuke Asakawa[2,3] Fumio Ohtake[4,5]

Abstract

This study examines the effects of COVID-19 related temporary school closures on the academic performance of fifth- and sixth-grade primary school students in Japan. Difference-in-differences and event studies were conducted using "Manabi Nara" data, a math achievement test administered to fourth-sixth graders at each term-end in Nara City. Children who experienced temporary school closure made the treatment group while inexperienced one-year older children were the control group. The results showed lowered math scores in the short term, but scores significantly increased six months after school closure. Further, the lower the students' academic achievement was, the greater was their improvement in their math scores. We found that increased motivation and attitude shifts toward math during this period contributed to improved scores. Finally, students with disadvantaged living conditions around school vacations saw their math scores and motivation and attitude toward math fall, particularly in the bottom 25% of their fourth-grade academic performance.

Keywords：COVID-19, School Closure, Learning Loss, Elementary School Students, Math Scores, DID and Event Study, Living conditions, Learning Disparity

JEL Code: I21, I24, I28

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[2] Specially Appointed Researcher and Ph.D. student, Graduate School of Economics, Osaka University, 1-7, Machikaneyama, Toyonaka, Osaka 560-0043, Japan. Email: shinsuke.asakawa@gmail.com

[3] Research Fellow, Japan Society for the Promotion of Science

[4] Professor, Graduate School of Economics, Osaka University, 1-7, Machikaneyama, Toyonaka, Osaka 560-0043, Japan. Email: ohtake@econ.osaka-u.ac.jp

[5] Specially Appointed Professor, Center for Infectious Disease Education and Research (CiDER), Osaka University

1. Introduction

In 2020, approximately 1.5 billion students across 188 countries were forced to stay home due to temporary school closures (OECD, 2021; UNESCO, 2021). Almost a year after the spread of COVID-19, more than half of the OECD countries have not yet fully reopened their schools (OECD, 2021).

Existing studies examining the relationship between temporary school closures to stop the spread of COVID-19 and students' academic performance have shown that temporary school closures hurt students' academic performance in the short term,[6] and that the effects of temporary school closures vary among students.[7] This result is consistent with other existing studies that have found that a temporary school closure or a reduction in school days decreased students' academic achievement.[8] Furthermore, some estimates suggest that the learning loss due to temporary school closure is about $16,000 per student

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[6] Many existing studies have shown that temporary school closures due to COVID-19 reduced students' academic performance in the short term and that students with more disadvantaged home environments had lower learning time (Aucejo, French, Araya & Zafar, 2020; Bonal & González, 2020; Grätz & Lipps, 2021; Reimer, Smith, Andersen & Sortkær, 2021). Others show that students with lower academic performance and home environments reported lower academic performance (Agostinelli, Doepke, Sorrenti & Zillibotti, 2020; Andrew, Cattan, Costa-Dias, Farquharson, Kraftman, Krutikova, phimister et al., 2020; Engzell, Frey & Verhagen, 2021; Kuhlfeld, Soland, Tarasawa, Johnson, Ruzek & Liu, 2020; Van Lancker & Parolin, 2020; Maldonado & De Witte, 2020; Schult, Mahler, Fauth & Lindner, 2021).

[7] The difference in the ability to adapt to online education is seen as a factor causing the heterogeneity in school closure effects. While online education was adopted in many countries during the temporary school closure, existing studies show significant differences in adaptability to online education depending on students' academic ability, household income, internet environment, and region of residence (Bacher-Hicks, Goodman & Mulhern, 2020; Bansak & Starr, 2021; Bayrakdar & Guveli, 2020; Chetty, Friedman, Hendren, Stepner & The Opportunity Insights Team, 2020; Ikeda & Yamaguchi, 2020; van der Velde, Sense, Spijkers, Meeter & van Rijn, 2021).

[8] Studies examining the effects of school closures and reduced class days include summer vacations (Atteberry & McEachin, 2020; Cooper, Nye, Charlton, Lindsey & Greathouse, 1996; Downey, Von Hippel & Broh, 2004; Kuhfeld, 2019; Kuhfeld, et al. 2020; von Hippel, Workman & Downey, 2018); natural disasters (Andrabi, Daniels & Das, 2020; Hansen, 2011; Goodman, 2014; Marcotte, 2007; Marcotte & Hemelt, 2008; Sacerdote, 2012; Thamtanajit, 2020); infectious diseases (Meyers & Thomasson, 2020); teachers' strikes (Belot & Webbink, 2010; Wills, 2014); and reduced class days (Aucejo & Romano, 2016; Kawaguchi, 2016; Motegi & Oikawa, 2019).

(Azevedo et al., 2020) or 3% of the lifetime income (Hanushek & Woessman, 2020). Compensating for this learning loss due to school closure has become an important policy issue in many countries. On the other hand, the medium-term impact of temporary school closures remains unresolved due to the difficulty of obtaining test data with high frequency and comparability among multiple cohorts.

This study, therefore, examines the short-term — third term of the fiscal year (FY) 2019 and first term of FY2020 — and mid- and long-term — second and third term of FY2020 — effects of the COVID-19 related temporary closure of elementary schools in Japan, using the "Manabi Nara" math test data of elementary school students in Nara City, which is one of the core cities with a population of more than 200,000.[9]

However, Nara City implemented two policy interventions after the temporary closure of schools — the shortening of the summer vacation and the distribution of one tablet (ICT) terminal per student. The summer vacation was shortened to compensate for the drastic reduction in school days due to the temporary closure. Moreover, to increase the efficiency of education, Nara City distributed an ICT terminal to each elementary school student in order of readiness from September 2020 onward. As a result, the students' academic performance by the end of the second term of FY2020 may be higher than before. The number of days to introduce ICT terminals also varied by about one month across schools, which may cause heterogeneity in academic performance when measured from the end of the second term. Therefore, we consider the effect of the shortened

[9] "Manabi Nara." has two advantages. First, we can capture short term variations as a result of the impact of temporary school closures because the same math test is administered to all students in the same grade at the end of each term. The second advantage is we can obtain information on math scores not only for children born between April 2, 2009, and April 1, 2010 in the COVID-19 experienced cohort (FY2020 P6 cohort) but also for children born between April 2, 2008, and April 1, 2009 in the COVID-19 unexperienced cohort (FY2019 P6 cohort). See Appendix Table A-1 for the correspondence of year and grade by cohort.

summer vacation and the earliness of the ICT terminal's introduction to identify the impact of the shorter school days due to temporary school closures.

The baseline analysis in this study is a difference-in-differences (DID) analysis.[10] The first difference compares the math test scores between children who experienced temporary school closures due to COVID-19 and children who did not experience school closure in grades 5 and 6. The second difference is the difference before and after temporary school closures. Then, by adding the cross-terms of the COVID-19 experience dummy and the "third term of grade 6" dummy, we decompose and separately estimate the entire period after the policy intervention of temporary school closure (from the third term of grade 5 to the third term of grade 6) and after the second term of grade 6. This procedure enables us to estimate the short- and medium-term effects of temporary school closures, considering the shortened summer vacation and benefits of the introduction of ICT. In addition, we conduct an event study and estimate the difference between the two groups for each term to confirm the parallel trend before the second term of grade 5 and test whether the effects of temporary school closure vary by term.

So far, the existing studies have not yet examined the effects of living conditions, including the home environment and mental health, on academic performance during and after the temporary school closure due to COVID-19. Therefore, as a part of this study, we also use the answers to the "Living Conditions Survey" conducted in Nara City in May (during the school closure) and June (after the school closure) 2020 to examine

[10] When COVID-19 temporary school closures occurred in March 2020, the FY2020 P6 cohort was at the end of the third term of fifth grade, and the FY2019 P6 cohort was at the end of the third term of the sixth grade. Therefore, we consider the period from the end of the third term of the fifth grade to the end of the second term of sixth grade as the policy intervention for reducing school days due to temporary school closure. The difference between the pre-intervention (the first term and the second term of the fifth grade) and the post-intervention (f the third term of t fifth grade to the second term of the sixth grade) was the second difference.

whether disadvantaged living conditions affected students' academic performance after the temporary school closure.

Based on the above discussion, we examine the following questions.

1. Did the reduction in school days due to temporary closures lower the academic performance of students?
2. Did the effects of temporary school closures vary by academic quartile or disadvantaged living conditions?
3. Did students' motivation and attitudes toward math change after a certain period had passed since the temporary school closure?

This study obtained the following evidence: For the first question, considering the term immediately prior to the temporary closure (the third term of grade 5), the decrease in school days resulted in a decline in academic performance for students with lower academic performance, as of the third term of grade 4. However, math scores increased significantly after six months from the school closure (the second and third terms of grade 6). Thus, the negative effects before the first term of grade 6 were canceled out for the lower-performing students, and their math scores in the second and third terms of grade 6 improved. Regarding the second question, students with low math scores a year before the temporary school closure were the most negatively affected by school closure in the short term. However, they too turned around and showed the highest improvement in math test scores in the medium to long term. Furthermore, in the lowest quartile, the students who faced disadvantaged living conditions during and after school closure were significantly more hindered in the growth of their math scores from the second semester of grade six. Consequently, students who were disadvantaged during and after the temporary closure of the school experienced a greater decline in math scores in the short term and had lower growth in math scores even during the improvement phase after the second semester of grade 6. Finally, for the third question, the motivation and attitude toward math were also enhanced when math scores rose (the second and third terms of grade 6). However, disadvantaged living conditions also had negative impacts, especially in the lowest academic ability groups.[11]

This study makes two main contributions. First, using high-frequency data, such as the results of math tests conducted every semester, we examined the effect experiencing the change in the school days due to temporary school closures or shortened summer vacations under the COVID-19 epidemic had on the math scores of students. Moreover, we also clarified if these changes in school day reduce the gap in academic achievement. Existing studies have shown that the summer vacation decreases academic achievement, especially in the lower grades[12], while the effect of shortening the summer vacation is still unknown. On the other hand, with regard to the effect of ICT terminals, online learning under temporary school closure improves academic performance when teachers support students, while it significantly reduces the study time of low-achieving students when sufficient support is not available (Carlana & La Ferrara, 2021; Grewenig, Lergetporer, Werner, Woesmann & Zierow, 2020). However, ICT implementation in face-to-face classes has not yet been proven to be effective. Therefore, our contribution is to examine the impact of the combination of two policy interventions on student

[11] Students in the lowest quartile of the third term math scores as of fourth grade did not study printouts during the school closure, were unable to concentrate on their studies after the closure, did not get enough sleep, and felt unmotivated and anxious during and after the closure.

[12] See Downey et al. (2004); Kuhfeld (2019); Kuhfeld et al. (2020); von Hippel et al. (2018).

achievement: the increase in school days due to the shortened summer vacation and the introduction of ICT terminals in face-to-face classes with enhanced teacher support.

The second contribution is to examine whether disadvantaged living conditions during and after the temporary school closure harm students' academic performance and whether the effects are heterogeneous across academic strata. Existing studies show that the effect of home study under temporary school closure differs depending on students' abilities and household characteristics during temporary closure.[13] Moreover, many studies show that the living conditions themselves worsen due to school closures.[14] Thus, we cannot deny the possibility that the deterioration of living conditions creates heterogeneity in the effects of temporary school closures. Therefore, our second contribution is to examine the causal relationship between living conditions and students' academic achievement during and after school closures.

This paper consists of seven sections: Section 2 describes the changes in school days in elementary schools in Nara City, including temporary school closures and shortened summer vacations, Section 3 describes the data, Section 4 explains the estimation method, Section 5 presents the results of the baseline empirical analysis, and Section 6 examines the heterogeneity of the effects of temporary school closures. Finally, Section 7 provides a summary of the study.

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[13] Study time (Aucejo et al., 2020; Bonal & González, 2020; Gratz & Lipps, 2020; Reimer et al., 2021); online learning (Bacher-Hicks et al., 2020; Bansak & Starr, 2021; Bayrakdar & Guveli, 2020; Chetty et al., 2020; Ikeda & Yamaguchi, 2020; van der Velde et al., 2021)

[14] Many existing studies show that mothers are more affected by COVID-19 than fathers. For example, COVID-19 reduces women's employment (Alon, Doepke, Olmstead-Rumsey & Tertilt, 2020; Collins, Landivar, Ruppanner & Scarborough, 2021; Craig & Churchill, 2021; Heggeness, 2020), increases mothers' additional parenting time (Del Boca, Oggero, Profeta & Rossi, 2020; Farré, Fawaz, Gonzalez & Graves, 2020; Yamamura & Tsutsui, 2021b; Zamarro & Prados, 2021), worsening parental mental health and well-being (Cheng, Mendolia, Paloyo, Savage & Tani, 2021; Huebener, Waights, Speiss, Siegel & Wagner, 2021; Takaku & Yokoyama, 2021; Yamamura & Tsutsui, 2021a), and increased domestic violence (Pereda & Díaz-Faes, 2020; Baron, Goldstein & Wallace, 2020; Hsu & Henke, 2021).

2. School closure and shortening of summer vacation in Nara City

Across Japan, primary and junior high schools, high schools, and special-needs schools have been temporarily closed since March 2, 2020, to arrest the spread of the COVID-19 epidemic.[15]

In response to the government's request, Nara City implemented temporary school closures for approximately three months from the same date. As a result, students enrolled in elementary and junior high schools, high schools, and special-needs schools in FY 2019-2020 lost 23 class days in the third term of FY 2019 and 54 class days in the first term of FY 2020 compared to the previous year.[16] On the other hand, Nara City shortened the summer vacation by 20 days in FY2020 from the previous year to compensate for the fewer class days (see Figure 1). Thus, this study considers the temporary school closure and the associated shortened summer vacation as two policy interventions regarding the school day and examines the policy effects of each intervention. The following sections provide an overview of each policy.

(Figure 1 around here).

[15] As of March 5, 2020, 18,923 of the 19,161 elementary schools in Japan were closed (The Japan times, 2020). However, since the temporary school closure was not mandatory but requested by the Prime Minister, the timing of the closure varied by local governments（Yamamura & Tsutsui, 2021a; 2021b）。

[16] In response to a government request, Nara City has temporarily closed the city's elementary, junior high, and senior high schools from March 2 to April 5, 2020 (with a spring break from March 25 to April 5). As a result, the third term of the 2019 school year was shortened by 23 days (from March 2 to March 24, including weekends and holidays) compared to the previous year. In addition, after the school opening ceremony and explanation of the school closure schedule on April 6, the school was closed again for one month, from April 7 to May 7. During this period, due to the nationwide COVID-19 pandemic and the declaration of a state of emergency on April 16, on April 28 Nara City decided to extend the re-opening deadline to May 31. As a result, the first term of the 2020 school year was shortened by only 54 days (April 8 to May 31, 2020, including weekends and holidays) compared to the previous year.

2.1. Temporary school closure (Primary school)

During the temporary school closure, students were required to study at home.[17] Elementary school students watched videos at home streamed by teachers and studied independently using paper-based study handouts. The teachers collected and graded the filled-in handouts to check the students' understanding because they could not learn by themselves if they studied at home for a long time.[18] Thus, given that all elementary schools in Nara City were closed temporarily at the same time and in the same manner, this study considers the temporary closure of elementary schools as the first policy intervention and examines their effects.

2.2. Shortened summer vacation

As shown in Table 1, the summer vacation in Nara City was drastically shortened to 16 days (August 8 to August 24) in FY2020 (from 36 days in the previous year) to compensate for the delay in learning caused by the temporary school closure due to COVID-19. As a result, students' academic performance at the end of the second term may have increased (not decreased due to the summer vacation) compared to the previous year because the learning interruptions caused by the summer vacation were greatly reduced in elementary schools.

(Table 1 around here).

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[17] Children (grades 1-6) who were unable to stay at home due to their parents' employment or other reasons, could attend elementary school during regular class hours from Monday to Friday. During this time the teachers did not conduct classes, and the students who attended school engaged in self-study. Students with any type of fever or cold symptoms were not allowed to attend school.

[18] Since May, Nara City has been lending school-based tablets and Wi-Fi routers to junior high school students from households that do not own tablets and/or have an internet connection. Junior high and elementary students were also given tablets to use, which allowed elementary school students to study at home using study handouts during most of the temporary school closure. As a result, the distribution and collection of assignments and teachers' study guides were also able to be completed online.

Before FY2018, the summer vacation duration was fixed between the first weekday after July 21 and September 1. However, in FY2019, before the COVID-19 epidemic, the summer vacation was already shortened by seven days compared to the previous year (FY2018). This reduction was mainly to accommodate increases in the curriculum, such as introducing English as a compulsory subject. Thus, the effect of the summer vacation reduction in FY2020, which was to compensate for the temporary school closure due to COVID-19, on students may vary depending on their academic performance.

Therefore, after considering the summer vacation itself, this study estimates the impact of each policy intervention on children's academic achievement by considering (1) the shortening of summer vacation before the COVID-19 epidemic; and (2) the shortening of summer vacation after the COVID-19 epidemic as different policy interventions.

3. Data

This study uses information collected over five terms (from the first term of the fifth grade to the third term of the sixth grade) from the panel data "Manabi Nara." The survey tracks the math test score at the end of each term over three years (from the fourth to the sixth grade) for every child in all 43 elementary schools in Nara City (about 2,700 students per grade). The cohort used and the test timing are shown in Figure 2.

(Figure 2 around here).

These data have two advantages. First, students in the same grade take the city-wide math test at the end of each term (three times a year: July, December, and March). Second, we can obtain information on the students who experienced the COVID-19 school closure

(FY2020 P6 cohort) and compare it with the students one grade higher (FY2019 P6 cohort) who did not experience the COVID-19 epidemic. The high frequency of test results across the two grades is a significant advantage of the present data.

Using the DID and event study, we estimate the impact of the COVID-19 temporary school closure on academic achievement by comparing the children who experienced COVID-19 school closure with those who did not (first difference) with the difference before and after the period in which the school days were reduced due to COVID-19 (second difference). Therefore, we create a COVID-19 experience dummy "COVID19" that takes the value 1 for the FY2020 P6 cohort and 0 for the FY2019 P6 cohort to represent the first difference.

3.1. Outcome variable: math test scores

This study uses math test scores at the end of each term as the outcome variable to examine changes in the academic performance of students.

We first check the average math scores per term for the FY2020 P6 cohort and the FY2019 P6 cohort in Figures 3 and 4 to see if the school closure associated with COVID-19 affected students' math test scores. Figure 3 shows that the academic performance of the FY2020 P6 cohort significantly decreased in the first term of grade 6 compared to that of the FY2019 P6 cohort. In contrast, it increased dramatically after the second term of grade 6. Figure 4 shows the mean outcome variables per term, divided into four quartiles, calculated by the scores at the end of the third term of the fourth grade. The results indicate that, especially in the lower quantiles (bottom 50%), both the decline in academic achievement before and after the temporary school closure (third term of grade 5 and first term of grade 6), and the increase after the second term of grade 6, are more prominent.

(Figures 3 and 4 around here).

The following sections analyze which policy interventions caused the changes in Figures 3 and 4 and whether the changes in academic performance differed depending on the living conditions during the temporary school closure, using DID and event studies.

3.2. Temporary school closure related to COVID-19

Nara City implemented temporary school closure from the third term of the fifth grade (March 2) to the first term of the sixth grade (May 31). However, before the temporary school closure, some elementary schools were already able to take the end-of-term test for grade 5 students, usually held in March 2020, while others started school closures without taking the test due to the government's urgent request to close schools.

Typically, the end-of-term tests are conducted after the examination content has been completed. However, the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) had already notified the prefectures and designated cities' education committees of the possibility of temporary school closures as of February 18, and the government even requested temporary school closures on February 27.[19] As a result, some elementary schools may have moved up the examination schedule keeping the

[19] The notification can be found at the following URL (https://www.mext.go.jp/content/20200218-mxt_kouhou02-000004520_3.pdf). In the third term of the fifth grade in the FY2020 P6 cohort, many elementary schools did not administer math exams due to the reduced school days as a result of the temporary school closures and failure to complete the test content. If the test scores of students in the FY2020 P6 cohort who took the test in the third term of fifth grade in 2020 varied from those who did not, a self-selection problem would arise. Therefore, we tested for differences in the means and variances of test scores during periods other than the third term of the fifth grade between the following groups: 1) students who took the test in the third term of the fifth grade and those who did not, and 2) students who took the test in the third term of the fifth grade and the whole FY2020 P6 cohort. The results show that the mean and variances of both groups did not differ at the 10% significance level (see Appendix Table A-2). Therefore, this study also uses the third term of the fifth grade of the FY2020 P6 cohort for analysis.

possibility of temporary school closures in mind. Existing studies show that the test scores decline when exogenous shocks lead to an earlier examination date (Goodman 2014; Marcotte 2007; Marcotte and Hemelt 2008). Therefore, students' academic performance may have also declined in the third term of grade 5, just before the temporary school closure.

This study defines the third term of the fifth grade and later as the period after the temporary school closure, while the previous term is defined as the period before school closures. Specifically, to perform DID/Event study estimation, we create a dummy for temporary school closure “P5T3_P6T3,” which takes the value one after the third term of grade 5, and 0 before the temporary school closure.

3.3. Shortened summer vacation

As shown in Table 1, the summer vacation in Nara City was significantly shortened to 16 days, from August 8 to August 24, 2020. However, the previous year's summer vacation was also shortened by approximately one week compared to the summer vacation before FY2018 in response to the curriculum expansion.

Therefore, we first create a dummy for the summer break (summer break) to estimate the effect of the summer break itself, taking the value of 1 when the test is conducted in the second term, which is just after the summer break, and 0 in the other terms. We also define the number of shortened days (shortened days) as the number of days obtained by subtracting the summer vacation periods in 2019 (36 days) and 2020 (16 days) from the 43-day summer vacation period in FY2018 and assigned to the end of the second term of the FY2020 P6 and FY2019 P6 cohorts, and 0 otherwise. The coefficient of shortened days shows the effect per day of shortening the summer vacation.

Furthermore, we construct a dummy for the end of the third term of the sixth grade "P6T3," which takes the value 1 for the second term of the sixth grade and 0 for the prior terms. The variable decomposes the effect of reducing school days due to COVID-19 and shortens summer vacation. Thus, we can verify whether the change in academic achievement after the shortening of the summer vacation shortening following the temporary closure is different from that of the previous year by checking the coefficient of the intersection term between COVID19 dummy and P6T3 dummy.

3.4. Heterogeneity of living conditions

In Nara City, most elementary school students studied at home in the same manner (video viewing and paper-based print learning) at the same time without any physical contact with teachers (see Section 2). However, existing studies suggest that the living conditions of elementary school students during temporary school closures, such as their home environment and physical and mental conditions, differ among students.[20] For example, Yamamura and Tsutsui (2021a) found that COVID-19-induced temporary school closure aggravated mothers' mental health among elementary school-aged children and a low educational background. This finding suggests that the effects of temporary school closure on the family environment and the mental health of parents and children may differ depending on the characteristics of the primary guardian during the closure, such as gender and educational background.

