**The Effects of Summer Heat on Test Scores: Evidence Panel Data**

**Hyunkuk Cho**

**Yeungnam University**

**School of Economics and Finance**

**280 Daehak-ro, Gyeongsan, Korea 712-749**

 **Email: hkcho@ynu.ac.kr, phone: 82-53-810-2718, fax: 82-53-810-4651**

**Abstract**

This paper contributes to the literature by being the first to analyze the effect of summer heat on students’ test scores. For the analysis, this paper combines individual-level test score data and city-level daily temperature data. To control for unobserved heterogeneity across different cities, this paper compares the test scores of students within the same city over time (city-fixed effects estimation). This paper finds that summer heat has negative effects on students’ test scores: Ten additional days with maximum daily temperature exceeding 34°C during summer, relative to a day with maximum daily temperature of 28–30°C, decreased the test scores by 1–2 percentile points. The effect is larger for boys and for cities whose summers are relatively cooler. In addition, the current years’ test scores are negatively affected by the previous summer’s heat as well.

Keywords: climate change; summer heat; academic achievement

JEL Classifications: I2; Q54

**I. Introduction**

 It is well documented that summer is getting hotter and hotter. For example, Della-Marta et al. (2007) find that during the period 1880~2005 the length of heat waves over western European countries doubled and the frequency of summer heat tripled. Habeeb et al. (2015) find that the frequency, duration, and intensity of summer heat in 50 large U.S. cities significantly increased from 1961 to 2010. The 2003 European heat wave and the 2010 Russian heat wave are the two recent well-known examples of hot summers.

 It is shown that summer heat has a negative effect on human health. Deschênes and Greenstone (2011) analyze U.S. data from 1968 to 2002 to find that an additional day with a mean temperature exceeding 90°F, relative to a day in the 50– 60°F range, increases the annual age-adjusted mortality rate by about 0.1 percent. Barreca (2012) examines U.S. data from 1973 to 2002 to show that exposure to three additional days with temperatures exceeding 90°F, relative to a day with temperatures between 60° and 70°F, leads to 0.54 additional deaths per 100,000 inhabitants. More than 70,000 people died in Europe during the summer of 2003 (Robine et al., 2008).

 Summer heat is likely to affect students’ learning negatively, too, as studies show that high temperature has negative effects on memory (e.g., Gaoua et al., 2011) and attention (e.g, Simmons et al., 2008). The increased temperature may cause negative effects by decreasing cerebral blood flow (e.g., Drevets and Raichle, 1998; Ogoh et al., 2013) and increasing heat-related fatigue (e.g. McMorris et al., 2006). Students’ learning may also be disrupted if they have to spend time to take care of family members who are sick from the summer heat. In addition, students could become sick from food poisoning, which happens more frequently when the temperature is high (Bentham and Langford, 2001), or they may have sleep deprivation, resulting in increased errors of commission during the daytime (Lim and Dinges, 2008).

 No studies have yet examined the effect of summer heat on students’ academic achievement. This paper contributes to the literature by being the first to analyze the effect of summer heat on students’ test scores.[[1]](#footnote-1) For the analysis, this paper combines individual-level test score data and city-level daily temperature data. The test score data are from the Korean college entrance exam administered in November each year. The data consist of 1.7 million observations over the five years from 2009 to 2013. The 1.7 million observations represent almost 50% of the population, as about 0.6 million high school seniors take the test each year.[[2]](#footnote-2) Since the test score data include information on which city the students’ schools are located in, it is possible to merge the test score data with the temperature data and to examine the effect of summer heat on students’ academic achievement.

 Since a city is observed every year over the five-year period, one can address regional heterogeneity by comparing the test scores of students who live in the same city. That is, this paper examines whether high school seniors living in a particular city whose senior year is very hot perform differently from high school seniors in the same city whose senior year is relatively cool (city-fixed effects estimation). By doing so, this paper controls for factors that affect test scores and are correlated with summer temperature. For example, when students in large cities perform better than students in small cities and summer temperature is higher in large cities, comparing the test scores of students in different cities could produce biased results.