Therefore, we examined whether the effect of temporary school closure differs

[20] See the following studies: parental employment (Alon et al., 2020; Collins et al., 2021; Craig & Churchill, 2021; Heggeness, 2020), parenting time (Del Boca et al., 2020; Farré et al., 2020; Yamamura & Tsutsui, 2021b; Zamarro & Prados, 2021), parental mental health and well-being (Cheng et al., 2021; Huebener et al., 2021; Takaku & Yokoyama, 2021; Yamamura & Tsutsui, 2021a), domestic violence (Pereda & Díaz-Faes, 2020; Baron et al., 2020; Hsu & Henke, 2021)

depending on living conditions during and after temporary school closure.[21] Data are from the questionnaire results of "Survey of living conditions during the vacation (May)" and "Survey of living conditions after school re-opening (June)," which were conducted in conjunction with "Manabi Nara." Specifically, we first created living condition dummy variables for each of the two questionnaire items. We assigned one if the respondent answered "quite applicable/applicable" to a disadvantaged living condition or "not quite applicable / not applicable" to an advantaged living condition and 0 otherwise. Then, we used the average of the May and June questionnaire results as a variable to indicate the difference in living conditions.[22] By adding these dummy variables to the explanatory variables, we estimate the effects of temporary school closures, considering the effect of heterogeneity caused by disadvantaged living conditions.[23]

3.5. Introduction of ICT terminals

In Japan, the lag in the introduction of ICT to education compared to OECD countries has been a problem for a long time (OECD 2020). Therefore, MEXT had planned to distribute one tablet (ICT) terminal per student from around FY 2018, before the COVID-19 epidemic, to coincide with the introduction of the new education guidelines in FY 2020. Later, the temporary school closure reaffirmed the priority of online education, and

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[21] Video production skill and the speed at which the class is taught may differ among schools and classes. Therefore, this study deals with the unobservable heterogeneity of school and classroom units by controlling for school and class fixed effects, as described below.

[22] We create a variable equal to 1 if both May and June are equal to 1, 0.5 if one equals 1, and 0 if both are equal to 0. Thus, the two variables "studied using handouts from school (May)" and "sometimes have difficulty concentrating on studies (June)" are used in the analysis without averaging them as different variables. However, even if we assume that both variables mean "I can't concentrate on my studies" and use both averages as variables, the main results of the analysis remained the same.

[23] See Appendix Table A-3 for a detailed description of the disadvantaged living condition dummy and Appendix Figure 1 for a histogram of the variables for the disadvantaged living conditions.

as a result, the introduction of ICT terminals was promoted nationwide after the school closure in Japan. For example, in Nara City, ICT terminals were sequentially introduced to elementary schools from September 14 to October 12, as shown in Figure 5.

(Figure 5 around here).

Since ICT terminals enable individualized and proficiency-based learning, the government expects that the learning effect is higher than traditional group learning.[24] Therefore, at the end of the second term of the sixth-grade students and later, the ICT terminal introduction is likely to have affected the students' academic achievement in addition to the shortened summer vacation. Furthermore, the difference of 28 days between the earliest and the latest elementary schools receiving the ICT terminals could have a heterogeneous effect on academic achievement.

However, the effect of the introduction of ICT terminals and the shortened summer vacation cannot be distinguished because both interventions were timed after the end of the first term test. Thus, we consider the coefficient of the intersection term between the COVID-19 dummy and the After P6T2 dummy to be the effect of ICT introduction in addition to the shortening of the summer vacation. We focus on the difference in the early days of introduction and examine the heterogeneity of the effects. This is measured as the

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[24] The program to promote ICT in education in Japan is called the "GIGA School Program" and can be found at URL:https://www.mext.go.jp/en/content/20200716-mxt_kokusai-000005414_04.pdf. The program has three objectives (https://www.mext.go.jp/content/20200625-mxt_syoto01-000003278_1.pdf). The first is to realize interactive teaching by allowing teachers to understand the responses of each student. The second is to enable individualized learning based on each student's level of achievement. The third is that by sharing each person's opinions in real-time, it is possible to obtain various opinions. Therefore, the primary goal of the GIGA School Program was to improve classes to realize active, interactive, and deep learning and the ICT introduction was a means to achieve this goal.

difference between the start date of the use of ICT terminals in each elementary school and the start date of the slowest elementary school to receive the terminals. We thus use the variable "ICT early days" as a control variable.

Table 2 shows the descriptive statistics for the variables explained in Sections 2.1-2.5.

(Table 2 around here).

4. Estimation method

This study uses DID as the main estimation method. In addition, we estimate the event study type DID (Event study) to confirm the medium- and long-term effects of the policy intervention and test the trends of the treatment and control groups before the policy intervention (i.e., common trend).

4.1. Full sample analysis

In this section, we first test the hypothesis that temporary school closures due to COVID-19 lowered the academic performance in math.

The FY2019 P6 cohort cannot be considered a control group without considering the impact of the shortened summer vacation because the summer vacation was shortened in Nara City even before 2020. Therefore, we use the following estimation model as a baseline to identify the effects of temporary school closures alone.

4.1.1. Baseline DID

$$Y_{i,t} = \alpha_1 COVID19_i \times P5T3\_P6T3_t + \alpha_2 COVID19_i + \alpha_3 P5T3\_P6T3_t + \mu_s + \mu_g + \mu_c + \epsilon_{i,t} \quad (1)$$

$Y_{i,t}$ is the math score of an individual i in term t. $COVID19_i$ is a dummy variable that takes the value of 1 for the FY2020 P6 cohort, and $P5T3\_P6T3_t$ is a dummy variable that takes the value of 1 when the testing period is after the third term of the fifth grade. μ_s, μ_g and μ_c are the school (s), grade (g), and classroom (c) fixed effects, respectively. The parameter of interest is α_1, which shows if the temporary school closure had a significant effect on the math achievement of the treatment group ($COVID19_i$).

Therefore, the temporary school closure to prevent the COVID-19 epidemic and the shortening of summer vacation to compensate for the significantly reduced school days can be considered as a set of policy interventions related to changes in the number of school days. Thus, we estimate the following model in addition to the baseline DID to separately identify the effects of school closures and shortened summer vacation.

4.1.2. Baseline DID + Summer break (SB)

$$Y_{i,t} = \alpha_1 COVID19_i \times P5T3\_P6T3_t + \alpha_2 COVID19_i + \alpha_3 P5T3\_P6T3_t + \alpha_4 Summer\ break_t + \alpha_5 Shortened\ days_{i,t} + \mu_s + \mu_g + \mu_c + \epsilon_{i,t} \quad (2)$$

$Summer\ break_t$ is a dummy variable that takes the value one if the test period is the end of the second term immediately after the summer break, and $Shortened\ days_{i,t}$ is the number of shortened days in 2019 and 2020 compared to the summer break in 2018. The new parameters of interest are α_4 and α_5, where α_4 measures if the summer vacation itself has a significant impact on math achievement, while α_5 indicates if shortening the summer vacation in 2019 had a significant impact on math achievement.

We also add an interaction term of $COVID19_i$ and $After\ P6T2_t$ to the estimation equation to extract the effects of the second and third terms of grade 6 only.

4.1.3. Baseline DID + SB + After P6T2

$$Y_{i,t} = \alpha_1 COVID19_i \times P5T3\_P6T3_t + \alpha_2 COVID19_i + \alpha_3 P5T3\_P6T3_t$$
$$+\alpha_4 Summer\ break_t + \alpha_5 Shortened\ days_{i,t} + \alpha_6 COVID19_i \times After\ P6T2_t$$
$$+ \alpha_7 After\ P6T2_t + \mu_s + \mu_g + \mu_c + \epsilon_{i,t} \quad (3)$$

The notable parameter here is α_6, which shows that only the treatment group changed its math achievement after the shortened summer vacation. In other words, by adding $COVID19_i \times After\ P6T2_t$, the parameters α_4 and α_5 were modified to coefficients indicating only the summer break effects other than those of the sixth grade in the treatment group. As a result, we can decompose the impact of the summer vacation in grade 6 after the COVID-19 epidemic and the impact of summer vacation at other times.

Next, we estimate the following baseline event study model to confirm the policy intervention's medium- and long-term effects and clarify whether the common trend assumption before the policy intervention holds.

4.1.4. Baseline Event study

$$Y_{i,t} = \sum_{t=-2}^{3} \beta_t COVID19_i \times School\ close_t + \mu_s + \mu_g + \mu_c + \epsilon_i \quad (4)$$

$School\ close_t$ is a dummy variable here that takes the value of 1 when the test period is t.[25] Checking each parameter enables us to test the following hypothesis: β_{-2} and β_{-1} show that the effect of temporary school closures cannot be identified because no

[25] We define $t = 0$ as the end of the third term of the fifth grade when the temporary school closure began. For the correspondence between $School\ close$ and each grade and term, see Appendix Table A-4.

parallel trend is established between the treatment and control groups. $\beta_0 \sim \beta_2$ represent the fact that temporary school closure had a significant effect on the math achievement of the treatment group in period t.

We also estimate the following model to identify the summer break effects in addition to the temporal school closure effects:

4.1.5. Baseline DID + SB

$$Y_{i,t} = \sum_{t=-2}^{3} \beta_t COVID19_i \times School\ close_t + \beta_4 Summer\ break_t + \beta_5 Shortened\ days_{i,t} + \mu_s + \mu_g + \mu_c + \epsilon_i \tag{5}$$

The value of β_4 helps determine that the summer vacation itself significantly affects math scores. β_5 indicates that shortening the summer vacation in 2019 has an impact on math achievement.

4.2. Subsample analysis

The effects of the temporary school closure may differ depending on students' academic performance before the intervention. Therefore, the full sample analysis may offset the estimated effects if the effects are heterogeneous across student achievement quartiles.

Thus, we calculate the quantiles for each treatment and control group based on the math scores one term prior to the period used in the analysis (i.e., the third term of the fourth grade) and divided the students into four subsamples. Then, we examine whether the effect is heterogeneous across achievement quartiles by estimating only those equations for which the common trend assumption is satisfied in the event study.

5. Results

In this section, we first present the DID and event study results using the full sample. We then show the subsample analyses for each quartile in the third term of the fourth grade.

5.1. Full sample results

The baseline estimations using equations (1) and (4) are shown in Columns 1 and 4 of Table 3. We also present the DID and event study results, controlling for variables related to the summer vacation, in Columns 2 and 5 of Table 3. Column 3 of Table 3 shows the estimated effects in the second term of the sixth grade.

(Table 3 around here).

We find that the coefficient "COVID19 × P5T3_P6T3," representing the overall effect, including the impact of temporary school closure and shortened summer vacation, is positive and significant (5.275) in Column 1 of Table 3. Thus, we can conclude that the overall effect of temporary school closure and shortened summer vacation increased math scores by approximately 5.3 points.

Next, the result from equation (2), controlling for the effect of the shortened summer vacation, shows that the coefficient of "COVID19 × P5T3_P6T3" is still positive and significant (4.474), and the coefficient of “Shortened days” is positive and significant (0.2333 per day) in Column 2 of Table 3. These results suggest that the reduction in summer vacation days partly caused an overall improvement in math scores. We also confirm that the coefficient of "Summer break" is negative and significant (-3.976), indicating that the summer break itself lowered the math test score.

Column 3 of Table 3, which shows the result from equation (2) (controlling for the effect of the shortened summer vacation), shows that the coefficient of "COVID19 × P5T3_P6T3" is negative (-2.082) and significant at the 10% level in Table 3, Column 2. This result indicates that the temporary school closure lowered the math score by about 2.1 points. On the other hand, the coefficient of "COVID19 × After P6T2" is positive and significant (11.64), indicating that the math score increased by about 11.64 points in the second term of the sixth grade. We also confirm the effect of shortening the summer break and find that the coefficient of Shortened days has changed to negative and insignificant (-0.0004). These results suggest that the effect of shortened summer break is the opposite before the COVID19 school closure (Shortened days) and after (COVID19 × After P6T2). The coefficient of "Summer break" is still negative and significant (-2.555), but the absolute magnitude is smaller than that in Column 2. However, Column 2 does not distinguish whether the shortened summer vacation was before or after COVID19. As a result, the individual effect of the summer vacation and the effect of the COVID19 school closure "COVID19 × P5T3_P6T3" may not have been correctly identified. Therefore, we make our conclusions based on the results in Column 3.

In summary, the temporary closure of the school caused a drop of about 2.1 points in mathematics scores, but the shortened summer vacation and the introduction of ICT terminals increased mathematics scores by about 9.1 points in the medium- and long-term.[26]

Next, we confirm the results of the event study in Columns 4 and 5. Both results show that math scores decreased just before the temporary school closure and increased in the

[26] Considering that the summer vacation of the FY2020 P6 cohort was 27 days shorter than that of the FY2018 cohort due to temporary school closures, the FY2020 P6 cohort increased their math scores by approximately 9.1 points (11.64 -0.0004×27-2.555) in the second term of sixth grade.

second term of the sixth grade. However, the results for parallel trends differ between the two results. In Column 4, which does not consider the effect of the shortened summer vacation, the coefficient is significant for the second term of the fifth grade (SC = −1). On the other hand, in Column 5, where the summer break dummy (Summer break) and the shortened days of summer vacation (Shortened days) are taken into account, parallel trends can be confirmed for the terms before the third term of the fifth grade. Therefore, as with the DID results, we use the event study based on Column 5 for the main estimation, adding the variable for the summer vacation.

From Column 5, we find that math scores decreased in the third term of the fifth grade and the first term of the sixth grade by about 4.79 points and 2.97 points, respectively. However, the coefficient of "COVID19×P6T2" and "COVID19×P6T3" are positive and significant (14.41 and 7.22, respectively). These results are consistent with the DID results. Therefore, we conclude that the negative effects of the temporary school closure remained for a short period until the end of the term following the closure. However, after the end of the next term, academic performance turned around and improved significantly, resulting in higher academic performance levels than that before the closure.

5.2. Subsample analysis

Next, we calculate the score quantile (P4T3) using the math scores of the third term of the fourth grade and examine if the effects of the policy intervention differ depending on the math performance prior to the temporary school closure. Tables 4 and 5 present the baseline DID and event study results, including the overall effects of the temporary school closure and shortened summer vacation, in Columns 1 to 4, and the results of equation (3) are shown in Columns 5 to 8.

(Tables 4 and 5 around here).

First, Columns 1-4 of Table 4 show that the temporary closure of schools due to COVID 19 eventually increased math scores in all quartiles except the highest academic quartile. However, all but the fourth quartile showed positive coefficients at the 1% significance level (about 7.137, 7.410, and 6.479 points, respectively).

Next, we confirm the effects of the shortened summer vacation and the second term of the sixth grade, and the temporary school closures separately in Columns 5-8. The results show that the coefficient of "COVID19 × P5T3_P6T3" is negative and significant for the first and fourth quantiles. In contrast, the coefficient of "COVID19 × After P6T2" is more significant for the students in the lower academic quartiles in P4T3. Furthermore, comparing the magnitudes of the estimated coefficients, "COVID19 × After P6T2" (+) is much larger than "COVID19 × P5T3_P6T3" (-) for all quantiles. We also find that the lower the math score quantiles in P4T3, the higher the math scores increase in the second term of the sixth grade. These results indicate that the shortened summer break and the introduction of ICT terminals improved math scores, especially in the lower academic quartiles. In addition, the summer break significantly lowered the math scores in the higher quartiles, and shortened days of summer break significantly lowered the scores only in the first quartile and increased the scores only in the fourth quartile. Thus, the study reveals that the summer break itself lowered the academic performance of the middle and upper quartiles, while the shortened summer break, on the contrary, lowered the academic performance of the lowest quartile.

Next, we proceed with the event study results. We first examine the coefficients of "COVID19 × P5T1" and "COVID19 × P5T2" to verify the parallel trend. Similar to the full-sample analysis results, Columns 1-4 of Table 5, which do not control the variable on summer vacation, show that the coefficient is significant in the second term of the fifth grade (SC = -1), except for the fourth quartile. On the other hand, Columns 5-8 of Table 5 show that the pre-treatment differences between the treatment and control groups are not significant for most terms. Therefore, we mainly discuss the results in Columns 5 to 8, even for the subsample analysis, where parallel trends can be assumed.[27]

The coefficients for "COVID19 × P5T3" are negative and significant for all quartiles; the first to third quartiles show a larger drop in math scores due to temporary school closure than the fourth quartile. However, the coefficients for "COVID19 × P6T1" are negative at 5% and 1% only for the bottom 25% and top 25%, respectively. These results suggest that while the lowest and middle quartiles (second and third quartiles) of math scores declined by the same degree in the third term of grade 5, the middle quartiles were faster to recover from the decline in math scores by the first term of grade 6 than the lowest quartiles. We also find that "COVID19 × P6T2" and "COVID19 × P6T3" yielded positive and significant coefficients for all quartiles, indicating that math scores improved in the second term of the sixth grade. Finally, we found that the summer break itself decreased the math scores of the middle and upper quartiles, and the lower the quartile, the lower the math score caused by the shortened summer vacation in 2019.

These findings in the event study are consistent with the DID results. Therefore, we conclude that math scores increased significantly from the end of the second term of grade 6, especially in the lower quartiles.

[27] In the fourth quartile, the coefficient of "COVID19 × P5T1" is significant, but the coefficient of "COVID19 × P5T2," which is the term before the temporary school closure, is non-significant for all quartiles. As a result, a parallel trend is established here.

6. Effect heterogeneity due to disadvantaged living conditions

The literature shows that living conditions, such as home environment and physical and mental conditions, differed during the COVID-19 pandemic (see Section 3.4.) Therefore, the effect of temporary school closure on math scores may vary among students with different living conditions. However, differences in the timing of the introduction of ICT terminals may also lead to heterogeneity in the effects of ICT terminals; the earlier the school introduced ICT terminals, the more pronounced the change in mathematics scores would be.[28] Therefore, we control for the number of days earlier that ICT was introduced when compared to the schools with the latest introduction (ICT early days).

To test the hypothesis that disadvantaged living conditions during and after the temporary school closure lead to heterogeneity in the effects of the temporary school closure, we add the living situation dummies — treatment variables — and the number of days that ICT was introduced earlier — a control variable — to equations (1)–(5).

6.1. Full sample analysis

Table 6 shows the estimation results of equations (1) through (5) with variables representing the disadvantaged living conditions and earliness of ICT adoption as explanatory variables. Figure 6 shows the estimated coefficients. Figure 7 also graphically compares the estimated results from the event study that controls only for the summer vacation dummy and school/class fixed effects (green line), with the estimated results when the disadvantaged living environment is also controlled for (pink line).

[28] The coefficients can be both positive and negative. Based on the results of Section 5, the introduction of ICT terminals does not lower math scores, and consequently a positive coefficient is the result of the teachers' appropriate utilization of ICT, while a negative coefficient is evidence that ICT terminals were not used appropriately.

(Table 6 and Figures 6 and 7 here).

From the results in Table 6, several explanatory variables show different coefficients considering disadvantaged living conditions and the earliness of ICT adoption.

Notably, in Columns 3 and 5, the negative and significant coefficients of "COVID19 × P5T3_P6T3" for DID and "COVID19 × P6T1" for the event study in Table 3 have changed to positive values. However, the coefficient of "COVID19 × P5T3," which is the result immediately before the disadvantaged living condition treatment, is still negative and significant. These results indicate that the greatest decline in math scores in P6T1 can be explained by the disadvantaged living conditions created due to temporary school closures. The graphical results also show that, compared to the results in Section 5, the coefficients of all samples are positive and significantly more prominent in the first term of sixth grade, and that the sign has changed from negative to positive in Figure 7.

Next, we observe that the magnitude of the coefficient "COVID 19 × School close = 2" in Column 5 has increased compared to the results in Table 6 (from 14.41 to 21.11). Figure 7 also shows that the difference between the coefficients with and without considering the disadvantaged living conditions is larger in the second term of the sixth grade than in the first term.

The coefficients of the living condition dummies are similar for both the DID and event study. We have five significant coefficients at the 5% level for the disadvantaged living condition dummies. First, students who did less print learning during the school closure, "Lack print study (May)," had lower math scores of about 8.1 points. Second, students who had difficulty concentrating on their studies after the closure, "Lack study (June)," had lower math scores about 2.7 to 3 points. Third, students who did not get enough sleep during and after the closure, "Lack sleep," had lower math scores of about 2.1-2.6 points. Fourth, students who reported feeling uninspired during and after the closure, "No passion," received about 5.3 points lower math scores. Finally, students who did not do much physical activity during and after the closure, "No sport," got about 2.4 to 3.1 points lower.

The coefficients of "ICT early days" are negative for the both estimation methods. However, the variable is negatively correlated with the math scores before the temporary closure of the school (see Appendix Table A-5). Therefore, the coefficient of "ICT early days" may become negative and significant due to the positive correlation that it develops with the disadvantaged living environment when latter variable is taken into account. Thus, we conduct the same estimation after matching the sample based on the grade 4 math scores just before the sample period (see Appendix A) and find that the coefficient of "ICT early days" has become non-significant at the 5% level (see Appendix Table A-6).[29] This finding suggests that the early introduction of ICT terminals does not affect the math scores on average, considering the self-selection problem of how early to implement ICT based on the difference in the math scores before ICT introduction.

In summary, we can conclude that the disadvantaged living environment hindered students' growth in math scores after school closure.

6.2. Subsample analysis

Tables 7 and 8 show the results of the subsample analysis after incorporating the variables related to the living condition and earliness of ICT introduction; Columns 1-4 and 5-8

[29] See the Appendix B for greater detail. Appendix Figure 6 shows that using the full sample without matching estimation, the estimated coefficients with and without considering the early days of ICT adoption are similar, and the difference is not statistically significant. Therefore, we can conclude that, regardless of the matching estimation, considering the early adoption of ICT does not bias the results in Table 6.

show the results without and with the variables related to the summer break, respectively. Figure 8 shows only the estimated coefficients. Figure 9 graphically shows the results obtained from the subsample event study in the same manner as Figures 6 and 9.

(Tables 7 and 8, Figures 8 and 9 around here).

Especially for the first quantile, the DID results show that "COVID19 × P5T3_P6T3" in Column 1 in Table 7 has larger coefficients than the one in Table 4. Moreover, the overall effect, "COVID19 × After P6T2" − "COVID19 × P5T3_P6T3," estimated in Column 5 in Table 7 also become higher than the results in Table 4 because the coefficient of "COVID19 × P5T3_P6T3" changes from negative to positive. For the event study results in the first quartile, we also find that the coefficient of "COVID19 × P6T1" that was negative in Table 4 (significant at the 5% level in Column 5) changes to positive and significant at the 5% level in both Columns 1 and 5 in Table 8.[30] These results indicate that the decline in math scores in the first quartile was mostly derived from disadvantaged living conditions during and after the temporary school closure. Moreover, these results are consistent with the finding in Figure 11 that the difference in coefficients with and without consideration of the disadvantaged living conditions is most pronounced for the lowest-performing students.

We also found that the effects of disadvantaged living conditions on math scores differed between the lower and upper achievement groups. Disadvantaged living conditions had a negative impact, especially in the lower academic ability groups. For

[30] Similar to Table 5, the Event study results in Columns 1-4 of Table 8 reveal that the coefficients of "COVID19 × School close=-1" are significant in the second term of the fifth grade except for the fourth quartile. In contrast, Columns 5-8 of Table 8 show that the coefficients are non-significant in all quartiles. As a result, we discuss the results in Columns 5-8 assuming the parallel tread.

almost all students, the coefficients for "Lack study (June)" are negative and significant. Only in the first quartile, "Lack sleep" and "Bad health" show negative and significant coefficients. For students in the bottom 50% only, we confirm negative and significant coefficients for "Lack print study (May)" and positive coefficients for "Feel unsafe" In the first and third quantiles of students, the math scores of the students who answered "No passion" showed negative and significant coefficients. Finally, only in the second and fourth quartiles, “No sport” shows positive and significant coefficients.

The results show that "ICT early days" have a negative and significant coefficient (about -0.46 points per day and about -0.33 points per day) only in the first and third quartiles in both DID and event study as the full sample results.[31] However, Appendix B show that considering the early days of ICT adoption makes the estimated coefficients larger, but the difference between the coefficients with and without considering "ICT early days" is statistically insignificant. Therefore, we conclude that the relatively early introduction of ICT terminals did not fatally bias the results in Tables 7 and 8 because the early ICT adoption reduced test scores only in some quintiles, but the magnitude was not significant.

The results for the other variables are similar to those in Tables 3 and 4. We conclude that, especially in the bottom quartile, the students who faced disadvantaged living conditions during and after temporary school closure did not improve their math scores sufficiently after school closure.

[31] The estimate including “ICT early days” without considering the living conditions and the matching estimate as the full-sample analysis reveal similar results (see Appendix Tables A-7 and A-8).

7. Mechanism

The analysis in the previous section shows that the COVID-19 related temporary school closure lowers students' math scores in the short term but increases their math scores in the medium-to-long term by increasing the number of school days. However, the mechanism behind the improvement in math scores has still not been clarified. For example, increasing school days to compensate for the delay in learning during the temporary school closure period may have caused students to dislike studying or caused their mental health or non-cognitive abilities to deteriorate due to intense studying. If such an adverse effect occurs, it would be difficult to rejoice in the mid-to long-term improvement of math scores. Therefore, this section aims to elucidate the mechanism of mid -to long-term increases in math scores by examining whether students' motivation and attitude toward learning math changed due to the temporary school closure, as well as looking at the estimation method introduced in Section 4.

7.1. Data

In addition to the "Manabi Nara" conducted at the end of each term to measure the level of learning achievement in math, Nara City conducts a questionnaire for students twice a year to understand their motivation and attitude for learning math. The survey is conducted every May and December. However, in May 2020, when the school was temporarily closed, this survey was not conducted because the living conditions survey introduced in Section 3.4 was conducted. However, we have four surveys (two time points and two cohorts) conducted in December for the COVID-19 experienced group (FY 2020 P6 cohort) and the COVID-19 not-experienced group (FY 2019 P6 cohort) in grades 5 and 6. Therefore, we can make causal inferences about the effect of temporary school closures on the students' motivation and attitude toward learning math by estimating the DID between cohorts (first difference) before and after the temporary school closure (second difference). For the first difference, as in Section 4, we create a COVID-19 experience dummy "COVID19" that takes 1 for the COVID-19 experienced group and 0 otherwise. For the second difference, we make a "P6 survey" dummy that takes 1 for December in P6 after the temporary school closure and 0 for December in P5.

We use 10 outcome variables common to the four surveys, including students' motivation and attitudes toward learning math.[32] For these questions, students choose one of the following four options: "Yes," "Partly Yes," "Partly No," and "No." Therefore, this study creates a dummy variable that takes one if the student chooses "Yes" or "Partly Yes," and 0 otherwise, and uses it as the outcome variable.[33]

Figures 10 and 11 show the difference between the means of the outcome variables over the two years for the full sample, and for each quartile of the fourth-grade third-semester math scores. Panel A shows the results for the FY2020 P6 cohort and Panel B shows the results for the FY2019 P6 cohort.

(Figures 10 and 11 here).

7.2. Estimation method

Figures 10 and 11 show that the COVID-19 experience group has slightly improved motivation and attitude toward learning math in both the full sample and quartile subsamples. However, these differences in means do not consider not only the effects of

[32] See Appendix Table 9 for details of each question and definitions of each of the outcome variables.
[33] See histogram of the motivation and attitude of math for FY2019 P6 Cohort and FY 2020 P6 Cohort in Appendix Figure 2 and 3, respectively.

school and classroom, but also the living conditions under temporary school closures. In addition, Panel B of Figures 10 and 11 show that several outcomes declined from grade 5 to grade 6 in the COVID-19 non-experienced group. In such a case, the effect of the temporary school closure may be underestimated if only the COVID-19-experienced group is used for a comparison before and after the temporary school closure.

Therefore, we use the following DID to test the effect of temporary school closure on motivation and attitude toward learning math:

$$Y_{i,t} = \gamma\ COVID19_i \times P6\ survey_{i,t} + X_{i,t} + \mu_s + \mu_c + \epsilon_i \tag{6}$$

$Y_{i,t}$ includes the 10 outcome variables of individual i in term t, capturing the students' motivation and attitude toward learning math. $COVID19_i \times P6\ survey_{i,t}$ takes 1 if the student belongs to the COVID-19 experienced group and the survey timing is December of grade 6. Hence, the parameter of interest—the coefficient γ—captures the effects of temporal school closure on students' motivation and attitude toward learning math. $X_{i,t}$ include other treatment variables, representing the living conditions during and after temporal school closures and the earliness of ICT introduction. μ_s and μ_c are the school (s) and classroom (c) fixed effects, respectively.[34]

7.3. Results

Figures 12 and 13 show the estimated coefficients γ of equation (6) for each outcome variable in the full sample and subsample, respectively; Panel A shows the results without

[34] Here, only one survey is available for each cohort in each year, and thus, the year fixed effects μ_g and $P6\ survey_{i,t}$ are perfectly consistent. Therefore, we exclude μ_g from the estimation in equation (6).

$X_{i,t}$, and Panel B shows the results with $X_{i,t}$.[35]

(Figures 12 and 13 around here).

The full sample analyses (Panel A in Figure 12) show that the COVID-19 experienced group increased the percentage of "Yes"/"Partially Yes" responses on several outcome variables among motivations and attitudes toward learning math, such as "Like math," "Math will be useful," "High motivation for Reco-sheets (reflection study sheets)," and "Motivation for other Reco-sheets." Moreover, the results of considering $X_{i,t}$ (Panel B in Figure 12) show that the coefficients of all outcome variables are statistically significant and higher than those in Panel A.

The subsample analysis without $X_{i,t}$ (Panel A in Figure 13), indicates that the COVID-19 experience group also demonstrates a higher and more significant coefficient of the outcome variables, but no significant differences are observed in the fourth quartile group. On the other hand, Panel B in Figure 13 also shows that higher and more significant coefficients are observed for many outcome variables, not only for the lower quartile but also for the fourth quantile. However, the estimated coefficients are the largest for the lowest academic achievement group, suggesting that the effect of disadvantaged living conditions may differ across academic quartiles.

Overall, the cohort who experienced temporary school closure due to COVID-19 show higher motivation and attitude toward math in the medium term. Specifically, students who chose "Like math" and "High motivation for the Reco Sheet (reflective learning sheet)" increased significantly. This finding suggests that the increase in math scores in the second semester of the sixth grade (six months after the temporary school closure) is

[35] Appendix Tables A-10 and A-11 show the DID results without and with considering $X_{i,t}$, respectively.

not the result of being forced to learn but is the result of the students' increased motivation to learn. Moreover, the effect of disadvantageous living conditions has resulted in more significant coefficients for the outcome variables, especially in the first quartile, which is also consistent with the fact that the disadvantaged living conditions hindered the increase in math scores in the medium- and long-term. Therefore, we conclude that the math scores increase when a certain period has passed after the temporary school closure due to the shortened summer vacation, fewer school events, and because the teachers' efforts after the second semester in FY2020 increased the students’ motivation and attitude toward learning math.

8. Conclusion

This study examined the short- and middle-term effects of three policy interventions on elementary school students: temporary school closures aimed at curbing the COVID-19 epidemic in Japan, a shortened summer vacation, and the introduction of ICT terminals.

However, in Japan, the National Achievement Test for elementary school students is conducted only once a year; therefore, short-term changes in academic achievement before and after temporary school closures cannot be captured. Hence, we used two cohorts of children — those who experienced COVID-19 school closures (FY2020 P6 cohort) and those who did not (FY2019 P6 cohort) — from the "Manabi Nara" math achievement test. This test is administered at the end of each term to the fourth through sixth graders in Nara City.

The analysis defined the former cohort of children as the treatment group and the latter as the control group. We then examined whether the difference between the two groups changed before and after the temporary school closure by using the DID and event study to analyze the data.

We present three main pieces of evidence. First, the temporary school closure decreased math scores, and the lower the quartile, the lower were the math scores of the student just before the temporary school closure (the third term of the fifth grade). Moreover, in the first and fourth quartiles, the negative effect on math scores persisted immediately after the temporary school closure (the first term of the sixth grade). Second, the drastic shortening of the summer break to compensate for the decrease in school days due to school closure and the introduction of ICT terminals significantly recovered and improved math scores. Once again, the lower quartile of math scores showed a more significant increase in math scores from the second term of the sixth grade. Third, motivation and attitude toward math also improved along with improving math scores six months after the school closure. Fourth, students that have disadvantaged living conditions during and after the school closure had lower math scores and motivation and attitude toward math. Further, the students from disadvantaged living conditions were negatively affected, especially in the lowest 25 % of academic ability groups.

These results have two implications. First, the increase in school days due to the shortened summer vacation and the introduction of ICT terminals in face-to-face classes can counteract the decline and reduce the gap in academic performance caused by temporary school closures. In Japan, besides the increase in school days due to the shortened summer vacation, the introduction of ICT terminals under face-to-face classes with full support from teachers is likely to have improved academic performance, especially among low-achieving students. These results suggest the importance of face-to-face support by teachers in promoting ICT use in education and have important policy implications when considering how to compensate for the loss of education due to temporary school closures.

The second policy implication is that students' disadvantaged living conditions should be taken care of appropriately according to their academic ability because the negative impact of disadvantaged living conditions under temporary school closure on academic performance varies according to students' academic achievement. For example, Carlana and La Ferrara (2021) found that online support for students from disadvantaged families during temporary school closures improved their academic performance. However, existing studies have not discussed the need for support for students from more privileged backgrounds. Therefore, our findings, which strongly support the need to improve disadvantaged living conditions regardless of academic hierarchy, can be considered substantial evidence to discuss the negative side effects of temporary school closure due to the COVID-19 pandemic.

One limitation of this study is that the data is from the core city (Nara City). We used the uniform test "Manabi Nara" for elementary school students in Nara City to examine the effect of temporary school closure on COVID-19. While this data has the advantage of a high frequency of testing, it has the disadvantage of not grasping the nationwide effect of temporary school closures. Therefore, a future study will be conducted to examine the effects of temporary school closures on the whole of Japan by using other nationwide surveys.

Appendix

Appendix A: Matching estimation

ICT terminals started being introduced earlier in schools with lower academic achievement (see Appendix Table A-5). In this case, the results may not be an effect of early ICT adoption, but simply a comparison of the growth in P6T2 between schools with low and high math scores. Therefore, as a robustness check, we created an ICT earliest dummy (ICT earliest), set to 1 if the earliest adoption of ICT terminals is in the top 50% and 0 otherwise, and matched the sample students using the following equation:

$$ICT\ earliest_{i,t} = \delta\ score_i + \varepsilon_{i,t} \qquad (A-1)$$

$score_i$ represents the math scores in the third term of the fourth grade. We compared nearest matching methods with two different distances: 0.2 calipers calculated by propensity score (NNM caliper 0.2) and Mahalanobis distance (NNM mahalanobis).

We discuss the validity of these matching methods and distances. Appendix Figure 4 shows that, for both estimation methods, the standardized mean difference after matching was within the range of 0.1 in terms of absolute value, which is considered a guideline. In particular, the test score of P4T3 was -0.2 in the original model before adjustment, which exceeded the guideline, so we can conclude that the matching was meaningful. Next, we confirmed which students were left behind by the matching, specifically whether the students were significantly reduced in certain quartiles. Appendix Figure 5 illustrates the cumulative density distribution (CDF, left axis) and the density distribution (PDF, right axis) of the test score before (green line) and after matching (orange and blue lines, for NNM caliper 0.2 and NNM mahalanobis), respectively. This figure shows that the CDF and PDF are almost unchanged before and after matching.

Based on the above results, this study considers that matching does not change the distribution of students' test scores but mitigates the effect of self-selection on the earliness of ICT terminal adoption derived from past test scores (in grade 4).

Appendix B: Effect heterogeneity of early adoption of ICT terminals

In Section 6, disadvantaged living conditions and early adoption of ICT terminals are included as explanatory variables at the same time, so we could not independently estimate the impact of the early adoption of ICT terminals on test scores. In other words, the result of Section 6 was the effect of the early adoption of ICT terminals conditioned by the effects of disadvantaged living conditions.

Hence, here we do not consider disadvantaged living conditions and estimate the following equation, which adds only the relatively earliness of ICT terminal adoption to the baseline estimation in equation (1):

Baseline DID + SB + Early ICT

$$\begin{aligned}Y_{i,t} &= \alpha_1 COVID19_i \times P5T3\_P6T3_t + \alpha_2 COVID19_i + \alpha_3 P5T3\_P6T3_t \\ &\quad + \alpha_4 Summer\ break_t + \alpha_5 Shortened\ days_{i,t} + \alpha_6 COVID19_i \times After\ P6T2_t \\ &\quad + \alpha_7 After\ P6T2_t + \alpha_8 ICT\ early\ days_{i,t} + \mu_s + \mu_g + \mu_c + \epsilon_{i,\,t} \qquad (A-2)\end{aligned}$$

Baseline Event study + SB + Early ICT

$$\begin{aligned}Y_{i,t} &= \sum_{t=-2}^{3} \beta_t COVID19_i \times School\ close_t + \beta_4 Summer\ break_t + \beta_5 Shortened\ days_{i,t} \\ &\quad + \beta_6 ICT\ early\ days_{i,t} + \mu_s + \mu_g + \mu_c + \epsilon_i \qquad (A-3)\end{aligned}$$

The difference between equations (1) and (2) and equations (A-2) and (A-3) is the addition of $ICT\ early\ days_{i,t}$ as an explanatory variable. This variable takes the value of the difference between the start date of ICT use at the elementary school of individual i and the start date of the slowest elementary school if $SC = 2$ or $SC = 3$ and 0 otherwise because ICT has not been introduced except in the second term of the sixth grade of the FY2020 P6 cohort. The parameters of interest are α_8 and β_6, and they show that early ICT introduction significantly affects math scores.

Full sample analysis

Appendix Table A-12 shows the results of the full sample estimation using equations (A-2) and (A-3) in Columns 3 and 4. In Columns 1 and 2, the results of equations (3) and (5) are included for comparison. We also graphically compare the estimated results from the event study in Figure Appendix Figure 6, where only the summer break dummy and school/class fixed effects are controlled for (green line), with the estimated results where the impact of early adoption of ICT is additionally controlled for (orange line).

(Appendix Tables A-12 and Figure Appendix Figure 6 around here)

The results show that although the estimated coefficient of "ICT early days" is negative in both the DID and event studies, the significant effect of the early introduction of ICT terminals on math scores was not confirmed. Moreover, the significance and signs of the coefficients of the other variables are similar to those obtained in Table 3. Moreover, comparing the magnitude of the coefficients, the addition of "ICT early days," which has a negative coefficient on test scores, resulted in a considerable estimated increase in scores in the second term of the sixth grade. Appendix Figure 6 also shows that while the coefficients become larger when the effect of early ICT adoption is considered, the difference is not significant. Therefore, we conclude that, on average, the early adoption of ICT does not have a significant impact.

Subsample analysis

Appendix Tables A-13 and A-14 and show the results of the subsample estimation using equations (A-2) and (A-3). Columns 1 to 4 of each table show the results of the baseline estimation for comparison. Appendix Figure 7 shows the estimation results obtained from the subsample event study in the same manner as in Figure 6.

(Appendix Tables A-13 and A-14; Appendix Figure 7 here)

The results show that "ICT early days" have a negative and significant effect (at the 10% level) on math scores only in the third and fourth quartiles only in the event study. The results for the other quartiles were similar to those for the full sample estimation. However, Appendix Figure 7 shows that considering the early days of ICT adoption makes the estimated coefficients larger, but the difference is not significant. In summary, the early introduction of ICT terminals lowered the test scores only in the third and fourth quartiles, although the magnitude was not significant.

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List of Figures

Figure 1: Timelines for policy interventions

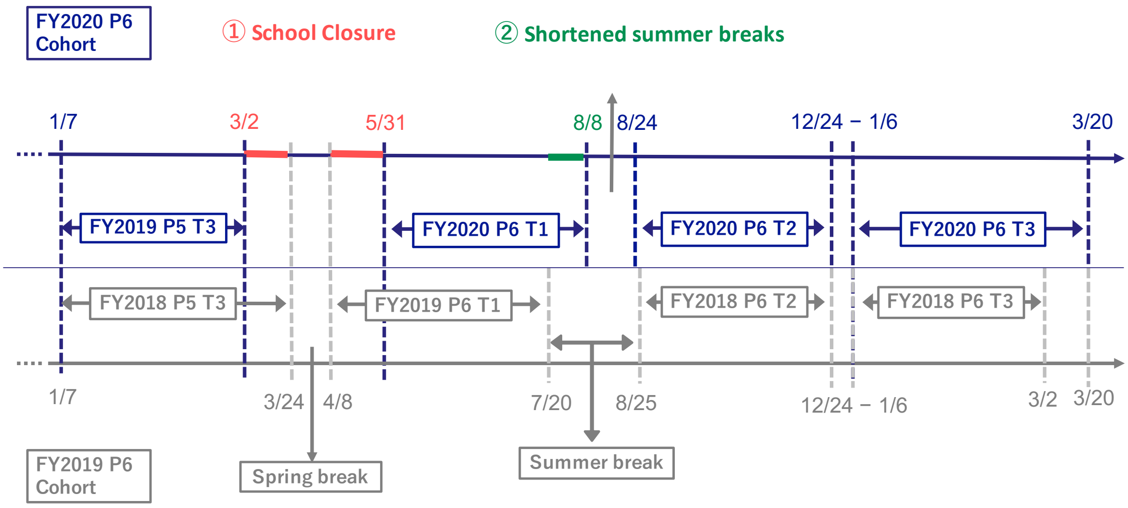


Figure 2: Cohort Types and Timing

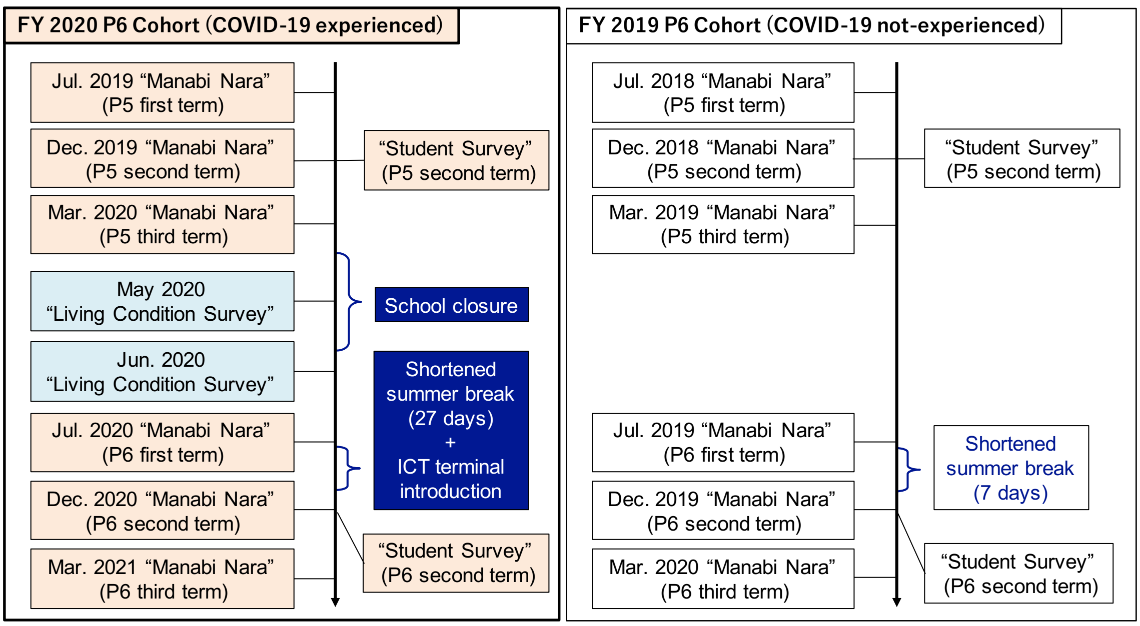


Figure 3: Change in math test scores (by cohort)