 This paper includes 164 cities in the analysis, including Seoul and Busan, the two largest cities in Korea. In 2009, the first year of the data this paper examines, Korea had 165 cities, and thus the sample represents the entire country. Each city in the analysis has an average of 10,137 observations over the five years, while the median is 2,004 observations over the five years. Seoul has the largest number of observations, 374,169, over the five years and Busan has the second-largest number, 113,284 observations.

 This paper finds that summer heat has negative effects on students’ test scores: An additional day with maximum daily temperature exceeding 34°C (or about 93°F) during summer, relative to a day with maximum temperature 28–30°C, decreases test scores by 0.1–0.2 percentile points. The effect is larger for boys and cities whose summers are relatively cooler. In addition, the current years’ test scores are negatively affected by the previous summer’s heat.

 The remainder of this paper is organized as follows: The next section describes the empirical strategy of this paper; Section III describes the data used in this paper; Section IV presents the estimation results; and Section V concludes the paper.

**II. Empirical Strategy**

Consider the following equation for student iwho attends school s in city c in year t.

*Aict = β0 +* + *β6Rainct* + *β7Femalei* + ***SsctB***+ *αc + γt + εict*(1)

where *A* is the percentile rank of the student, *Temp* is the number of days during summer, from May to September, whose highest daily temperature is in one of the following five bins: –28°C, 28–30°C, 30–32°C, 32–34°C, and 34°C–. For example, *Tempct1* indicates how many days are included in the first bin, and *Tempct5* shows the number of days in the fifth bin: If *Tempct1* = 5, this means that city c has 5 days with the highest daily temperature lower than 28°C during summer in year t, and *Tempct5* = 10 means that city c has 10 days with the highest daily temperature equal to or higher than 34°C during summer in year t. This paper uses the daily high temperature instead of mean temperature because students are not likely to spend time on studying during the time of day when the temperature is lowest. *Rain* is total rainfall during summer, and *Female* is a dummy variable indicating whether a student is female. ***S*** is a vector of school variables, including the average years of education and experience that the teachers have, a dummy variable indicating whether the school is a private school, and a dummy variable indicating whether the school is a coeducational school. In addition, *α* is a city-fixed effect, *γ* is a year-fixed effect, and *ε i*s an error term.

 The parameters of interest are *β1* ~ *β5*, which measure the effect of summer temperature on students’ test scores. The negative parameters mean that high temperature decreases students’ test scores. By including *α* in the equation, this paper compares the test scores of students within the same city over time to estimate within-city estimates so that it can control for unobserved heterogeneity across different cities. In addition, the standard errors are clustered at the city-year level, because the error terms are likely to be correlated within the same city over time and across different cities in the same year.

 There are two factors that can make the estimates downward-biased. First, the summer temperature of each city is likely to be positively correlated: If a city has an unusually hot summer in a year, it is likely that other cities have hot summers in the same year, too, given that Korea is not a large country.[[3]](#footnote-3) If this is the case, the percentile rank may not reflect how much students actually learn, for all the students in Korea may learn less in a year with a hot summer but could still have a percentile rank as good as the one in a year with a cool summer. The second factor is that an unusually hot summer could exhaust students and cause them not to take the test. If this happens, the true effect could be underestimated.

**III. Data**

 This paper combines two sources of data, individual-level test score data and city-level daily temperature data. The city-level weather data come from the Korean Meteorological Administration.[[4]](#footnote-4) The data include the highest daily temperature and the amount of daily rainfall during the summer, from May to September, over the five years between 2009 and 2013. The data enable calculation of how many summer days a city has at a certain temperature and of total rainfall during the summer in each year. Out of the 164 cities this paper analyzes, eight cities have no weather information. This paper uses the weather information of the adjacent cities for these eight cities.[[5]](#footnote-5) Table 1 shows how many days, on average, each city had its highest daily temperature at certain levels during the five years. For example, the cities had an average of 2.2 days with a highest daily temperature equal to or greater than 34°C in 2009, and the number was 9.6 in 2013. One can see that the years of 2010, 2012, and 2013 had relatively hot summers, and the other two years had relatively cool summers.

 The test score data are from the Korean Ministry of Education and contain information on the scores for the Korean college entrance exam, which is administered one time in November each year.[[6]](#footnote-6) High school seniors who want to go to college take the test, and this paper uses the scores of tests that were taken between 2009 and 2013. The test score data also include information on the students’ gender and the schools that the students attended. The school information includes the location of the school, each teacher’s years of education and experience, whether the school is a private school, whether the school is a coeducational school, *etc*. The exam score that this paper uses is the percentile rank, so if a student’s score is 60, that student’s score is higher than 60% of the other test takers’ scores.

 The ministry does not provide the test scores of all test takers but provides almost 50% of them. When the ministry does sampling, firstly, it chooses 70% of schools that were open all the years between 2009 and 2013. When choosing schools, the ministry considers the school’s location (city), whether the school is a single sex or coeducational school, whether the school is a private or public school, and whether the school is a college preparatory or vocational school (stratified sampling). After choosing schools, the ministry randomly chooses 70% of the test takers enrolled in those schools. In this way, about 1.7 million students in 1,729 high schools were chosen.[[7]](#footnote-7) Table 2 shows the descriptive statistics about the students and their schools. About 47% of the test takers are female students. Teachers’ average years of education and experience are about 17 years, respectively.

**IV. Results**

 Table 3 shows the estimation results. The first three columns are results from the ordinary least squares (OLS) estimation, and the last three columns are from the city-fixed effect (FE). estimation. The OLS estimates indicate that summer heat has no significant or positive effect on students’ test scores. An additional day with the highest daily temperature between 32°C and 34°C, relative to a day with the highest daily temperature between 28°C and 30°C, increased the test scores by 0.1–0.2 percentile points. Additional days with the highest daily temperature of other categories had no effects. However, the OLS estimates could have bias arising from comparing the test scores of students across different cities. The FE estimates compare within the same cities over time to address this problem.

 The FE estimates in the last three columns of Table 3 show that summer heat had negative effects on students’ academic achievement. An additional day with the highest daily temperature equal to or greater than 34°C, relative to a day with the highest daily temperature between 28°C and 30°C, reduced the test scores by 0.1–0.2 percentile points. The results imply that having ten additional days with the highest daily temperature, say, 35°C, relative to a day with the highest temperature equal to, say, 28°C, decreases the test scores by 1–2 percentile points. In addition, an additional day with the highest daily temperature between 30°C and 32°C, relative to a day with the highest temperature between 28°C and 30°C, decreased the test scores by 0.03–0.1 percentile points.

 This paper estimates the summer temperature effect based on the summer heat students usually experience. Students who live in areas that have relatively hot summers, like Texas in the United States, may be affected less by high temperature in the summer: They may have well-equipped air conditioning systems and may be well adapted to hot summers. On the contrary, students who live in areas that have relatively cool summers, like Alaska in the United States, may be more affected by high temperature in summer because they do not experience hot summers very often. This paper examines how hot the summers were in each city between 2004 and 2008 (five years), before 2009, the first year of the data that this paper examines. A city is considered to (usually) have hot summers if the average of highest daily temperature during the three summer months of June, July, and August in these five years is equal to or greater than 28.5°C. About 750,000 students in 104 cities are included in this category. About 910,000 students in 60 cities are included in the other category. [[8]](#footnote-8)

 Table 4 shows the results. The first three columns examine 60 cities that had an average of highest daily temperature below 28.5°C during the three summer months between 2004 and 2008, and the last three columns analyze 104 cities that had an average of highest daily temperature equal to or greater than 28.5°C. All six columns control for city-fixed effects so that all the estimates are within-city estimates. As expected, hot summers have greater effects on the test scores of students who live in relatively cool areas: The estimates in the first three columns are larger in magnitude than the estimates in the last three columns. For example, if cities with the average of highest daily temperature below 28.5°C have one more day with the highest daily temperature equal to or greater than 34°C, relative to a day with the highest daily temperature between 28°C and 30°C, the Korean test scores of students in the cities decrease by 0.1 percentile points. The estimate for the other cities is almost half that, 0.06 percentile points. The estimates for the English test are −0.22 and −0.15, respectively, and the estimates for the math test are −0.14 and −0.06, respectively.