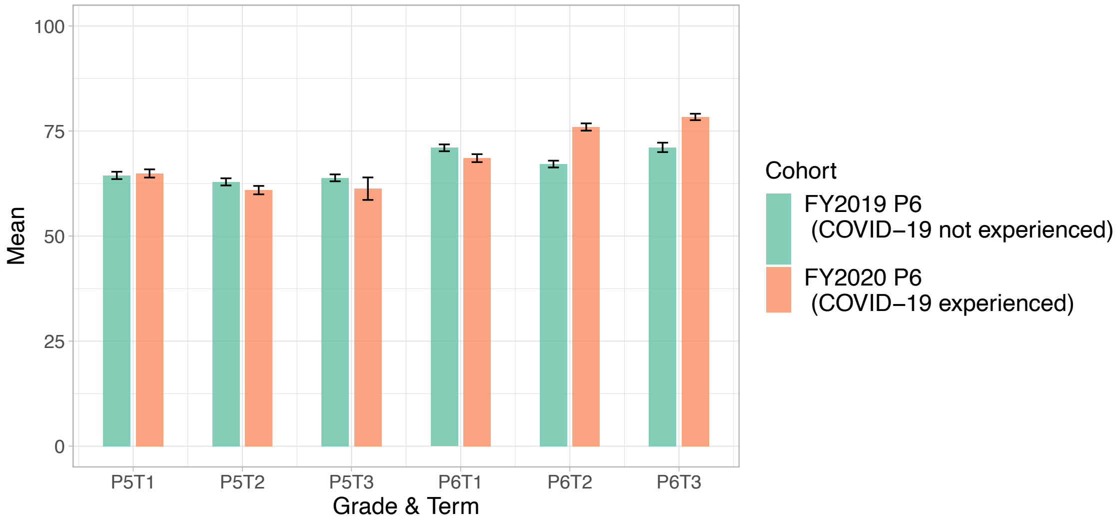


Figure 4: Change in math test scores (by cohort and quantiles)

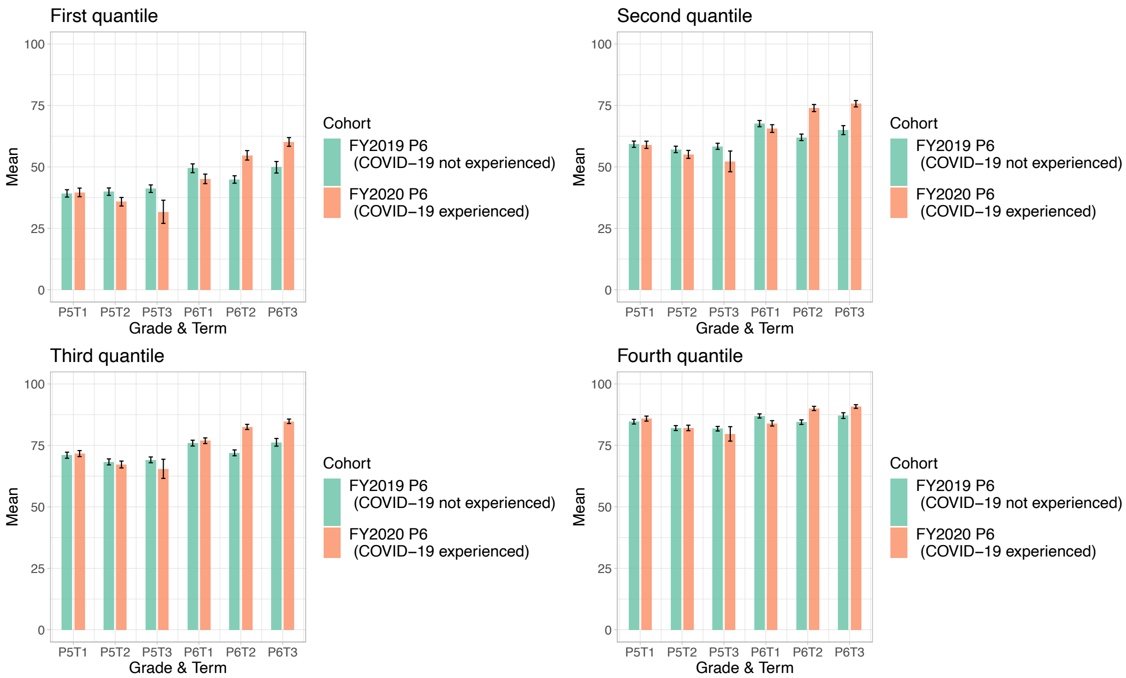


Figure 5: ICT Terminal Distribution

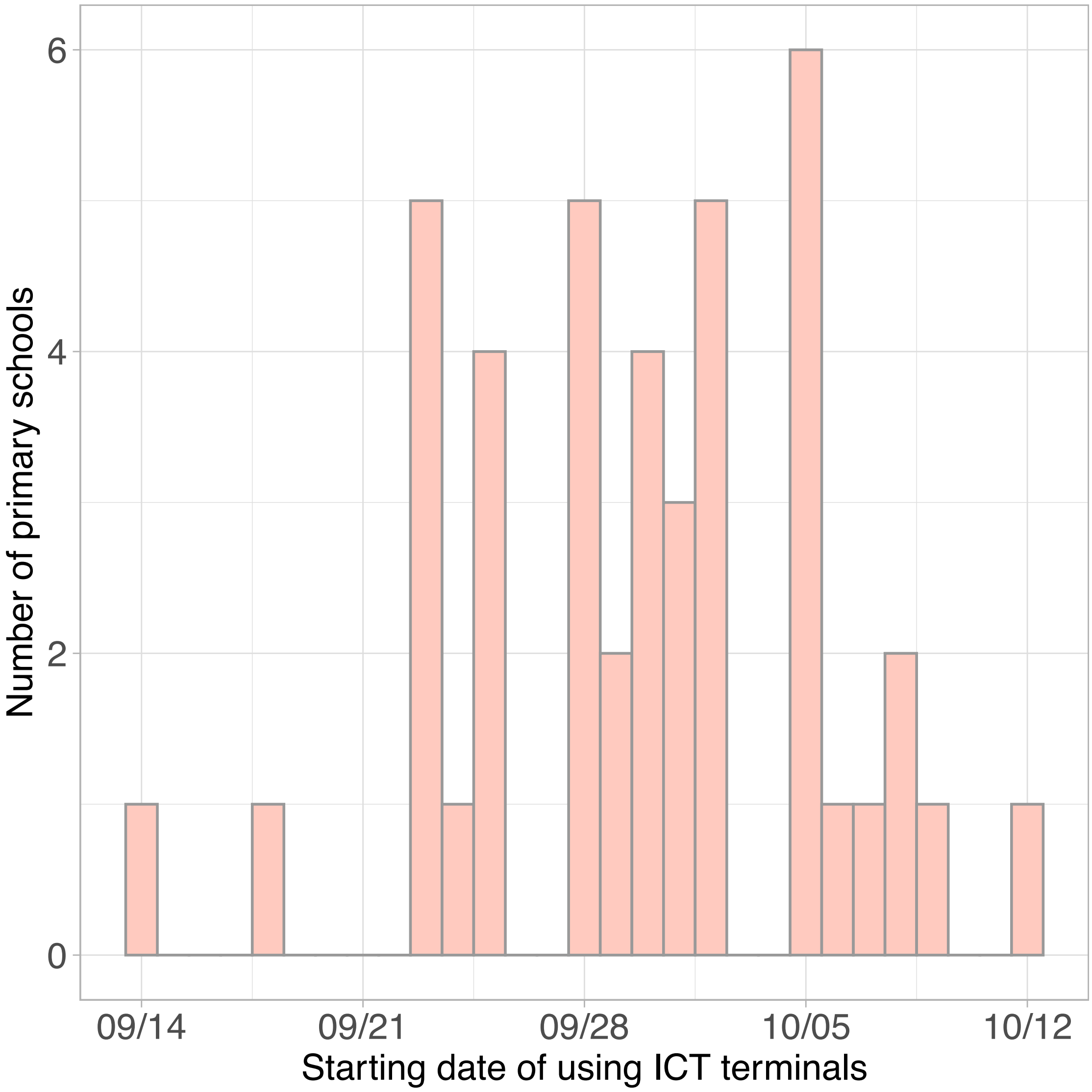


Figure 6: The Effects of Policy Intervention and Living Condition (Full sample)

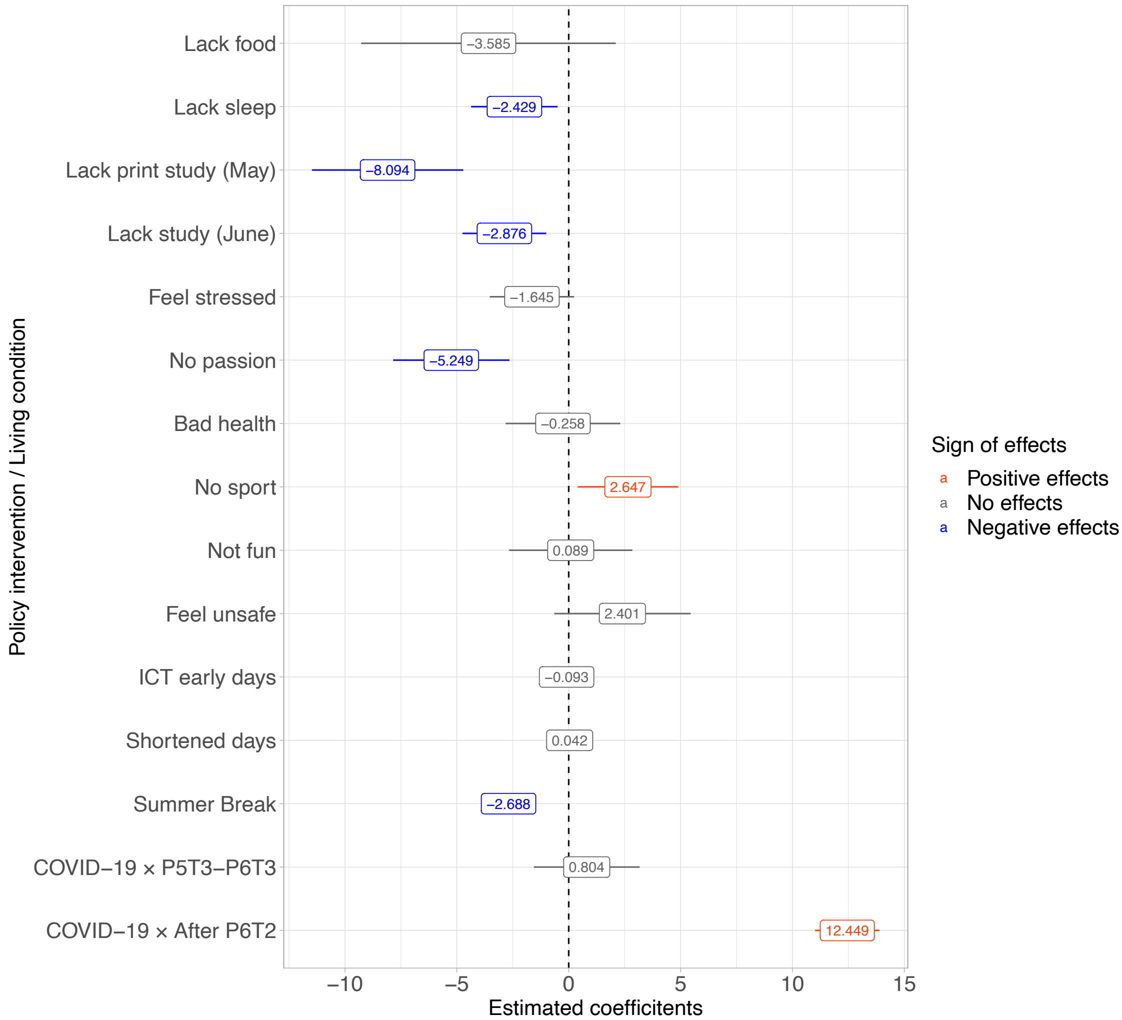


Figure 7: The Effect of Treatment Variables- Baseline vs Baseline + Early ICT + Living Condition (Full sample)

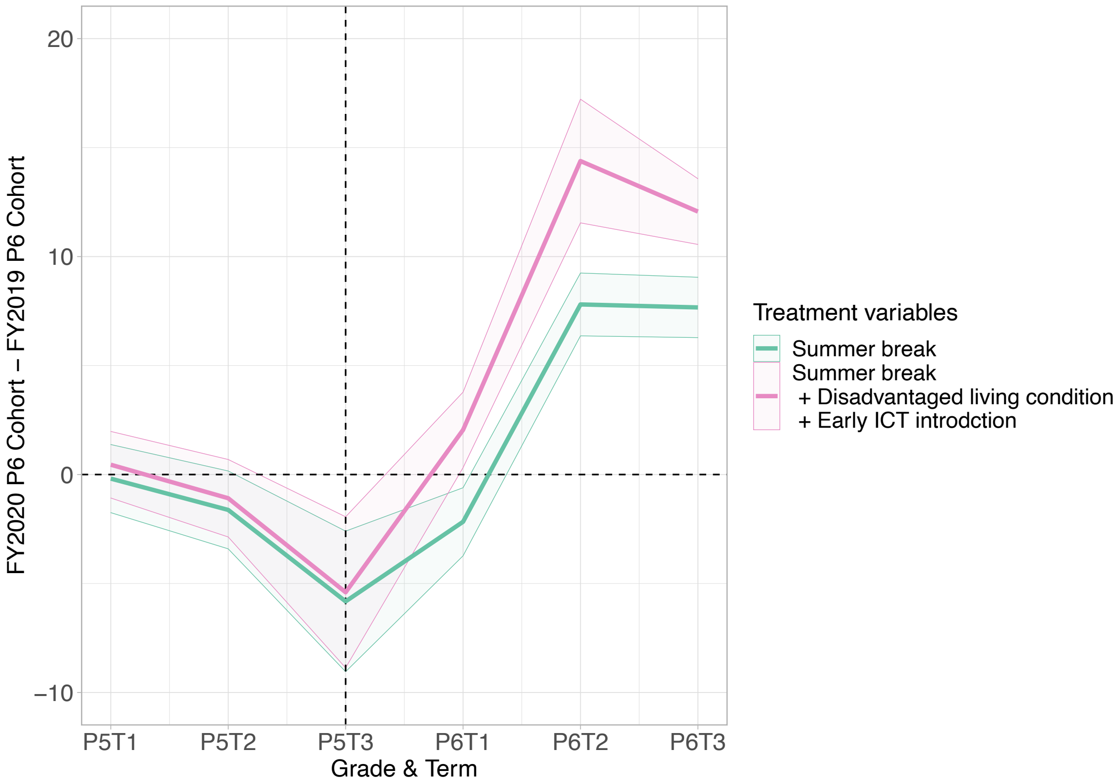


Figure 8: Estimated coefficients (Baseline + Early ICT + Living Condition, Subsample)

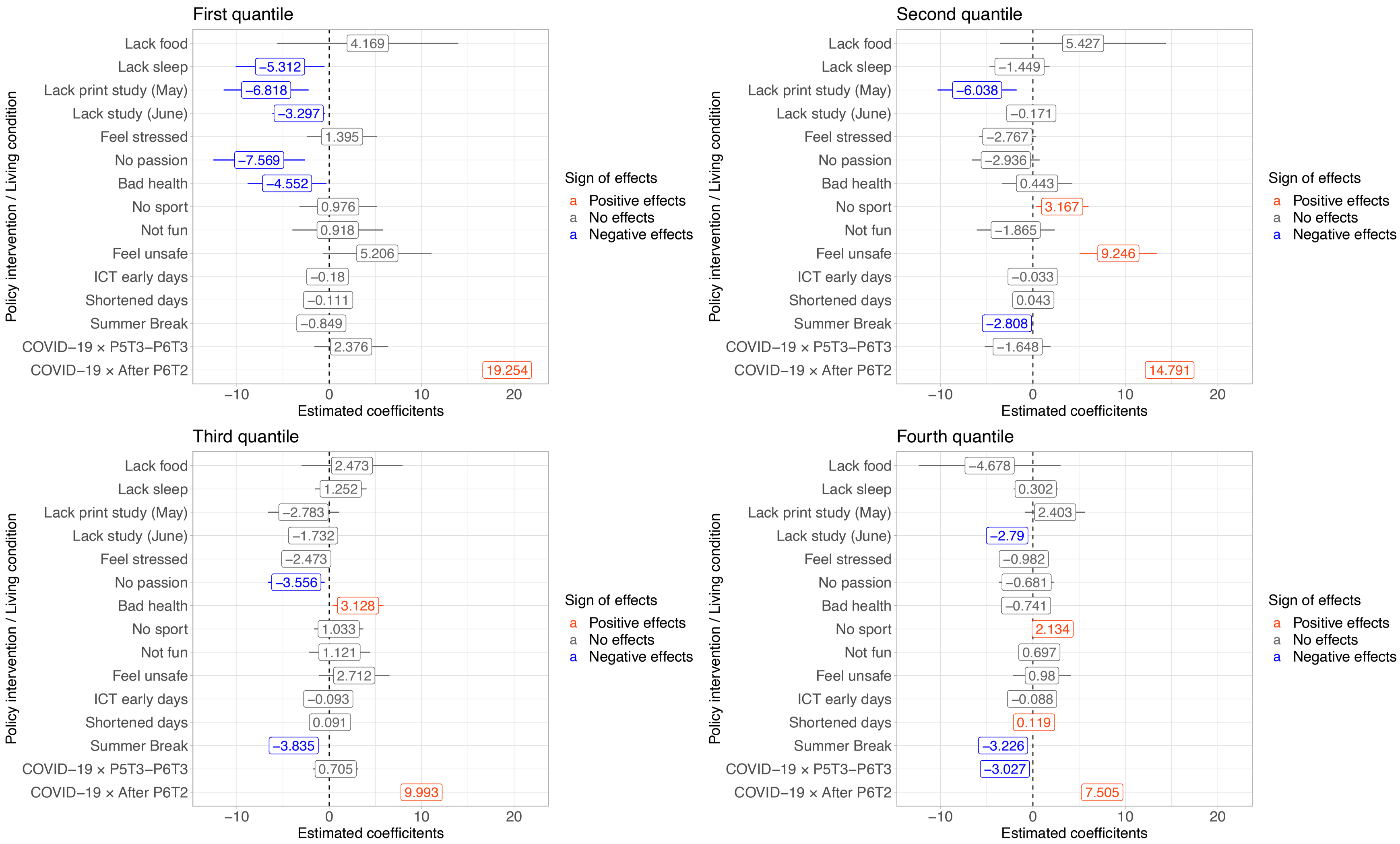


Figure 9: Baseline vs Baseline + Early ICT + Living Condition (Subsample)

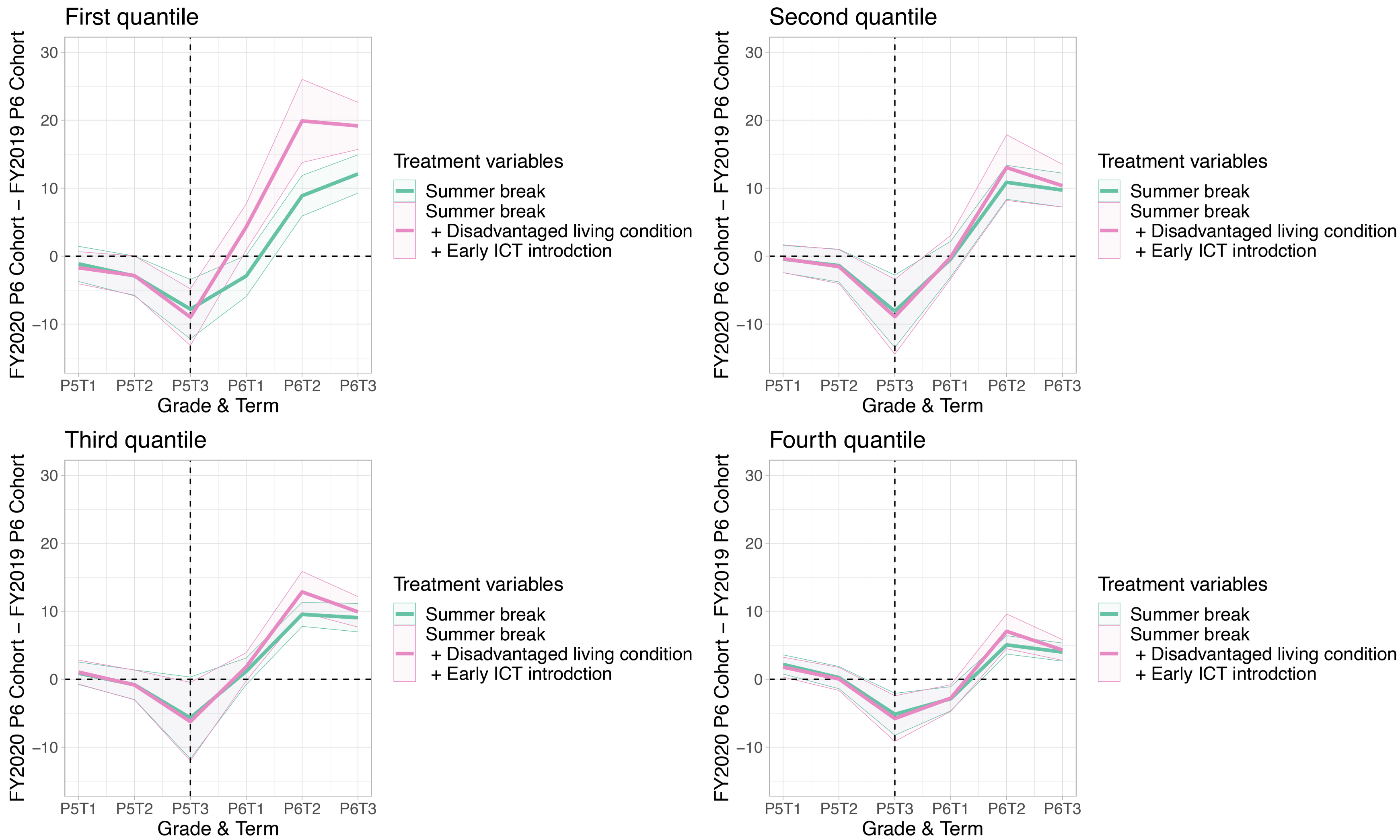
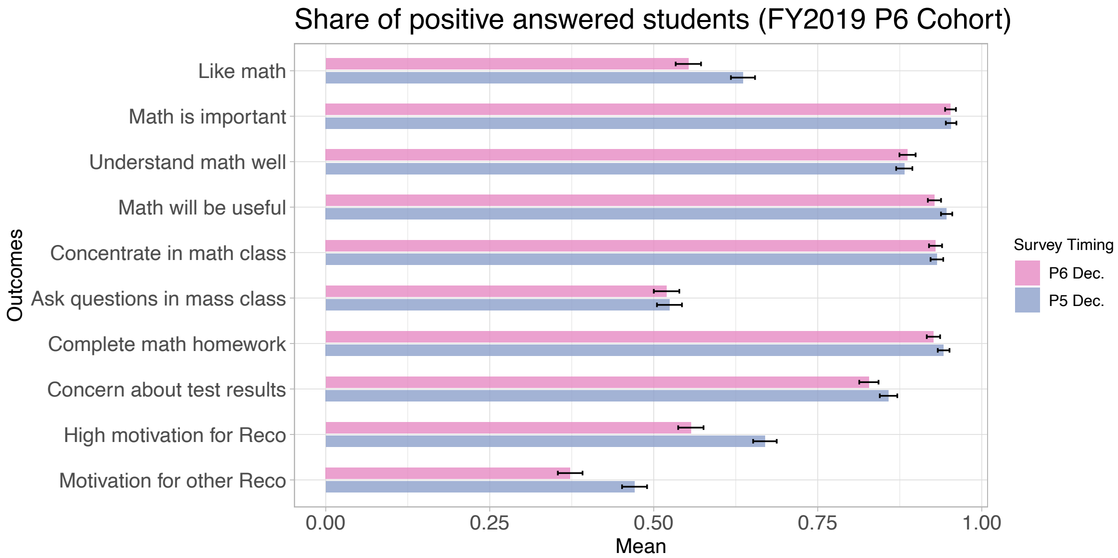


Figure 10: Mean of Positive Responses by Cohort (Full sample)

Panel A: FY2019 P6 Cohort



Panel B: FY2019 P6 Cohort

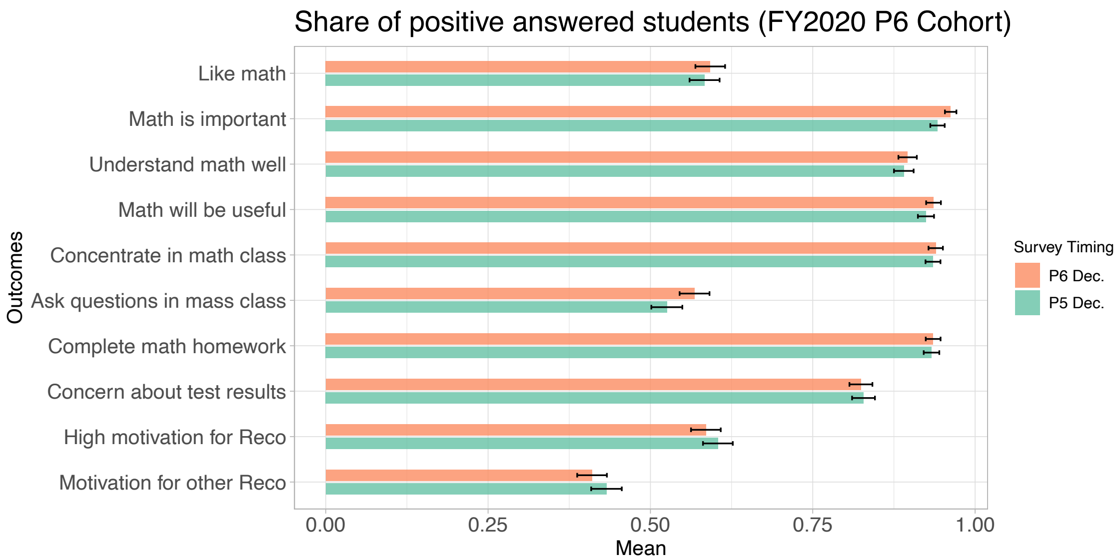
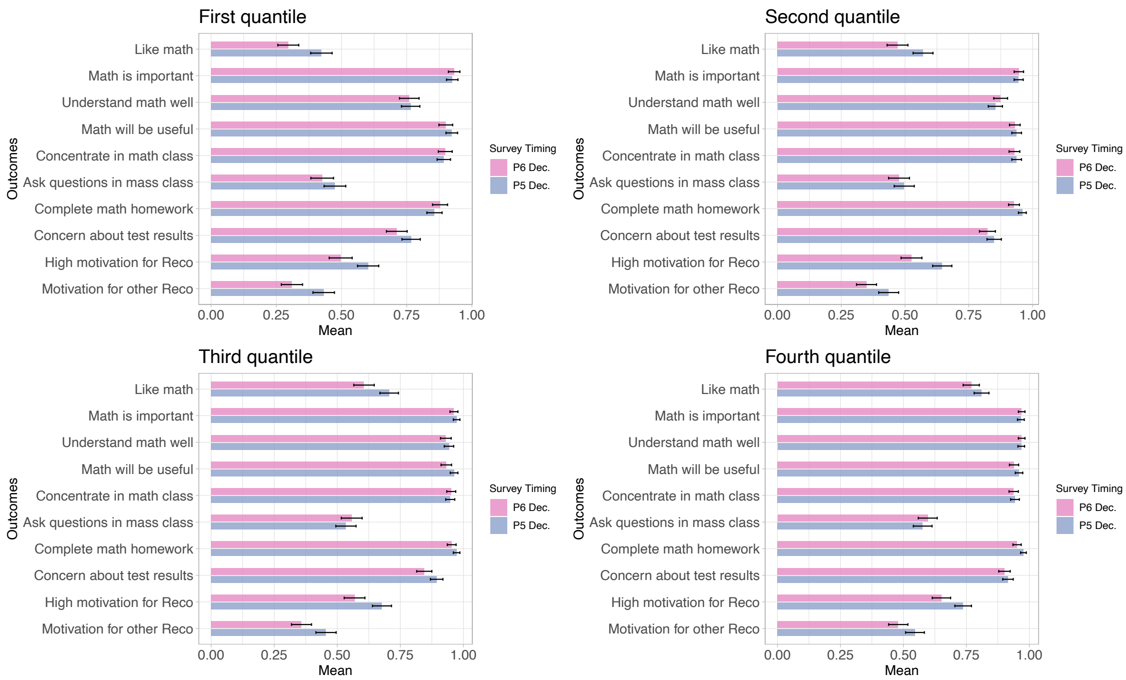


Figure 11: Positive Student Responses by Cohort (Subsample)

Panel A: FY2019 P6 Cohort



Panel B: FY2020 P6 Cohort

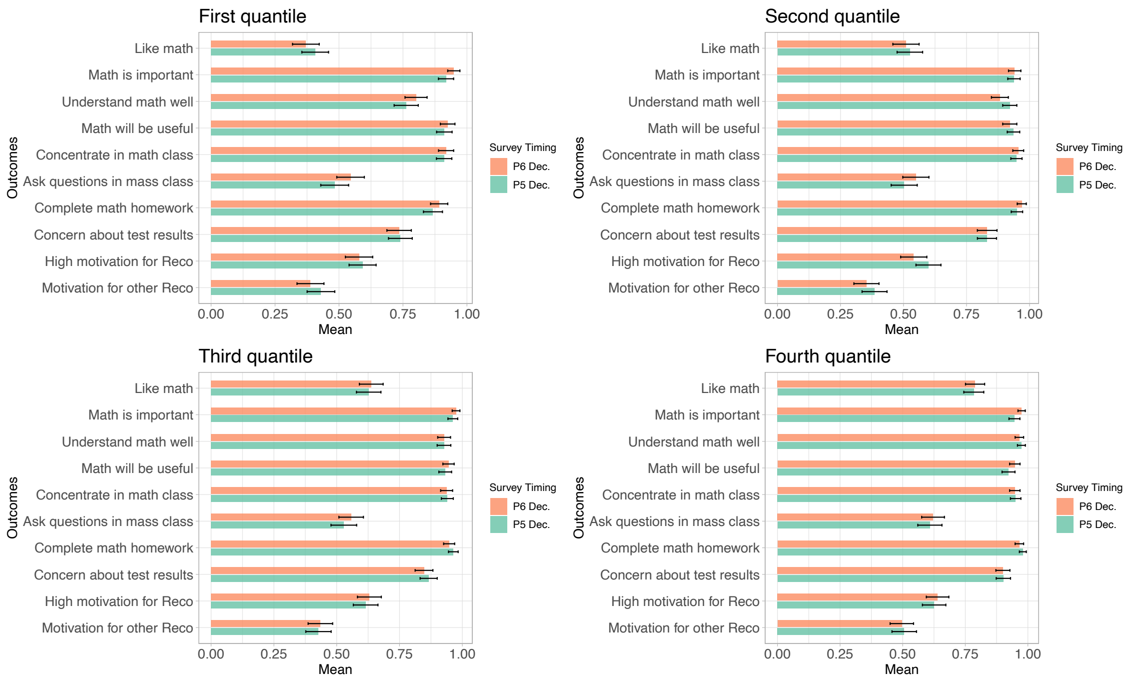
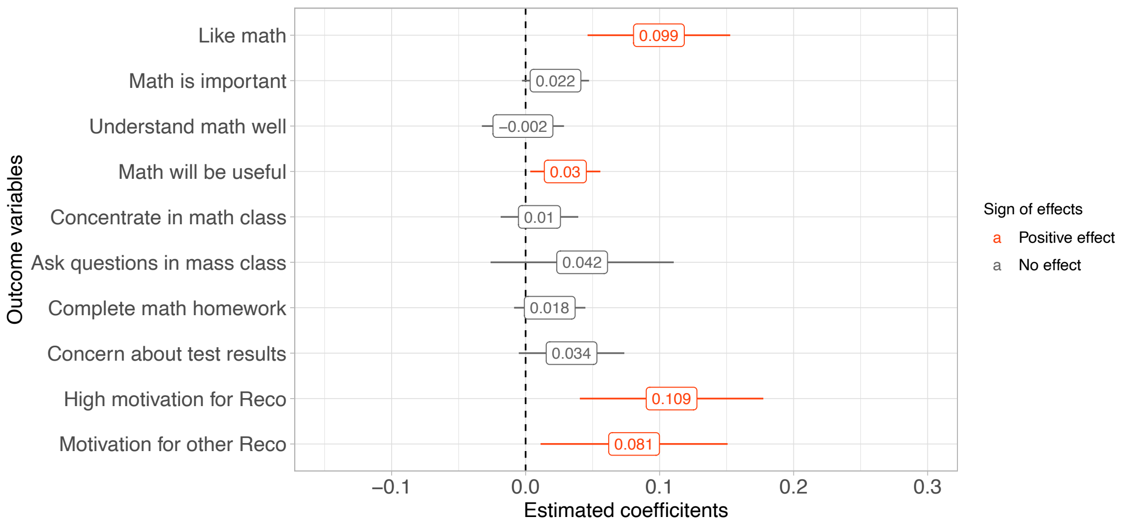


Figure 12: Estimated coefficients of other outcome variables (Full sample)

Panel A: Without other treatment variables



Panel B: With other treatment variables

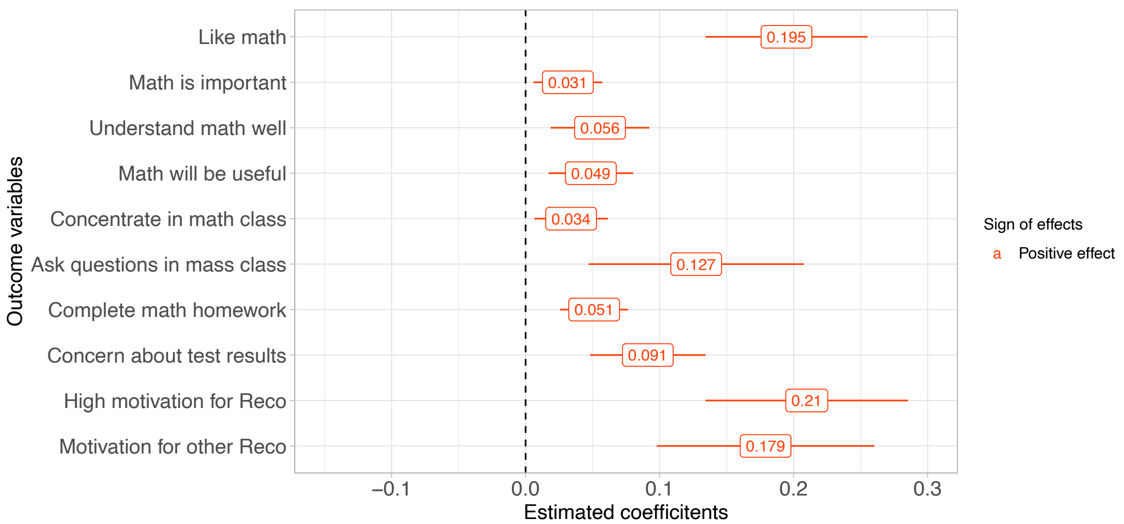
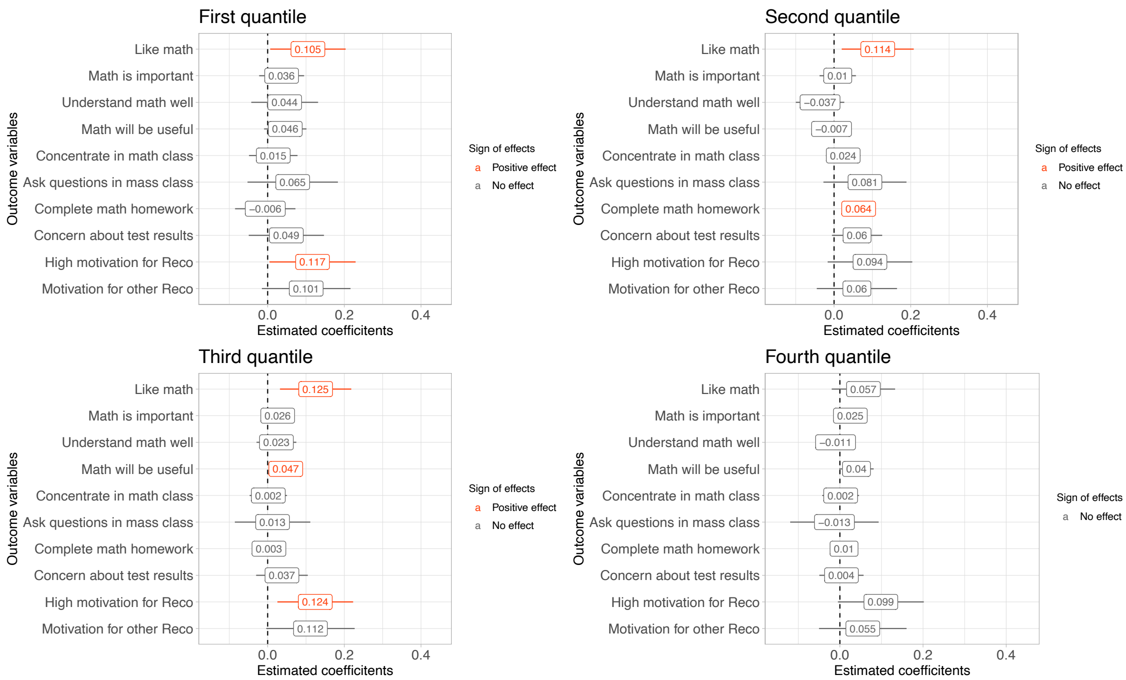
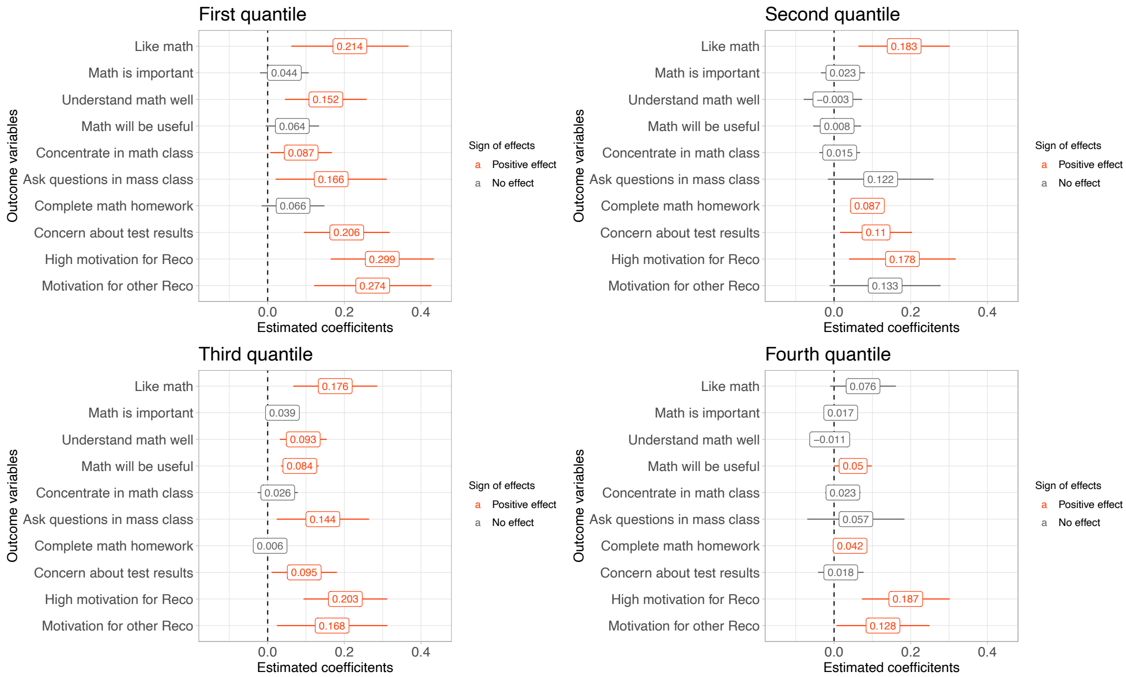


Figure 13: Estimated coefficients of other outcome variables (Subsample)

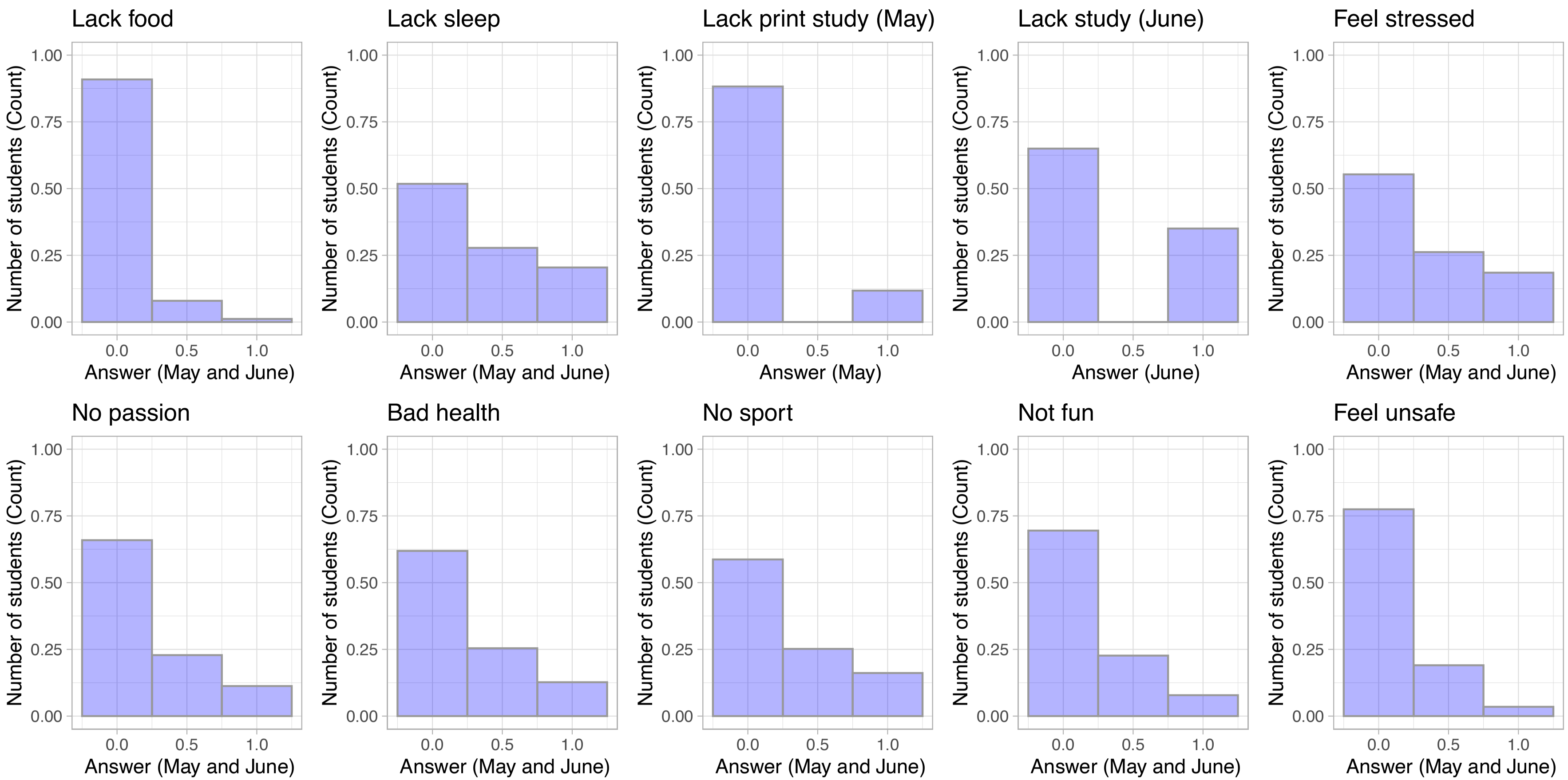
Panel A: Without other treatment variables