 Previous studies find that the effects of summer heat on mortality and heat-related illness are larger for men than for women (e.g., Deschênes & Greenstone, 2011; Bai et al., 2014). This implies that the summer heat effects on academic achievement could be larger for boys than for girls. Table 5 shows the effects by gender. The first three columns are for boys, and the last three columns are for girls. As shown in the table, boys are more likely to be affected by high temperature in summer. For boys, when the Korean test score is the dependent variable, the coefficients on the number of days with the highest daily temperature equal to or greater than 34°C is −0.097. It is −0.082 for girls. In addition, one more day with the highest temperature between 30°C and 32°C decreases the boys’ Korean test scores by 0.06 percentile points but has no effect on the girls’ Korean test scores.

 This study also estimates the effects of the temperature of the summer one year before. To estimate the effects, this paper includes the temperature in the current year and one lagged year in the regression equation. Consequently, the test score data from the year 2009 are excluded in the analysis, and the number of observations decreases to about 1.3 million. Table 6 shows the results. The first three columns include only the current year temperature, and the last three columns include both years’ temperatures. The table shows that the summer heat of last year has negative effects on the test scores of the current year, while the previous year’s summer effect is smaller than the current year’s summer effect. For example, an additional day of the previous year with the highest daily temperature equal to or greater than 34°C, relative to a day with the highest daily temperature between 28°C and 30°C, decreases the current year’s Korean and English test scores by 0.07 percentile points, respectively. The corresponding estimates for the current year are 0.08 and 0.2 percentile points, respectively.

**V. Conclusion**

 This paper is the first to estimate the effects of summer heat on students’ academic achievement. To control for regional heterogeneity across different cities, this paper compares the test scores of students within the same city over time. This paper finds that an additional day with the highest daily temperature equal to or greater than 34°C, relative to a day with the highest daily temperature between 28°C and 30°C, reduces the test scores by 0.1–0.2 percentile points. The effects are larger for boys and cities that have relatively cool summers. In addition, the current years’ test scores are negatively affected by the previous year’s summer heat.

**References**

Bai, L. et al. (2014). The effects of summer temperature and heat waves on heat-related
 illness in a coastal city of China, 2011–2013. *Environmental Research*, 132, 212-219.

Barreca, A. I. (2012). Climate change, humidity, and mortality in the United States. *Journal
 of Environmental Economics and Management*, 63(1), 19-34.

Bentham, G., & Langford, I. H. (2001). Environmental temperatures and the incidence of
 food poisoning in England and Wales. *International Journal of Biometeorology*, 45(1),
 22-26.

Della-Marta, P. M. et al. (2007). Doubled length of western European summer heat waves
 since 1880. *Journal of Geophysical Research: Atmospheres* (1984–2012), 112(D15).

Deschênes, O., & Greenstone, M. (2011). Climate Change, Mortality, and Adaptation:
 Evidence from Annual Fluctuations in Weather in the US. *American Economic Journal:
 Applied Economics*, 3(4), 152-185.

Drevets, W.C., & Raichle, M.E. (1998). Reciprocal suppression of regional cerebral blood
 flow during emotional versus higher cognitive processes: implications for interactions
 between emotion and cognition. *Cognition and Emotion*, 12(3), 353-385.

Habeeb, D. et al. (2015). Rising heat wave trends in large US cities. *Natural Hazards*, 76(3),
 1651-1665.

Gaoua, N. et al. (2011). Alterations in cognitive performance during passive hyperthermia are
 task dependent. *International Journal of Hyperthermia*, 27(1), 1-9.

Lim, J., & Dinges, D. F. (2008). Sleep deprivation and vigilant attention. *Annals of the New
 York Academy of Sciences*, 1129(1), 305-322.

McMorris, T. et al. (2006). Heat stress, plasma concentrations of adrenaline, noradrenaline,
 5-hydroxytryptamine and cortisol, mood state and cognitive performance. *International
 Journal of Psychophysiology*, 61(2), 204-215.

Ogoh, S. et al. (2013). Blood flow distribution during heat stress: cerebral and systemic blood
 flow. *Journal of Cerebral Blood Flow & Metabolism*, 33(12), 1915-1920.

Robine, J. M. et al. (2008). Death toll exceeded 70,000 in Europe during the summer of 2003.
 *Comptes Rendus Biologies*, 331(2), 171-178.

Simmons, S. E. et al. (2008). The effect of passive heating and head cooling on perception,
 cardiovascular function and cognitive performance in the heat. *European Journal of
 Applied Physiology*, 104(2), 271-280.

Wargocki, P., & Wyon, D. P. (2007). The effects of moderately raised classroom
 temperatures and classroom ventilation rate on the performance of schoolwork by children
 (RP-1257). *Hvac&R Research*, 13(2), 193-220.

Table 1: Average Number of Days with Highest Daily Temperature of Certain Degrees

|  |  |
| --- | --- |
|  | Days with highest temperature during summer |
| ≥ 34°C | ≥ 32°Cand < 34°C | ≥ 30°Cand < 32°C | ≥ 28°Cand < 30°C | < 28°C |
| Year 2009 | 2.2 | 9.8 | 25.5 | 36.0 | 79.7 |
| 2010 | 7.2 | 19.0 | 30.6 | 28.5 | 67.7 |
| 2011 | 3.5 | 12.7 | 24.7 | 28.2 | 83.9 |
| 2012 | 9.2 | 12.9 | 19.6 | 31.1 | 80.1 |
| 2013 | 9.6 | 17.3 | 28.3 | 29.9 | 68.0 |
| The averages are calculated using 164 cities in Korea based on the highest daily temperature during May through September each year..  |

Table 2: Descriptive Statistics about the Students and Schools

|  |  |  |
| --- | --- | --- |
|  | Mean | Standard deviations |
| Students - female (%) | 47.1 | 49.9 |
| Teachers’ years of education  | 16.9 | 0.3 |
| Teachers’ years of experience | 17.4 | 3.8 |
| Private schools (%) | 42.9 | 49.5 |
| Coeducational schools (%) | 61.7 | 48.6 |
| Number of total schools | 1,729 |  |
| Number of observations | 1,662,533 |  |
|  |

Table 3: Estimation Results

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | OLS | FE |
|  | Dependent variable = | Dependent variable = |
|  | Korean test score(1) | English test score(2) | Math testscore(3) | Korean test score(4) | English test score(5) | Math testscore(6) |
| Days with highest daily temperature | ≥ 34°C | −0.003(0.063) | −0.057(0.077) |

|  |
| --- |
| 0.065 |
| (0.066) |

 |

|  |
| --- |
| −0.089\*\*\* |
| (0.017) |

 |

|  |
| --- |
| −0.182\*\*\* |
| (0.025) |

 |

|  |
| --- |
| −0.079\*\*\* |
| (0.021) |

 |
| ≥ 32°C and <34°C | 0.153\*\*(0.068) | 0.191\*\*(0.084) | 0.196\*\*\*(0.069) |

|  |
| --- |
| −0.013 |
| (0.015) |

 |

|  |
| --- |
| −0.019 |
| (0.020) |

 |

|  |
| --- |
| 0.012 |
| (0.018) |

 |
| ≥ 30°C and < 32°C | 0.059(0.057) | 0.037(0.083) | 0.095\*(0.054) |

|  |
| --- |
| −0.041\*\* |
| (0.018) |

 |

|  |
| --- |
| −0.081\*\*\* |
| (0.021) |

 |

|  |
| --- |
| −0.034\* |
| (0.019) |

 |
| < 28°C | 0.005(0.041) | −0.012(0.054) | 0.059(0.040) | −0.023(0.015) | −0.025(0.019) | −0.008(0.019) |
| City-fixed effects | No | No | No | Yes | Yes | Yes |
| Year-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Adjusted R2 | 0.02 | 0.03 | 0.02 | 0.05 | 0.07 | 0.05 |
| The number of cities | 164 | 164 | 164 | 164 | 164 | 164 |
| The number of observations | 1,662,533 | 1,662,533 | 1,662,533 | 1,662,533 | 1,662,533 | 1,662,533 |
| Standard errors are in parenthesis. They are clustered at the city-year level. These regressions also include a constant, the amount of total rainfall during summer, a dummy variable indicating whether a student is female, the average years of education and experience that the teachers have, a dummy variable indicating whether the school is a private school, and a dummy variable indicating whether the school is a coeducational school.\*\*\*: statistically significant at the 1% level \*\*: statistically significant at the 5% level \*: statistically significant at the 10% level |