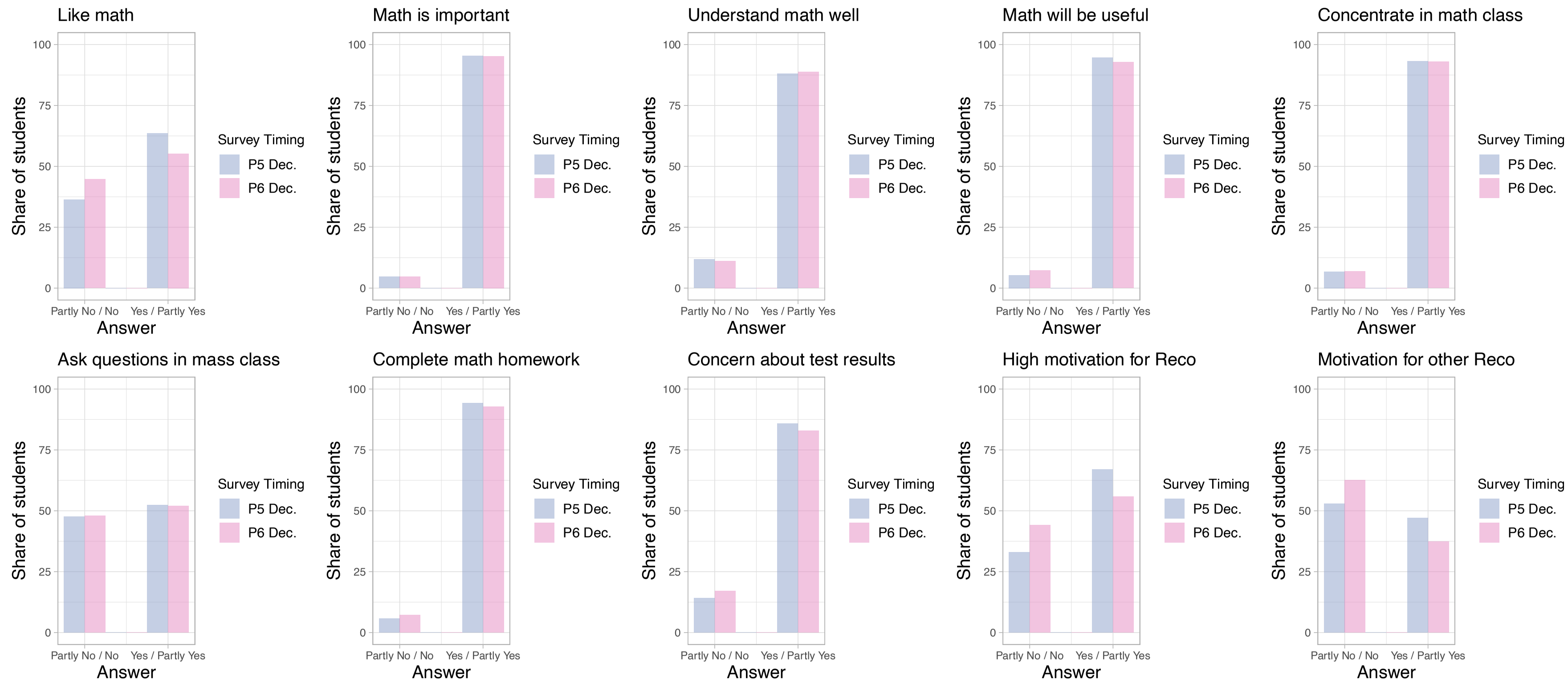
Panel B: With other treatment variables



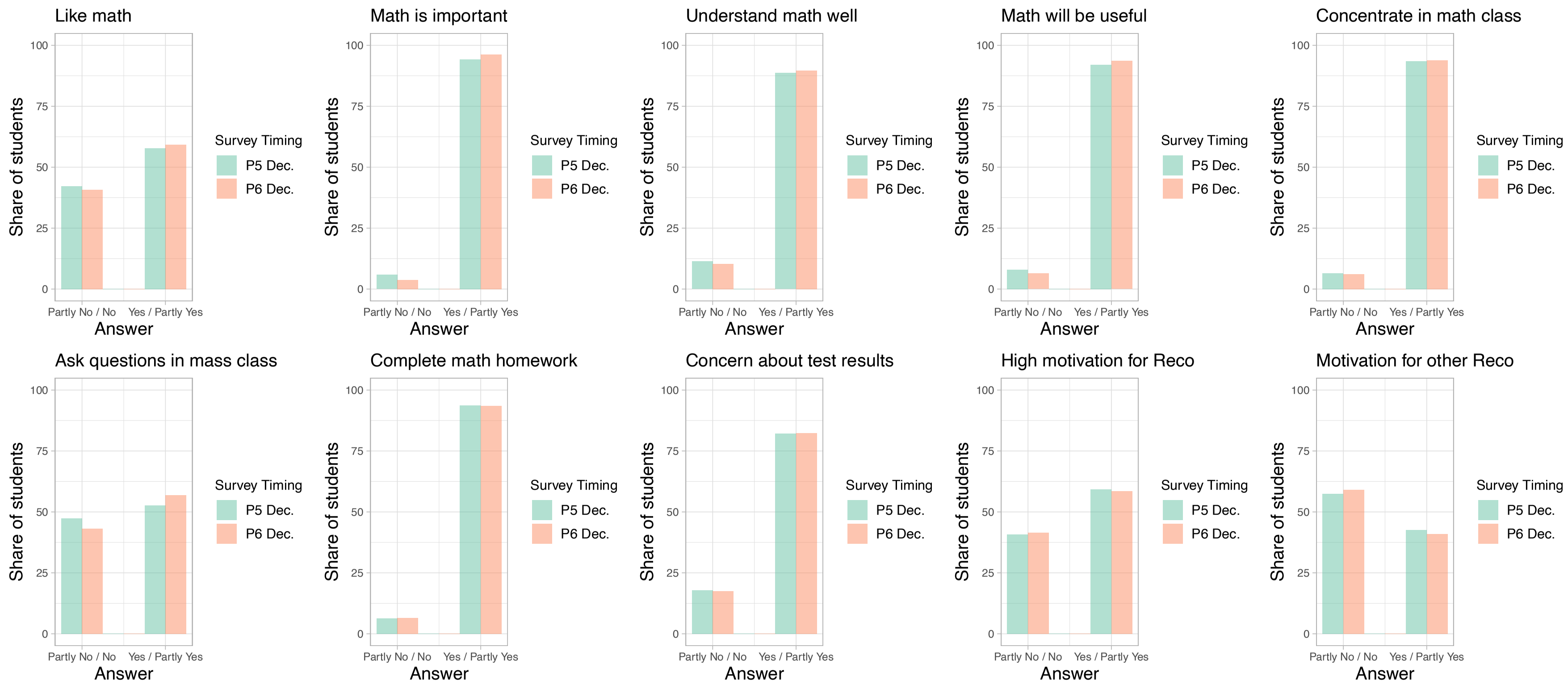
Appendix Figure 1: Histogram of the disadvantaged living conditions



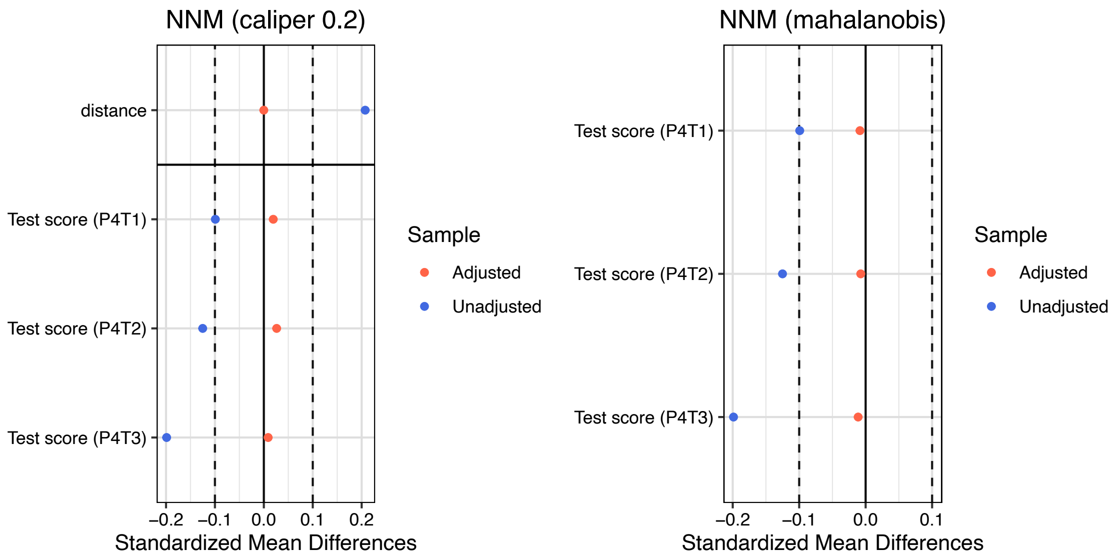
Appendix Figure 2: Histogram of the motivation and attitude of math (FY2019 P6 Cohort)



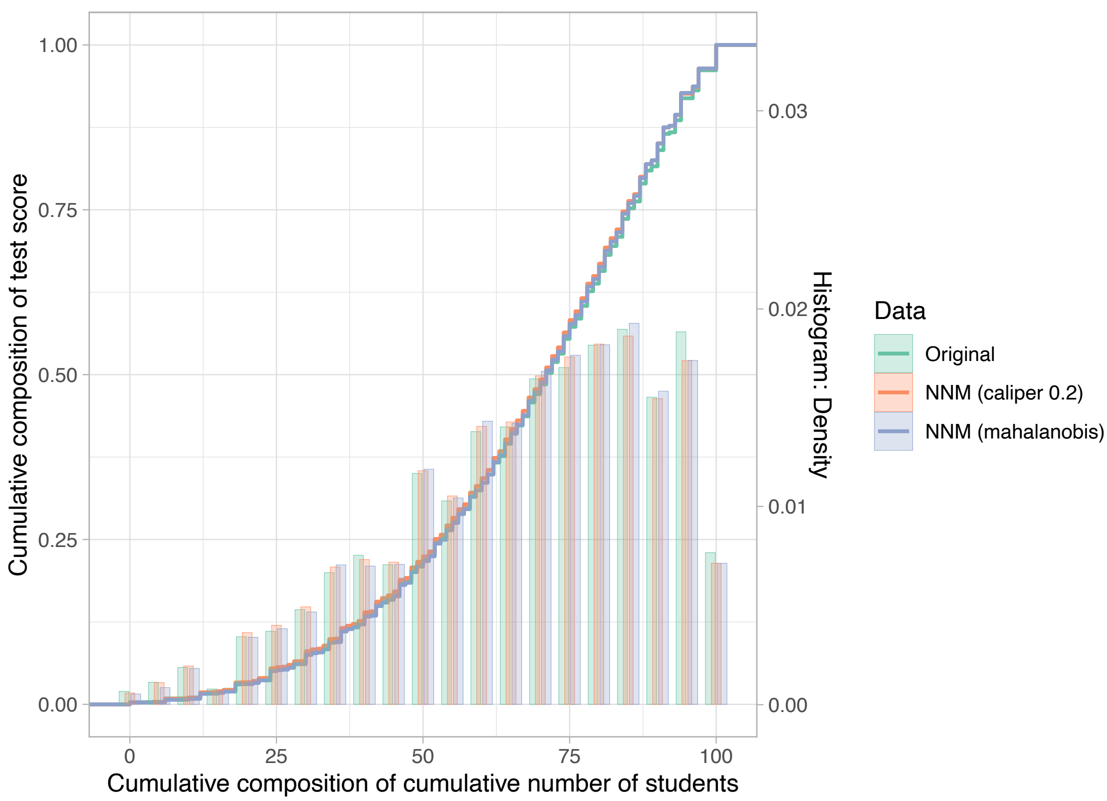
Appendix Figure 3: Histogram of the motivation and attitude of math (FY2020 P6 Cohort)



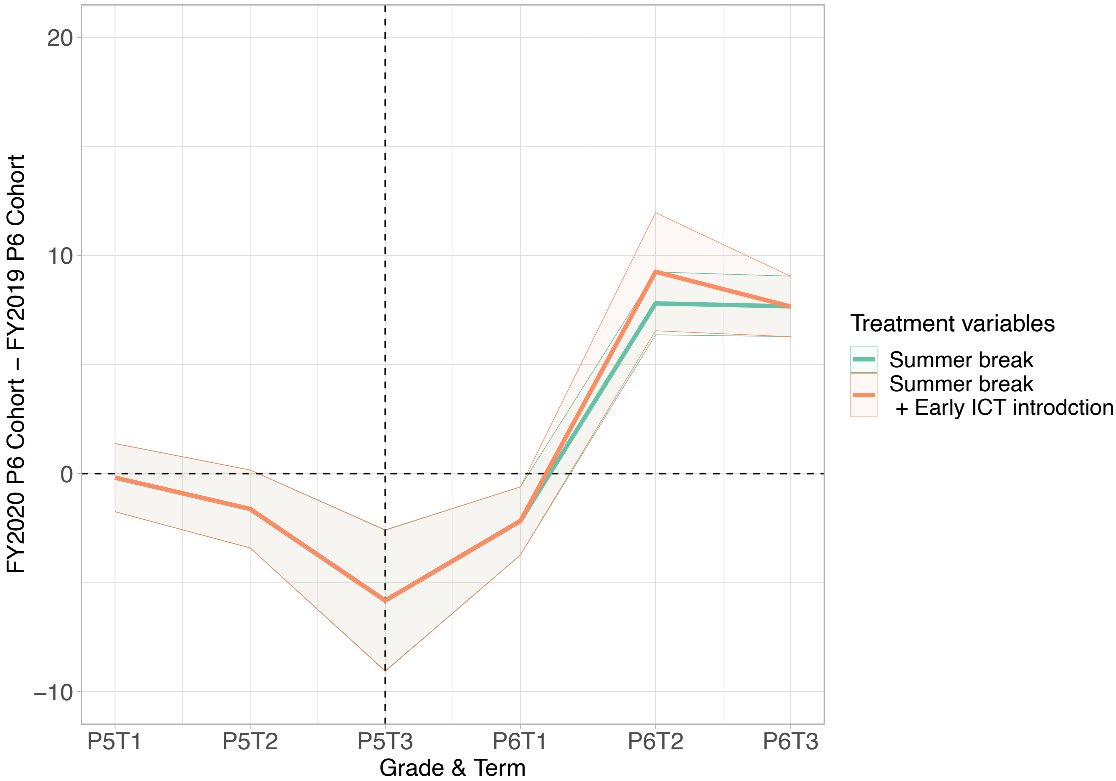
Appendix Figure 4: Standardized mean differences: Original and matched samples



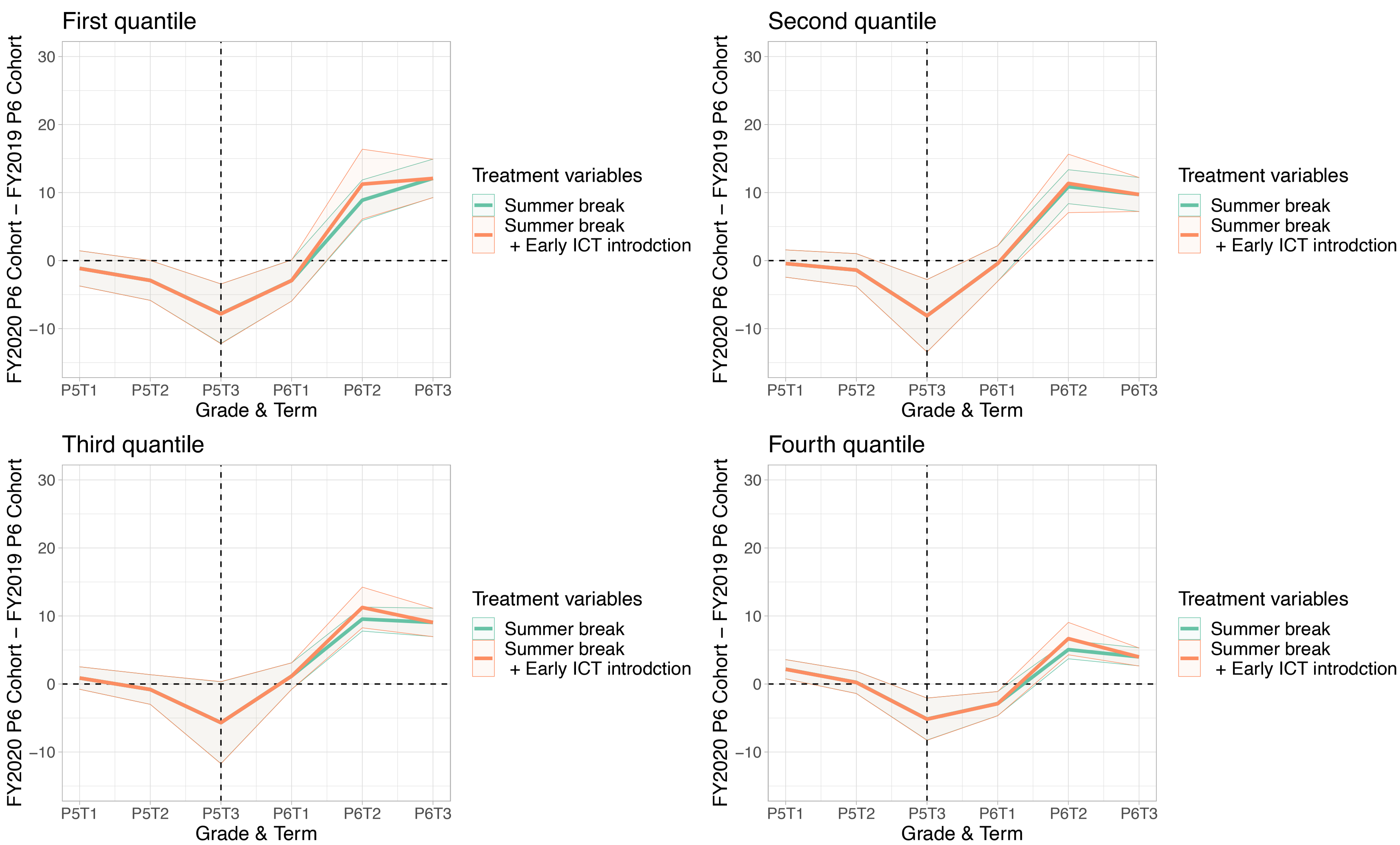
Appendix Figure 5: Test score distribution (CDF & PDF): Original and matched samples



Appendix Figure 6: Baseline vs Baseline + Early ICT：Full sample



Appendix Figure 7: Baseline vs Baseline + Early ICT (Subsample)



List of Tables

Table 1: Change in summer break days

Fiscal Year	Period	Days	Decreased days from 2018	Grade	
				FY2020-P6 Cohort	FY2019-P6 Cohort
2017	Jul. 21−Aug.31	41	2	-	P4
2018	Jul. 21−Sep.2	43	0	P4	P5
2019	Jul. 20−Aug. 25	36	7	P5	P6
2020	Aug. 8−24	16	27	P6	-

Table 2: Summary statistics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Test score	25,255	67.67	22.24	0	53	85	100
COVID19	25,255	0.44	0.50	0	0	1	1
P5T3_P6T3	25,255	0.62	0.49	0	0	1	1
After P6T2	25,255	0.32	0.47	0	0	1	1
Summer break	25,255	0.38	0.48	0	0	1	1
Shortened days	25,255	3.55	7.52	0	0	7	27
ICT early days	25,255	0.98	3.66	0	0	0	28
Lack food	24,118	0.01	0.09	0.00	0.00	0.00	1.00
Lack sleep	24,118	0.08	0.24	0.00	0.00	0.00	1.00
Lack print study (May)	24,118	0.03	0.17	0.00	0.00	0.00	1.00
Lack study (June)	24,118	0.08	0.28	0.00	0.00	0.00	1.00
Feel stressed	24,118	0.08	0.23	0.00	0.00	0.00	1.00
No passion	24,118	0.05	0.19	0.00	0.00	0.00	1.00
Bad health	24,118	0.06	0.20	0.00	0.00	0.00	1.00
No sport	24,118	0.07	0.22	0.00	0.00	0.00	1.00
Not fun	24,118	0.05	0.17	0.00	0.00	0.00	1.00
Feel unsafe	24,118	0.03	0.14	0.00	0.00	0.00	1.00

Table 3: Results of DID and event study estimation: Full sample

Dependent Variable:	Test score				
Model:	Baseline DID (1)	(1) + SB (2)	(2) + After P6T2 (3)	Baseline Event (4)	(4) + SB (5)
COVID19 × P5T3_P6T3	5.275***	4.474***	-2.082*		
	(1.063)	(1.043)	(1.090)		
COVID19 × After P6T2			11.64***		
			(0.7283)		
COVID19	-1.382*	-2.175**	-1.370		
	(0.8335)	(0.8526)	(0.8528)		
After P6T2			-1.322**		
			(0.5755)		
Summer break		-3.976***	-2.555***		-1.307***
		(0.4208)	(0.4650)		(0.4112)
Shortened days		0.2333***	-0.0004		-0.3001***
		(0.0235)	(0.0244)		(0.0879)
COVID19 × P5T1 (SC = -2)				0.5094	0.0797
				(0.7945)	(0.8091)
COVID19 × P5T2 (SC = -1)				-3.238***	-0.2613
				(0.9010)	(1.033)
COVID19 × P5T3 (SC = 0)				-5.465***	-5.858***
				(1.662)	(1.652)
COVID19 × P6T1 (SC = 1)				-1.301*	-2.692***
				(0.7764)	(0.8232)
COVID19 × P6T2 (SC = 2)				6.393***	14.41***
				(0.7292)	(2.036)
COVID19 × P6T3 (SC = 3)				8.608***	7.220***
				(0.6756)	(0.7362)
School FE	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes
Observations	25,117	25,117	25,117	25,117	25,117

Note: "SC" is the abbreviation for School close and indicates the difference in semesters from P5T3, the first to be affected by the temporary school closure. "Event" represents the results of event study estimation. "SB" implies the estimation adding variables related to summer vacation. "After P6T2" is the estimation including interaction term of "COVID19 × P6T2." "COVID19" is a dummy variable taking one if the student belongs to the FY2020 P6 cohort. "School close" means the difference of term from P5 T3 term. Standard errors in parentheses are clustered at the classroom level. *$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 4: Results of DID: Baseline and Baseline + Summer break (treatment effect by quantiles)

Dependent Variable:	Test score							
Model:	Baseline DID				Baseline DID + SB + After P6T2			
Score QT (P4T3)	1st QT (1)	2nd QT (2)	3rd QT (3)	4th QT (4)	1st QT (5)	2nd QT (6)	3rd QT (7)	4th QT (8)
COVID19 × P5T3_P6T3	7.137***	7.410***	6.479***	1.369	-3.594*	-1.586	0.2937	-3.389***
	(1.759)	(1.547)	(1.157)	(0.8997)	(1.830)	(1.571)	(1.164)	(1.036)
COVID19 × After P6T2					18.06***	14.38***	9.628***	7.093***
					(1.292)	(1.187)	(1.028)	(0.8459)
COVID19	-1.840	-1.435	-0.6142	0.4238	-1.264	-1.484	-0.7572	0.1665
	(1.308)	(1.071)	(0.8661)	(0.7079)	(1.317)	(1.096)	(0.8709)	(0.7122)
After P6T2					-2.457**	-3.549***	-1.059	0.0504
					(1.010)	(0.8751)	(0.7778)	(0.5366)
Summer break					-0.8205	-2.711***	-3.576***	-3.158***
					(0.7137)	(0.6282)	(0.6124)	(0.4851)
Shortened days					-0.1830***	0.0213	0.0394	0.0770***
					(0.0428)	(0.0365)	(0.0328)	(0.0263)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,253	5,975	5,905	6,624	5,253	5,975	5,905	6,624

Note: "SB" means the estimation adding variables related to summer vacation. "After P6T2" is the estimation including interaction term of "COVID19 × P6T2." "COVID19" means a dummy variable taking one if the student belongs to the FY2020 P6 cohort. "School close" means the difference of term from P5 T3 term. Standard errors in parentheses are clustered at the classroom level. **p<0.1; **p<0.05; ***p<0.01*

Table 5: Results of Event study: Baseline and Baseline + Summer break (treatment effect by quantiles)

Dependent Variable:	Test score							
Model:	Baseline Event				Baseline Event + SB			
Score QT (P4T3)	1st QT (1)	2nd QT (2)	3rd QT (3)	4th QT (4)	1st QT (5)	2nd QT (6)	3rd QT (7)	4th QT (8)
COVID19 × P5T1 (SC = -2)	-0.4796	0.5384	1.724**	2.852***	-0.5599	-0.0148	1.123	2.461***
	(1.314)	(1.015)	(0.8426)	(0.7193)	(1.329)	(1.029)	(0.8448)	(0.7052)
COVID19 × P5T2 (SC = -1)	-4.234***	-3.400***	-2.596**	-0.9564	-0.3226	0.4150	0.5355	1.059
	(1.425)	(1.178)	(1.059)	(0.7845)	(1.710)	(1.418)	(1.227)	(0.9333)
COVID19 × P5T3 (SC = 0)	-7.152***	-7.337***	-5.427*	-4.203**	-7.214***	-7.835***	-5.997*	-4.562***
	(2.230)	(2.745)	(3.068)	(1.656)	(2.227)	(2.751)	(3.050)	(1.656)
COVID19 × P6T1 (SC = 1)	-2.102	0.7495	2.290**	-2.216**	-3.738**	-1.019	0.7778	-3.188***
	(1.526)	(1.305)	(0.9553)	(0.9053)	(1.557)	(1.374)	(1.034)	(0.9296)
COVID19 × P6T2 (SC = 2)	7.718***	9.091***	7.927***	3.992***	20.67***	19.44***	15.59***	8.914***
	(1.472)	(1.260)	(0.9055)	(0.6615)	(3.977)	(3.254)	(2.816)	(2.279)
COVID19 × P6T3 (SC = 3)	12.91***	10.97***	10.13***	4.819***	11.28***	9.207***	8.625***	3.849***
	(1.410)	(1.247)	(1.026)	(0.6299)	(1.455)	(1.313)	(1.116)	(0.6789)
Summer break					-0.2804	-1.660***	-1.831***	-1.186**
					(0.7127)	(0.5863)	(0.6330)	(0.4879)
Shortened days					-0.5301***	-0.3871***	-0.2719**	-0.1743*
					(0.1587)	(0.1379)	(0.1271)	(0.0977)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,253	5,975	5,905	6,624	5,253	5,975	5,905	6,624

Note: "SC" is the abbreviation for School close and indicates the difference in semesters from P5T3, the first to be affected by the temporary school closure. "Event" represents the results of event study estimation. "SB" implies the estimation adding variables related to summer vacation. "After P6T2" is the estimation including interaction term of "COVID19 × P6T2." "COVID19" is a dummy variable taking one if the student belongs to the FY2020 P6 cohort. "School close" means the difference of term from P5 T3 term. Standard errors in parentheses are clustered at the classroom level. *$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 6: Results of DID and event study estimation: Treatment effect of disadvantaged living condition (Full sample)

Dependent Variable:	Test score				
	Baseline DID + DLC&ICT	(1) + SB	(2) + After P6T2	Baseline Event + DLC&ICT	(4) + SB
Model:	(1)	(2)	(3)	(4)	(5)
COVID19 × P5T3_P6T3	7.349***	7.131***	0.8043		
	(1.196)	(1.216)	(1.206)		
COVID19 × After P6T2			12.45***		
			(0.7357)		
COVID19	-0.7213	-1.489*	-0.8532		
	(0.8195)	(0.8507)	(0.8493)		
After P6T2			-1.648***		
			(0.5714)		
Summer break		-3.971***	-2.688***		-1.305***
		(0.4678)	(0.4939)		(0.4107)
Shortened days		0.2260***	0.0416		-0.3025***
		(0.0503)	(0.0492)		(0.0879)
ICT early days	0.1729***	0.0328	-0.0926	-0.1854**	-0.1885**
	(0.0391)	(0.0852)	(0.0764)	(0.0835)	(0.0837)
Lack food	-3.769	-3.765	-3.585	-3.579	-3.587
	(2.918)	(2.924)	(2.902)	(2.913)	(2.916)
Lack sleep	-2.069**	-2.117**	-2.429**	-2.649***	-2.648***
	(0.9988)	(0.9977)	(0.9856)	(0.9796)	(0.9797)
Lack print study (May)	-7.974***	-7.967***	-8.094***	-8.145***	-8.132***
	(1.725)	(1.724)	(1.726)	(1.728)	(1.728)
Lack study (June)	-2.684***	-2.704***	-2.876***	-2.974***	-2.972***
	(0.9559)	(0.9591)	(0.9546)	(0.9600)	(0.9603)
Feel stressed	-1.451	-1.479	-1.645*	-1.799*	-1.796*
	(0.9655)	(0.9646)	(0.9612)	(0.9536)	(0.9535)
No passion	-5.327***	-5.341***	-5.249***	-5.250***	-5.260***
	(1.335)	(1.333)	(1.326)	(1.325)	(1.325)
Bad health	-0.0756	-0.1105	-0.2577	-0.4283	-0.4337
	(1.315)	(1.313)	(1.307)	(1.310)	(1.310)
No sport	3.082***	3.007***	2.647**	2.353**	2.359**
	(1.145)	(1.144)	(1.144)	(1.154)	(1.153)
Not fun	0.1617	0.1460	0.0888	-0.0250	-0.0191
	(1.422)	(1.419)	(1.406)	(1.402)	(1.402)
Feel unsafe	2.563	2.529	2.401	2.214	2.226
	(1.557)	(1.556)	(1.554)	(1.555)	(1.555)
COVID19 × P5T1 (SC = -2)				1.214	0.7840
				(0.7733)	(0.7831)
COVID19 × P5T2 (SC = -1)				-2.618***	0.3732
				(0.8869)	(1.014)
COVID19 × P5T3 (SC = 0)				-4.666***	-5.058***
				(1.771)	(1.761)
COVID19 × P6T1 (SC = 1)				2.990***	1.586*
				(0.8620)	(0.9117)
COVID19 × P6T2 (SC = 2)				13.01***	21.11***
				(1.437)	(2.371)
COVID19 × P6T3 (SC = 3)				13.01***	11.60***
				(0.7386)	(0.8051)
School FE	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes
Observations	24,118	24,118	24,118	24,118	24,118

Note: "SC" is the abbreviation for School close and indicates the difference in semesters from P5T3, the first to be affected by the temporary school closure. "DLC" means the disadvantaged living conditions during school closure due to COVID19. "ICT" is equivalent to "ICT early days". Standard errors in parentheses are clustered at the classroom level. *$p<0.1$; **$p<0.05$; ***$p<0.01$

Table 7: Results of DID: Treatment effects of disadvantaged living condition by pre-treat score quantile

Dependent Variable:	Test score							
Model:	Baseline DID + DLC&ICT				(1)–(4) + SB + After P6T2			
Score QT (P4T3):	1st QT (1)	2nd QT (2)	3rd QT (3)	4th QT (4)	1st QT (5)	2nd QT (6)	3rd QT (7)	4th QT (8)
COVID19 × P5T3_P6T3	12.31***	6.139***	6.161***	0.8430	2.376	-1.648	0.7045	-3.027***
	(2.053)	(1.855)	(1.263)	(0.9671)	(2.026)	(1.814)	(1.239)	(1.085)
COVID19 × After P6T2					19.25***	14.79***	9.993***	7.505***
					(1.385)	(1.203)	(0.9768)	(0.8627)
COVID19	-2.089*	-1.433	-0.5415	0.1209	-1.752	-1.566	-0.8585	-0.3085
	(1.244)	(1.100)	(0.8706)	(0.7383)	(1.260)	(1.151)	(0.8684)	(0.7517)
After P6T2					-3.131***	-3.583***	-1.093	-0.1706
					(1.043)	(0.8703)	(0.7722)	(0.5438)
Summer break					-0.8487	-2.808***	-3.835***	-3.226***
					(0.7974)	(0.6691)	(0.6159)	(0.5237)
Shortened days					-0.1113	0.0434	0.0905	0.1191**
					(0.0931)	(0.0771)	(0.0574)	(0.0514)
ICT early days	0.0924	0.2479***	0.1253***	0.1679***	-0.1802	-0.0333	-0.0930	-0.0885
	(0.0687)	(0.0558)	(0.0427)	(0.0459)	(0.1393)	(0.1304)	(0.0902)	(0.0841)
Lack food	3.436	5.200	2.703	-5.025	4.169	5.427	2.473	-4.678
	(5.082)	(4.603)	(2.778)	(3.892)	(4.994)	(4.572)	(2.784)	(3.914)
Lack sleep	-4.690*	-1.012	1.454	0.6741	-5.312**	-1.449	1.252	0.3023
	(2.461)	(1.677)	(1.450)	(1.200)	(2.453)	(1.656)	(1.426)	(1.216)
Lack print study (May)	-6.795***	-5.700***	-2.691	2.601	-6.818***	-6.038***	-2.783	2.403
	(2.338)	(2.167)	(1.953)	(1.692)	(2.344)	(2.184)	(1.973)	(1.655)
Lack study (June)	-3.054**	0.0763	-1.521	-2.686***	-3.297**	-0.1707	-1.732*	-2.790***
	(1.471)	(1.295)	(0.9873)	(0.9747)	(1.455)	(1.279)	(0.9782)	(0.9695)
Feel stressed	1.574	-2.738*	-2.233*	-0.8937	1.395	-2.767*	-2.473*	-0.9824
	(1.958)	(1.574)	(1.327)	(0.9514)	(1.939)	(1.570)	(1.323)	(0.9546)
No passion	-7.517***	-3.016	-3.565**	-0.7208	-7.569***	-2.936	-3.556**	-0.6813
	(2.537)	(1.863)	(1.578)	(1.544)	(2.528)	(1.869)	(1.565)	(1.522)
Bad health	-4.332**	0.8027	3.173**	-0.5646	-4.552**	0.4432	3.128**	-0.7408
	(2.183)	(1.966)	(1.410)	(0.9369)	(2.178)	(1.942)	(1.402)	(0.9247)
No sport	1.539	3.756**	1.272	2.512***	0.9756	3.167**	1.033	2.134**
	(2.140)	(1.447)	(1.356)	(0.9415)	(2.140)	(1.455)	(1.360)	(0.9255)
Not fun	1.245	-1.929	1.274	0.6515	0.9184	-1.865	1.121	0.6970
	(2.488)	(2.167)	(1.701)	(1.176)	(2.500)	(2.148)	(1.692)	(1.153)
Feel unsafe	5.411*	9.259***	3.122	1.206	5.206*	9.246***	2.712	0.9805
	(2.982)	(2.137)	(1.943)	(1.610)	(2.989)	(2.142)	(1.945)	(1.594)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,935	5,766	5,715	6,504	4,935	5,766	5,715	6,504

Note: "DLC" means the home environment during school closure due to COVID19. "ICT"(= "ICT early days") means the difference between the start date of the use of ICT terminals in each elementary school and the one in the slowest elementary school. "Score QT (P4T3)" is calculated by the test score in P4 T3 term (= School close = −3). **p<0.1; **p<0.05; ***p<0.01*

Table 8: Results of Event study: Treatment effects of disadvantaged living condition by pre-treat score quantile

Dependent Variable:	Test score							
Model:	Event + DLC&ICT				(1)–(4) + SB			
Score QT (P4T3):	1st QT	2nd QT	3rd QT	4th QT	1st QT	2nd QT	3rd QT	4th QT
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
COVID19 × P5T1 (SC = -2)	-1.039	0.6101	1.958**	2.369***	-1.116	0.0529	1.350	1.979***
	(1.205)	(1.032)	(0.8939)	(0.7576)	(1.206)	(1.050)	(0.8999)	(0.7412)
COVID19 × P5T2 (SC = -1)	-4.190***	-3.483***	-2.667**	-1.142	-0.1947	0.3531	0.4814	0.9007
	(1.385)	(1.233)	(1.047)	(0.8189)	(1.663)	(1.470)	(1.204)	(0.9587)
COVID19 × P5T3 (SC = 0)	-8.322***	-7.967***	-5.359*	-5.225***	-8.380***	-8.469***	-5.930**	-5.584***
	(2.123)	(2.799)	(2.956)	(1.713)	(2.126)	(2.806)	(2.935)	(1.715)
COVID19 × P6T1 (SC = 1)	5.122***	1.049	2.952***	-2.060**	3.449**	-0.7367	1.414	-3.049***
	(1.719)	(1.610)	(1.030)	(0.9915)	(1.732)	(1.668)	(1.088)	(1.013)
COVID19 × P6T2 (SC = 2)	18.69***	11.27***	11.21***	5.981***	32.04***	21.71***	18.96***	11.02***
	(3.068)	(2.471)	(1.522)	(1.279)	(4.843)	(3.714)	(3.089)	(2.493)
COVID19 × P6T3 (SC = 3)	19.99***	11.55***	11.03***	5.013***	18.32***	9.764***	9.497***	4.027***
	(1.748)	(1.583)	(1.109)	(0.7561)	(1.777)	(1.633)	(1.181)	(0.8052)
Summer break					-0.2587	-1.665***	-1.834***	-1.185**
					(0.7152)	(0.5858)	(0.6335)	(0.4885)
Shortened days					-0.5447***	-0.3900***	-0.2747**	-0.1785*
					(0.1591)	(0.1385)	(0.1274)	(0.0980)
ICT early days	-0.3262**	-0.1181	-0.1879**	-0.1473	-0.3300**	-0.1209	-0.1904**	-0.1491
	(0.1580)	(0.1431)	(0.0906)	(0.0926)	(0.1582)	(0.1436)	(0.0910)	(0.0928)
Lack food	3.989	5.512	2.338	-4.593	3.975	5.509	2.347	-4.624
	(5.014)	(4.568)	(2.809)	(3.904)	(5.021)	(4.577)	(2.807)	(3.909)
Lack sleep	-5.774**	-1.691	0.9916	0.2366	-5.791**	-1.693	1.000	0.2460
	(2.436)	(1.652)	(1.421)	(1.231)	(2.434)	(1.654)	(1.421)	(1.229)
Lack print study (May)	-6.922***	-6.147***	-2.827	2.361	-6.897***	-6.139***	-2.824	2.376
	(2.352)	(2.180)	(1.988)	(1.649)	(2.351)	(2.184)	(1.987)	(1.648)
Lack study (June)	-3.448**	-0.2939	-1.823*	-2.800***	-3.442**	-0.2695	-1.821*	-2.805***
	(1.449)	(1.278)	(0.9768)	(0.9643)	(1.448)	(1.280)	(0.9762)	(0.9653)
Feel stressed	1.070	-2.863*	-2.681**	-0.9999	1.073	-2.888*	-2.675**	-0.9944
	(1.945)	(1.574)	(1.314)	(0.9501)	(1.946)	(1.576)	(1.315)	(0.9495)
No passion	-7.701***	-2.971	-3.484**	-0.6774	-7.712***	-2.967	-3.511**	-0.6863
	(2.537)	(1.867)	(1.557)	(1.520)	(2.534)	(1.869)	(1.556)	(1.521)
Bad health	-4.852**	0.2087	2.992**	-0.7838	-4.860**	0.1985	2.993**	-0.7881
	(2.198)	(1.954)	(1.399)	(0.9310)	(2.199)	(1.955)	(1.400)	(0.9290)
No sport	0.5344	2.867**	0.7509	2.054**	0.5216	2.872**	0.7690	2.063**
	(2.157)	(1.450)	(1.362)	(0.9288)	(2.158)	(1.449)	(1.360)	(0.9279)
Not fun	0.7252	-1.929	0.8818	0.6978	0.7202	-1.914	0.8971	0.7005
	(2.510)	(2.153)	(1.689)	(1.151)	(2.510)	(2.156)	(1.692)	(1.151)
Feel unsafe	5.061*	9.015***	2.394	0.9308	5.105*	9.004***	2.416	0.9343
	(3.015)	(2.165)	(1.949)	(1.602)	(3.009)	(2.164)	(1.951)	(1.599)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,935	5,766	5,715	6,504	4,935	5,766	5,715	6,504

Note: "SC" is the abbreviation for School close and indicates the difference in semesters from P5T3, the first to be affected by the temporary school closure. "Event" represents the results of event study estimation. "DLC" means the home environment during school closure due to COVID19. "Score QT (P4T3)" is calculated by the test score in P4 T3 term (= School close = −3). "ICT"(= "ICT early days") means the difference between the start date of the use of ICT terminals in each elementary school and the one in the slowest elementary school. "School close" means the difference of term from P5 T3 term. *$p<0.1$; **$p<0.05$; ***$p<0.01$

Table A-1: Corresponding list between cohort, year, and grade/term

Fiscal Year	Term	Grade and Term	
		FY2020 P6 Cohort	FY2019 P6 Cohort
2018	T1 (Apr.– Jul.)	-	P5T1
	T2 (Sep.– Dec.)	-	P5T2
	T3 (Jan.– Mar.)	-	P5T3
2019	T1 (Apr.– Jul.)	P5T1	P6T1
	T2 (Sep.– Dec.)	P5T2	P6T2
	T3 (Jan.– Mar.)	P5T3	P6T3
2020	T1 (Apr.– Jul.)	P6T1	-
	T2 (Sep.– Dec.)	P6T2	-
	T3 (Jan.– Mar.)	P6T3	-

Note: P5 and P6 mean that the cohort's grades are fifth and sixth in primary school.

Table A-2: Balance test between students tested in FY2020 P5T3 and the others: T-test and F-test

Data:	Students tested in FY2020 P5T3 vs other students				Students tested in FY2020 P5T3 vs all students			
Outcome variables:	T-test		F-test		T-test		F-test	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Test score	−0.1504	0.7779	−0.1165	0.8229	1.0513	0.1249	1.0393	0.2234

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table A-3: Definitions for disadvantaged living condition dummy

Living Condition	Definition
Lack food	= 1 if the student answered, "not applicable" or "not really applicable" to the question "I eat breakfast and lunch every day," or 0 otherwise
Lack sleep	= 1 if the student answered, "applicable" or "mostly applicable" to the question "I sometimes have difficulty sleeping," or 0 otherwise
Lack print study (May)	= 1 if the student answered, "not applicable" or "not really applicable" to the question "I studied using handouts from school during the temporary primary school closure," or 0 otherwise
Lack study (June)	= 1 If the student answered, "applicable" or "mostly applicable" to the question "I sometimes have difficulty concentrating on studies," or 0 otherwise
Feel stressed	= 1 if the student answered, "applicable" or "mostly applicable" to the question "I get upset, frustrated, or angry," or 0 otherwise
No passion	= 1 if the student answered, "applicable" or "mostly applicable" to the question "I have no motivation to do anything," or 0 otherwise
Bad health	= 1 if the student answered, "applicable" or "mostly applicable" to the question "I sometimes have physical problems such as a headache or stomachache," or 0 otherwise
No sport	= 1 if the student answered, "not applicable" or "not really applicable" to the question "I exercise a lot," or 0 otherwise
Not fun	= 1 if the student answered, "not applicable" or "not really applicable" to the question "I enjoy every day," or 0 otherwise
Feel unsafe	= 1 if the student answered, "applicable" or "mostly applicable" to the question "I have felt anxious about something," or 0 otherwise

Table A-4: Corresponding list between "School close" and grade/term

School close (SC)	Grade/term
−3	P4T3
−2	P5T1
−1	P5T2
	(decrease in school days due to COVID-19)
0	P5T3
1	P6T1
2	P6T2
3	P6T3

Table A-5: Correlation Test: Early days of ICT introduction and school characteristics

Correlation test b/w	Between P5T1 and P6T1		Between P5T1 and P5T3	
	Estimated coef.	P-value	Estimated coef.	P-value
ICT early days vs # of students	0.1015	0.103	0.0996^{*}	0.0667
ICT early days vs Test score	-0.2902^{***}	0.000	-0.1111^{**}	0.0406

Note: "# of students" and "Test score" are grouped by each term and each school. "ICT early days" means the number of days that the ICT were introduced earlier, counting from the school where they were last introduced. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table A-6: Comparison of original and matching results (DID & Event study): Treatment effect of living condition and early ICT introduction (Full sample)

Dependent Variable:	Test score					
Matching method:	Original		NNM (caliper 0.2)		NNM (mahalanobis)	
Model:	DID	Event	DID	Event	DID	Event
	(1)	(2)	(3)	(4)	(5)	(6)
COVID19 × P5T3_P6T3	0.8043		1.160		0.5294	
	(1.206)		(1.428)		(1.389)	
COVID19 × After P6T2	12.45***		13.30***		13.20***	
	(0.7357)		(0.8582)		(0.8276)	
COVID19	-0.8532		-1.532		-1.561*	
	(0.8493)		(0.9781)		(0.9315)	
After P6T2	-1.648***		-2.393***		-2.329***	
	(0.5714)		(0.6432)		(0.6526)	
Summer break	-2.688***	-1.305***	-2.406***	-0.9715**	-2.492***	-1.162**
	(0.4939)	(0.4107)	(0.5297)	(0.4660)	(0.5299)	(0.4543)
Shortened days	0.0416	-0.3025***	0.0110	-0.3514***	1.34×10^{-5}	-0.3744***
	(0.0492)	(0.0879)	(0.0558)	(0.1008)	(0.0568)	(0.0995)
ICT early days	-0.0926	-0.1885**	-0.0506	-0.1550*	-0.0305	-0.1194
	(0.0764)	(0.0837)	(0.0789)	(0.0814)	(0.0815)	(0.0846)
Lack food	-3.585	-3.587	-2.486	-2.456	-0.3640	-0.3978
	(2.902)	(2.916)	(3.308)	(3.320)	(3.069)	(3.080)
Lack sleep	-2.429**	-2.648***	-2.958**	-3.266***	-2.800**	-3.121***
	(0.9856)	(0.9797)	(1.193)	(1.184)	(1.189)	(1.182)
Lack print study (May)	-8.094***	-8.132***	-9.076***	-9.110***	-8.092***	-8.165***
	(1.726)	(1.728)	(2.071)	(2.076)	(1.800)	(1.804)
Lack study (June)	-2.876***	-2.972***	-2.700**	-2.843***	-2.555**	-2.694**
	(0.9546)	(0.9603)	(1.073)	(1.077)	(1.055)	(1.059)
	(1.726)	(1.728)	(2.071)	(2.076)	(1.800)	(1.804)
Feel stressed	-1.645*	-1.796*	-0.9597	-1.176	-0.5216	-0.7091
	(0.9612)	(0.9535)	(1.164)	(1.155)	(1.121)	(1.111)
No passion	-5.249***	-5.260***	-5.489***	-5.514***	-4.816***	-4.865***
	(1.326)	(1.325)	(1.760)	(1.758)	(1.545)	(1.546)
Bad health	-0.2577	-0.4337	-1.402	-1.645	-0.6174	-0.9131
	(1.307)	(1.310)	(1.536)	(1.548)	(1.469)	(1.476)
No sport	2.647**	2.359**	1.274	0.8625	1.150	0.7410
	(1.144)	(1.153)	(1.518)	(1.533)	(1.425)	(1.443)
Not fun	0.0888	-0.0191	1.358	1.204	0.2750	0.1313
	(1.406)	(1.402)	(1.861)	(1.852)	(1.779)	(1.772)
Feel unsafe	2.401	2.226	2.198	1.967	2.659	2.422
	(1.554)	(1.555)	(1.949)	(1.954)	(1.817)	(1.825)
COVID19 × P5T1 (SC = -2)		0.7840		0.2114		-0.1294
		(0.7831)		(0.9202)		(0.8800)
COVID19 × P5T2 (SC = -1)		0.3732		-0.3698		0.0393
		(1.014)		(1.126)		(1.074)
COVID19 × P5T3 (SC = 0)		-5.058***		-6.870***		-7.836***
		(1.761)		(1.957)		(1.541)
COVID19 × P6T1 (SC = 1)		1.586*		2.106*		1.396
		(0.9117)		(1.106)		(1.072)
COVID19 × P6T2 (SC = 2)		21.11***		22.21***		21.61***
		(2.371)		(2.584)		(2.433)
COVID19 × P6T3 (SC = 3)		11.60***		12.04***		11.30***
		(0.8051)		(0.9706)		(0.8964)
School FE	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,118	24,118	15,871	15,871	16,286	16,286