Table 4: Estimation Results by Past Summer Temperature

|  |  |  |
| --- | --- | --- |
|  | Average daily highest temperature < 28.5°C  | Average daily highest temperature ≥ 28.5°C |
| Dependent variable = | Dependent variable = |
| Korean test score(1) | English test score(2) | Math testscore(3) | Korean test score(4) | English test score(5) | Math testscore(6) |
| Days with highest daily temperature | ≥ 34°C | −0.138\*\*\*(0.029) | −0.231\*\*\*(0.040) | −0.161\*\*\*(0.031) | −0.054\*\*\*(0.021) | −0.149\*\*\*(0.035) | −0.060\*\*\*(0.023) |
| ≥ 32°Cand <34°C | 0.005(0.031) | −0.025(0.038) | −0.002(0.033) | −0.021(0.021) | −0.019(0.033) | −0.006(0.023) |
| ≥ 30°C and < 32°C | −0.084\*\*\*(0.024) | −0.119\*\*\*(0.031) | −0.101\*\*\*(0.030) | −0.023(0.021) | −0.049\*(0.025) | −0.020(0.021) |
| < 28°C | -0.013(0.018) | −0.027(0.022) | 0.028(0.020) | 0.014(0.024) | 0.020(0.031) | −0.028(0.027) |
| City-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Year-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Adjusted R2 | 0.04 | 0.05 | 0.04 | 0.06 | 0.08 | 0.06 |
| The number of cities | 60 | 60 | 60 | 104 | 104 | 104 |
| The number of observations | 909,047 | 909,047 | 909,047 | 753,486 | 753,486 | 753,486 |
| Standard errors are in parenthesis. They are clustered at the city-year level. The first three columns include 60 cities that have the average of highest daily temperature below 28.5°C during the three summer months between 2004 and 2008, and the last three columns include 104 cities that have the average of highest daily temperature equal to or greater than 28.5°C during the same period .These regressions also include a constant, the amount of total rainfall during summer, a dummy variable indicating whether a student is female, the average years of education and experience that the teachers have, a dummy variable indicating whether the school is a private school, and a dummy variable indicating whether the school is a coeducational school.\*\*\*: statistically significant at the 1% level \*: statistically significant at the 10% level  |

Table 5: Estimation Results by Gender

|  |  |  |
| --- | --- | --- |
|  | Boys | Girls |
| Dependent variable = | Dependent variable = |
| Korean test score(1) | English test score(2) | Math testscore(3) | Korean test score(4) | English test score(5) | Math testscore(6) |
| Days with highest daily temperature | ≥ 34°C | −0.097\*\*\*(0.023) | −0.184\*\*\*(0.026) | −0.078\*\*\*(0.027) | −0.082\*\*\*(0.018) | −0.178\*\*\*(0.030) | −0.081\*\*\*(0.021) |
| ≥ 32°Cand <34°C | −0.025(0.018) | −0.041\*(0.023) | 0.008(0.023) | 0.001(0.019) | 0.007(0.022) | 0.016(0.018) |
| ≥ 30°C and < 32°C | −0.059\*\*\*(0.020) | −0.097\*\*\*(0.024) | −0.049\*\*(0.023) | −0.019(0.021) | −0.060\*\*(0.024) | −0.015(0.020) |
| < 28°C | −0.020(0.017) | -0.028(0.021) | −0.015(0.023) | −0.026(0.017) | −0.021(0.021) | −0.001(0.019) |
| City-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Year-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Adjusted R2 | 0.06 | 0.08 | 0.06 | 0.04 | 0.06 | 0.04 |
| The number of observations | 880,082 | 880,082 | 880,082 | 782,451 | 782,451 | 782,451 |
| Standard errors are in parenthesis. They are clustered at the city-year level. These regressions also include a constant, the amount of total rainfall during summer, the average years of education and experience that the teachers have, a dummy variable indicating whether the school is a private school, and a dummy variable indicating whether the school is a coeducational school.\*\*\*: statistically significant at the 1% level \*\*: statistically significant at the 5% level \*: statistically significant at the 10% level  |

Table 6: Estimation Results Including One-Year Lags

|  |  |
| --- | --- |
|  | Dependent variable = |
| Korean test score(1) | English test score(2) | Math test score (3) | Korean test score(4) | English test score(5) | Math test score (6) |
| Days with highest daily temperature in current year | ≥ 34°C | −0.083\*\*\*(0.017) | −0.181\*\*\*(0.029) | −0.065\*\*\*(0.021) | −0.083\*\*\*(0.016) | −0.198\*\*\*(0.030) | −0.068\*\*\*(0.021) |
| ≥ 32°C and <34°C | −0.016(0.014) | −0.011(0.022) | 0.012(0.017) | −0.026(0.017) | −0.035(0.024) | −0.004(0.019) |
| ≥ 30°C and < 32°C | −0.049\*\*\*(0.017) | −0.095\*\*\*(0.024) | −0.030(0.020) | −0.054\*\*\*(0.016) | −0.093\*\*\*(0.024) | −0.043\*\*(0.021) |
| < 28°C | −0.032\*(0.016) | −0.022(0.023) | −0.001(0.019) | −0.041\*\*(0.016) | −0.040\*(0.023) | −0.014(0.019) |
| Days with highest daily temperature one year before | ≥ 34°C | -- | -- | -- | −0.067\*\*\*(0.020) | −0.072\*\*(0.033) | −0.024(0.022) |
| ≥ 32°Cand <34°C | -- | -- | -- | −0.018(0.015) | −0.005(0.025) | −0.043\*\*(0.019) |
| ≥ 30°C and < 32°C | -- | -- | -- | −0.030\*\*(0.014) | −0.004(0.022) | −0.041\*\*(0.018) |
| < 28°C | -- | -- | -- | −0.031\*\*(0.014) | −0.040\*\*(0.018) | −0.038\*\*(0.016) |
| City-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Year-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Adjusted R2 | 0.05 | 0.07 | 0.05 | 0.05 | 0.07 | 0.05 |
| The number of observations | 1,336,671 | 1,336,671 | 1,336,671 | 1,336,671 | 1,336,671 | 1,336,671 |
| Standard errors are in parenthesis. They are clustered at the city-year level. These regressions also include a constant, the amount of total rainfall during summer, a dummy variable indicating whether a student is female, the average years of education and experience that the teachers have, a dummy variable indicating whether the school is a private school, and a dummy variable indicating whether the school is a coeducational school.\*\*\*: statistically significant at the 1% level \*\*: statistically significant at the 5% level \*: statistically significant at the 10% level |

1. One related study is Wargocki and Wyon (2007) which examines the relationship between classroom temperatures and the test scores of 10-to-12- year-olds. The study conducts an experiment to compare the test scores of students in the classrooms of about 20~ 21°C and about 25°C and finds the negative effects of high temperatures. [↑](#footnote-ref-1)
2. In 2009, 638,216 students took the test. The numbers of students who took the test in the subsequent four years are 668,991, 648,946, 621,336, and 606,813, respectively. [↑](#footnote-ref-2)
3. The area of Korea is 100,210 km², which is about 24% the size of California (423,970 km²). [↑](#footnote-ref-3)
4. The data can be downloaded at http://minwon.kma.go.kr/main/main.do (written in Korean) [↑](#footnote-ref-4)
5. The number of students who live in these eight cities is about 82,000. Excluding these students in the analysis does not change the regression results. The results are available upon request. [↑](#footnote-ref-5)
6. The data can be obtained upon request at http://edss.moe.go.kr/index.jsp (written in Korean) [↑](#footnote-ref-6)
7. In 2009, the first year of the data this paper examines, there were 2,225 high schools in Korea. [↑](#footnote-ref-7)
8. The mean temperature of the largest city, Seoul, which has about 370,000 students is 28.4°C, and its inclusion in either category increases the number of students in that category abruptly. The inclusion of Seoul in either category does not change the qualitative results. [↑](#footnote-ref-8)