Note: Standard errors in parentheses are clustered at the classroom level. **p<0.1;* ***p<0.05;* ****p<0.01*

Table A-7: Matching results of DID: Treatment effect of ICT introduction and living condition by pre-treat score quantile

Dependent Variable:	Test score							
Matching method:	NNM PSM caliper 0.2				NNM mahalanobis			
Score QT (P4T3):	1st QT	2nd QT	3rd QT	4th QT	1st QT	2nd QT	3rd QT	4th QT
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
COVID19 × P5T3_P6T3	2.200	-1.388	-0.3091	-2.709**	1.309	-2.334	-0.9376	-2.774**
	(2.203)	(1.984)	(1.454)	(1.348)	(2.077)	(1.957)	(1.457)	(1.321)
COVID19 × After P6T2	19.20***	15.24***	11.39***	8.068***	19.64***	14.84***	11.14***	8.258***
	(1.614)	(1.274)	(1.129)	(1.027)	(1.622)	(1.275)	(1.110)	(1.049)
COVID19	-1.637	-1.945	-1.622	-0.0972	-2.266*	-1.763	-0.6037	-0.3810
	(1.331)	(1.271)	(1.008)	(0.9651)	(1.254)	(1.246)	(0.9734)	(0.9372)
After P6T2	-3.135***	-3.572***	-2.734***	-0.5446	-3.697***	-3.462***	-2.222**	-0.6975
	(1.199)	(0.9665)	(0.8689)	(0.6969)	(1.241)	(1.009)	(0.9283)	(0.6957)
Summer break	-0.4828	-3.007***	-3.337***	-2.800***	-0.4315	-2.583***	-3.654***	-3.054***
	(0.9342)	(0.7414)	(0.7364)	(0.6491)	(0.9571)	(0.7290)	(0.7327)	(0.6076)
Shortened days	-0.1926*	0.0967	0.0561	0.1331*	-0.1531	0.0083	0.0735	0.1232*
	(0.1120)	(0.0864)	(0.0772)	(0.0695)	(0.1118)	(0.0902)	(0.0674)	(0.0629)
ICT early days	-0.0718	-0.1202	-0.0371	-0.1391	-0.1388	0.0029	-0.0640	-0.1101
	(0.1603)	(0.1337)	(0.1051)	(0.1008)	(0.1583)	(0.1412)	(0.0923)	(0.0966)
Lack food	4.174	3.802	3.548	-9.541	7.861	8.450*	-0.6566	-7.961
	(5.942)	(4.971)	(3.276)	(5.859)	(5.634)	(4.750)	(3.765)	(4.828)
Lack sleep	-7.671**	-0.9455	2.621**	0.0413	-6.133**	-0.7080	1.776	-0.2958
	(3.019)	(1.665)	(1.302)	(1.463)	(2.936)	(1.691)	(1.361)	(1.420)
Lack print study (May)	-8.291***	-3.477	-2.190	0.9273	-7.148***	-5.269**	-1.215	2.107
	(2.899)	(2.324)	(2.090)	(2.890)	(2.736)	(2.357)	(2.046)	(2.336)
Lack study (June)	-2.484	-0.8534	-2.769***	-3.784***	-2.106	-0.0950	-1.994*	-3.158***
	(1.583)	(1.470)	(1.055)	(1.267)	(1.564)	(1.272)	(1.187)	(1.211)
Feel stressed	2.650	-3.204*	-2.358	-0.4592	2.020	-3.405*	-2.112	-0.0029
	(2.055)	(1.801)	(1.659)	(1.466)	(1.891)	(1.807)	(1.566)	(1.389)
No passion	-6.368**	-1.811	-3.723**	-1.461	-5.351*	-1.786	-3.313	0.1593
	(2.850)	(2.035)	(1.829)	(1.754)	(2.801)	(1.792)	(2.181)	(1.558)
Bad health	-4.714**	1.297	1.898	-1.563	-4.169*	1.132	2.681	-1.472
	(2.379)	(2.011)	(1.594)	(1.205)	(2.339)	(1.949)	(1.628)	(1.085)
No sport	0.5737	2.935	0.6031	1.316	-0.0242	2.944*	1.588	1.086
	(2.387)	(1.794)	(1.453)	(1.404)	(2.417)	(1.581)	(1.396)	(1.232)
Not fun	1.179	-3.491	2.198	2.322	-1.022	-1.588	1.809	-0.2994
	(3.094)	(2.226)	(1.971)	(1.473)	(3.008)	(2.159)	(2.086)	(1.509)
Feel unsafe	5.621	7.906***	3.809*	1.967	6.754**	9.576***	1.960	1.043
	(3.471)	(2.339)	(2.076)	(2.210)	(3.196)	(2.329)	(2.212)	(1.965)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,709	4,095	3,900	4,167	3,609	4,291	4,002	4,384

Note: "Score QT (P4T3)" is calculated by the test score in the P4 T3 term (= School close = −3). Standard errors in parentheses are clustered at the classroom level. **p<0.1; **p<0.05; ***p<0.01*

Table A-8: Matching results of Event study: Treatment effect of ICT introduction and living condition by pre-treat score quantile

Dependent Variable:	Test score							
Matching method:	NNM PSM caliper 0.2				NNM mahalanobis			
Score QT (P4T3):	1st QT (1)	2nd QT (2)	3rd QT (3)	4th QT (4)	1st QT (5)	2nd QT (6)	3rd QT (7)	4th QT (8)
COVID19 × P5T1 (SC = -2)	-1.182	-0.0379	0.4662	2.544***	-1.956	-0.3935	1.477	1.658*
	(1.319)	(1.216)	(1.043)	(0.9760)	(1.271)	(1.201)	(1.022)	(0.9042)
COVID19 × P5T2 (SC = -1)	-1.804	-0.2088	0.9342	0.7875	-1.464	0.4594	1.534	0.9708
	(1.731)	(1.611)	(1.344)	(1.158)	(1.756)	(1.518)	(1.365)	(1.132)
COVID19 × P5T3 (SC = 0)	-7.863***	-9.085***	-8.651***	-6.653***	-10.73***	-9.811***	-9.154***	-6.067***
	(2.437)	(3.103)	(2.703)	(1.920)	(1.795)	(2.900)	(2.641)	(1.996)
COVID19 × P6T1 (SC = 1)	3.965**	-0.5179	0.5039	-1.838	2.832	-1.504	0.9519	-2.440**
	(1.934)	(1.843)	(1.251)	(1.173)	(1.811)	(1.833)	(1.259)	(1.151)
COVID19 × P6T2 (SC = 2)	27.54***	22.56***	22.49***	12.82***	28.57***	20.62***	21.26***	12.48***
	(5.318)	(4.429)	(3.887)	(3.108)	(5.243)	(4.351)	(3.691)	(3.084)
COVID19 × P6T3 (SC = 3)	18.73***	10.32***	8.189***	5.159***	17.37***	9.141***	8.836***	4.742***
	(1.931)	(1.784)	(1.327)	(0.9804)	(1.843)	(1.789)	(1.350)	(0.9155)
Summer break	-0.4413	-1.594**	-1.275*	-0.5517	-0.2998	-1.447**	-1.627**	-1.192**
	(0.8468)	(0.6964)	(0.7526)	(0.5926)	(0.8835)	(0.6708)	(0.7523)	(0.5542)
Shortened days	-0.4272**	-0.3418**	-0.4811***	-0.1808	-0.4853***	-0.4191***	-0.3957**	-0.1925
	(0.1792)	(0.1618)	(0.1500)	(0.1236)	(0.1798)	(0.1572)	(0.1538)	(0.1192)
ICT early days	-0.2128	-0.2290	-0.1452	-0.2198**	-0.2707	-0.0632	-0.1688*	-0.1714
	(0.1820)	(0.1475)	(0.1105)	(0.1100)	(0.1773)	(0.1586)	(0.0902)	(0.1077)
Lack food	4.166	3.880	3.432	-9.342	7.553	8.558*	-0.7962	-7.933
	(6.010)	(4.973)	(3.288)	(5.833)	(5.680)	(4.744)	(3.793)	(4.816)
Lack sleep	-8.214***	-1.241	2.315*	-0.0980	-6.713**	-1.010	1.366	-0.3833
	(2.997)	(1.657)	(1.295)	(1.474)	(2.913)	(1.678)	(1.368)	(1.428)
Lack print study (May)	-8.400***	-3.555	-2.216	0.9159	-7.258***	-5.404**	-1.315	2.062
	(2.919)	(2.317)	(2.109)	(2.894)	(2.744)	(2.348)	(2.061)	(2.334)
Lack study (June)	-2.636*	-0.9574	-2.927***	-3.847***	-2.336	-0.2188	-2.133*	-3.186***
	(1.573)	(1.465)	(1.048)	(1.262)	(1.563)	(1.267)	(1.177)	(1.208)
Feel stressed	2.340	-3.370*	-2.658	-0.5279	1.715	-3.524*	-2.381	-0.0473
	(2.057)	(1.804)	(1.652)	(1.467)	(1.896)	(1.813)	(1.557)	(1.385)
No passion	-6.558**	-1.838	-3.627**	-1.483	-5.505*	-1.821	-3.255	0.1279
	(2.879)	(2.031)	(1.809)	(1.756)	(2.819)	(1.793)	(2.154)	(1.561)
Bad health	-5.124**	1.008	1.749	-1.680	-4.598*	0.8280	2.467	-1.581
	(2.412)	(2.031)	(1.595)	(1.206)	(2.374)	(1.965)	(1.631)	(1.091)
No sport	0.0387	2.537	0.2807	1.083	-0.5804	2.581	1.191	0.9539
	(2.433)	(1.787)	(1.459)	(1.410)	(2.454)	(1.575)	(1.405)	(1.230)
Not fun	1.041	-3.602	1.912	2.292	-1.231	-1.625	1.477	-0.3044
	(3.115)	(2.223)	(1.965)	(1.462)	(3.037)	(2.166)	(2.082)	(1.502)
Feel unsafe	5.469	7.587***	3.469*	1.865	6.536**	9.313***	1.537	0.9707
	(3.493)	(2.365)	(2.089)	(2.214)	(3.242)	(2.360)	(2.220)	(1.978)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,709	4,095	3,900	4,167	3,609	4,291	4,002	4,384

Note: "Score QT (P4T3)" is calculated by the test score in the P4 T3 term (= School close = −3). Standard errors in parentheses are clustered at the classroom level. *$p<0.1$; **$p<0.05$; ***$p<0.01$

Table A-9: Definition of outcome variables for motivation and attitude toward math

Outcome variables	Definition
Like math (Like math)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you like to study math?," or 0 otherwise
Math important (Math is important)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you think it is important to study math?," or 0 otherwise
Understand math well (Understand math)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you understand the content of the math class well?," or 0 otherwise
Math will be useful (Math useful)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you think that what you learned in math class will be useful in the future when you start working?," or 0 otherwise
Concentrate in math class (Math concentration)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you listen carefully to the teacher in math class?," or 0 otherwise
Ask questions in math class (Math question)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you ask questions to your teacher in math class if you don't understand something?," or 0 otherwise
Complete math homework (Math homework)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you complete your math homework regularly?," or 0 otherwise
Concern about test results (Math results)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you care about the results of the test?," or 0 otherwise
High motivation for Reco (Reco motivation)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "Do you have a high motivation to study using the Reco sheets (reflection study sheets)?," or 0 otherwise
Motivation for other Reco (Other Reco)	= 1 if the student answered, "applicable" or "mostly applicable" to the question "You receive 3 Reco-sheets each time. Do you want to try to work on the other numbered Reco-sheets besides your own?," or 0 otherwise

Note: Words in parentheses are abbreviations for the outcome variables used in Tables 9 and Table 10.

Table A-10: Results of DID: Motivation and attitude toward math (Full sample)

Estimation Method:	DID without covariates				
Dependent Variables:	Math like	Math important	Math understand	Math useful	Math concentration
Model:	(1)	(2)	(3)	(4)	(5)
COVID19 × P6 survey	**0.0995*****	0.0223*	-0.0020	**0.0296****	0.0103
	(0.0272)	(0.0128)	(0.0156)	(0.0133)	(0.0148)
School FE	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes
Observations	8,299	8,270	8,194	8,296	8,312

Dependent Variables:	Math question	Math homework	Math result	Reco motivation	Other reco
Model:	(6)	(7)	(8)	(9)	(10)
COVID19 × P6 survey	0.0422	0.0180	0.0343*	**0.1089*****	**0.0809****
	(0.0349)	(0.0136)	(0.0201)	(0.0349)	(0.0356)
School FE	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes
Observations	8,234	8,226	8,316	8,294	8,253

Note: For simplicity, the coefficients for COVID19 and P6 survey are not given. We use the abbreviations of outcome variables given in Appendix Table A-12. Standard errors in parentheses are clustered at the classroom level. **p<0.1;* ***p<0.05;* ****p<0.01*

Table A-11: Results of DID with covariates: Motivation and attitude toward math (Full sample)

Estimation Method:	DID with covariates				
Dependent Variables:	Math like	Math important	Math understand	Math useful	Math concentration
Model:	(1)	(2)	(3)	(4)	(5)
COVID19 × P6 survey	**0.1947***	**0.0315**	**0.0555***	**0.0487***	**0.0340**
	(0.0309)	(0.0131)	(0.0188)	(0.0161)	(0.0139)
School FE	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes
Observations	7,958	7,935	7,865	7,954	7,970

Dependent Variables:	Math question	Math homework	Math result	Reco motivation	Other reco
Model:	(6)	(7)	(8)	(9)	(10)
COVID19 × P6 survey	**0.1273***	**0.0512***	**0.0912***	**0.2098***	**0.1791***
	(0.0410)	(0.0129)	(0.0220)	(0.0386)	(0.0414)
School FE	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes
Observations	7,898	7,890	7,973	7,945	7,919

Note: For simplicity, the coefficients for COVID19 and P6 survey are not given. We use the abbreviations of outcome variables given in Appendix Table A-12. Standard errors in parentheses are clustered at the classroom level. *$p<0.1$; **$p<0.05$; ***$p<0.01$

Table A-12: Results of DID and event study estimation: Treatment effect of ICT introduction (Full sample)

Dependent Variable:	Test score			
	Without ICT		With ICT	
Model:	DID	Event	DID	Event
	(1)	(2)	(3)	(4)
ICT early days			-0.0429	-0.1227
			(0.0749)	(0.0822)
COVID19 × P5T3_P6T3	-2.042*		-1.972*	
	(1.080)		(1.112)	
COVID19 × After P6T2	11.53***		11.60***	
	(0.7357)		(0.7285)	
COVID19	-1.303		-1.374	
	(0.8497)		(0.8618)	
Summer break	-2.559***	-1.308***	-2.635***	-1.308***
	(0.4644)	(0.4112)	(0.4965)	(0.4112)
Shortened days	0.0023	-0.2994***	0.0228	-0.2999***
	(0.0247)	(0.0879)	(0.0483)	(0.0878)
After P6T2	-1.318**		-1.364**	
	(0.5752)		(0.5753)	
COVID19 × P5T1 (SC = -2)		0.1436		0.1461
		(0.8036)		(0.8036)
COVID19 × P5T2 (SC = -1)		-0.1794		-0.1746
		(1.029)		(1.029)
COVID19 × P5T3 (SC = 0)		-5.481***		-5.482***
		(1.639)		(1.650)
COVID19 × P6T1 (SC = 1)		-2.623***		-2.629***
		(0.8207)		(0.8204)
COVID19 × P6T2 (SC = 2)		14.45***		15.92***
		(2.036)		(2.351)
COVID19 × P6T3 (SC = 3)		7.214***		7.208***
		(0.7366)		(0.7365)
School FE	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes
Observations	25,246	25,246	25,246	25,246

Note: "ICT early days" means the number of days the ICT was introduced earlier, counting from the school where they were last introduced. "With (Without) ICT" mean the estimation used (not used) the "ICT early days." "Event" represents the results of event study estimation. "School close" means the difference of term from P5 T3 term. Standard errors in parentheses are clustered at the classroom level. *p<0.1; **p<0.05; ***p<0.01

Table A-13: Results of DID: Treatment effect of ICT introduction (By pre-treat score quantile)

Dependent Variable:	Test score							
Model:	DID (Without ICT)				DID (With ICT)			
Score QT (P4T3):	1st QT	2nd QT	3rd QT	4th QT	1st QT	2nd QT	3rd QT	4th QT
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ICT early days					-0.0564	0.0212	-0.0661	-0.0813
					(0.1308)	(0.1330)	(0.0854)	(0.0762)
COVID19 × P5T3_P6T3	-3.594*	-1.596	0.3437	-3.376***	-3.493*	-1.631	0.4523	-3.247***
	(1.830)	(1.567)	(1.159)	(1.018)	(1.880)	(1.591)	(1.192)	(1.043)
COVID19 × After P6T2	18.06***	14.31***	9.568***	7.032***	18.15***	14.28***	9.659***	7.146***
	(1.292)	(1.194)	(1.035)	(0.8667)	(1.264)	(1.191)	(1.035)	(0.8542)
COVID19	-1.264	-1.458	-0.7410	0.1167	-1.369	-1.421	-0.8514	-0.0216
	(1.317)	(1.097)	(0.8662)	(0.7193)	(1.327)	(1.117)	(0.8617)	(0.7266)
Summer break	-0.8205	-2.705***	-3.611***	-3.153***	-0.9258	-2.667***	-3.731***	-3.291***
	(0.7137)	(0.6296)	(0.6116)	(0.4849)	(0.7717)	(0.6689)	(0.6356)	(0.5182)
Shortened days	-0.1830***	0.0255	0.0392	0.0820***	-0.1538*	0.0152	0.0708	0.1195**
	(0.0428)	(0.0373)	(0.0326)	(0.0276)	(0.0863)	(0.0782)	(0.0555)	(0.0472)
After P6T2	-2.457**	-3.570***	-0.9970	-0.0127	-2.525**	-3.547***	-1.065	-0.0960
	(1.010)	(0.8743)	(0.7810)	(0.5387)	(1.023)	(0.8764)	(0.7861)	(0.5360)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,253	5,987	5,951	6,689	5,253	5,987	5,951	6,689

Note: "Score QT (P4T3)" is calculated by the test score in the P4 T3 term (= School close = −3). *p<0.1; **p<0.05; ***p<0.01

Table A-14: Results of Event study: Treatment effect of ICT introduction (By pre-treat score quantile)

Dependent Variable:	Test score							
Model:	Event (Without ICT)				Event (With ICT)			
Score QT (P4T3):	1st QT	2nd QT	3rd QT	4th QT	1st QT	2nd QT	3rd QT	4th QT
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ICT early days					-0.1862	-0.0407	-0.1453*	-0.1423*
					(0.1455)	(0.1469)	(0.0864)	(0.0825)
COVID19 × P5T1 (SC = -2)	-0.5599	-0.0122	1.180	2.371***	-0.5687	-0.0133	1.182	2.360***
	(1.329)	(1.027)	(0.8434)	(0.7154)	(1.330)	(1.027)	(0.8443)	(0.7160)
COVID19 × P5T2 (SC = -1)	-0.3226	0.4897	0.5062	1.085	-0.3252	0.4883	0.5096	1.076
	(1.710)	(1.420)	(1.221)	(0.9388)	(1.710)	(1.421)	(1.221)	(0.9399)
COVID19 × P5T3 (SC = 0)	-7.214***	-7.668***	-5.376*	-4.955***	-7.243***	-7.677***	-5.373*	-4.970***
	(2.227)	(2.716)	(3.059)	(1.573)	(2.245)	(2.718)	(3.072)	(1.584)
COVID19 × P6T1 (SC = 1)	-3.738**	-1.013	0.7562	-3.138***	-3.755**	-1.017	0.7501	-3.157***
	(1.557)	(1.372)	(1.032)	(0.9193)	(1.551)	(1.372)	(1.031)	(0.9204)
COVID19 × P6T2 (SC = 2)	20.67***	19.47***	15.60***	8.939***	23.08***	19.97***	17.32***	10.57***
	(3.977)	(3.252)	(2.816)	(2.279)	(4.409)	(3.481)	(3.045)	(2.444)
COVID19 × P6T3 (SC = 3)	11.28***	9.132***	8.647***	3.728***	11.26***	9.129***	8.641***	3.709***
	(1.455)	(1.311)	(1.107)	(0.7049)	(1.454)	(1.311)	(1.107)	(0.7034)
Summer break	-0.2804	-1.659***	-1.832***	-1.186**	-0.2807	-1.659***	-1.832***	-1.186**
	(0.7127)	(0.5863)	(0.6329)	(0.4879)	(0.7126)	(0.5864)	(0.6329)	(0.4880)
Shortened days	-0.5301***	-0.3870***	-0.2725**	-0.1749*	-0.5310***	-0.3871***	-0.2729**	-0.1754*
	(0.1587)	(0.1379)	(0.1271)	(0.0977)	(0.1586)	(0.1379)	(0.1271)	(0.0977)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classroom FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,253	5,987	5,951	6,689	5,253	5,987	5,951	6,689

Note: "Score QT (P4T3)" is calculated by the test score in the P4 T3 term (= School close = −3). "Event" represents the results of event study estimation. "School close" means the difference of term from P5 T3 term. *$p<0.1$; **$p<0.05$; ***$p<0.01$