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Do Single-Sex Schools Enhance Students' STEM (Science, Technology, Engineering, and Mathematics) Outcomes?

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Abstract

In many countries, males currently lag behind females in schooling attainment but females are still underrepresented in STEM studies. This pattern has raised renewed interest in the potential of single-sex schools for enhancing STEM outcomes. Utilizing the unique setting in Seoul, where assignment to single-sex or coeducational high schools is random, and with multiple years of administrative data from the national college entrance examinations and a longitudinal survey of high school seniors, we assess causal effects of single-sex schools on students' math test scores and choice of the science-math test. We also assess whether single-sex schools affect students' interests and self-efficacy in math and science, and expectations and actual choices of a STEM college major in university. We find significantly positive effects of all-boys schools consistently across different STEM outcomes but not for girls. We address one possible mechanism by conducting mediation analysis with the proportion of same-gender math teachers.

JEL Classification:

I21; I28; J24

Keywords

Single-Sex Schools; STEM; Random Assignment; Seoul

Introduction

Cultivating sufficient numbers of graduates in science, technology, engineering, and mathematics (STEM) occupations has become an important policy concern in many developed countries. A recent study predicted the need for 1 million STEM graduates over

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the next decade to respond to the growing labor market demand for STEM professionals in the United States (President's Council of Advisors on Science and Technology, 2012). However, the supply of U.S. STEM students is projected to be short (Chen, 2013).

In recent decades, worldwide females have significantly improved their schooling attainment and previous gender gaps favoring males have been substantially reduced and in many contexts including in most high-income countries reversed to favor females (Buchmann, DiPrete, & McDaniel, 2008; Grant & Behrman, 2010). The significant overall schooling progress of women is, however, accompanied by persistent underrepresentation of women in STEM college majors, particularly in engineering and mathematics (Freeman, 2004; NCES, 2007).

The lower likelihood for women to choose STEM majors in college naturally leads to limited supply of women in STEM occupations (Frehill, 1997; Xie & Shauman, 2003). Given the growing importance of the science and engineering workforce in globalized economies as well as concerns about gender equity, a variety of educational programs and research activities to attract women to STEM fields have been enacted (NSF, 2006a, 2006b). Given the growing demand for STEM-trained workers, to attract more female college graduates as well as male students to STEM fields efficiently, systematic evidence is required regarding what factors constrain or enhance students’ pursuit of STEM majors and entrance later to STEM occupations.

The major purpose of the current study is to assess the impact of one particular institution that can influence students’ STEM outcomes – single-sex schools (Mael, 1998; Sax, Shapiro, & Eagan, 2011; Sullivan, 2009). In this study we first examine causal effects of single-sex schools on high school seniors’ national college entrance exam scores on math for seven different senior cohorts (2004 to 2011, except 2007) in South Korea (hereafter, Korea). Our examination across seven different cohorts helps assess how robust are our estimates of the effects of single-sex schools. Secondly, we investigate causal effects of single-sex schools on students’ choice of advanced mathematics. There are two types of national college entrance examinations for math in Korea: general-math and science-math tests. The general-math test is taken by students who apply for university admissions as humanities and social science majors, while the more advanced science-math test is required for those who apply for STEM majors. Therefore, students’ choice of the science-math test is an important outcome to be examined with respect to STEM careers. Thirdly, using different data from a small-scale longitudinal survey of high school seniors, we assess whether single-sex schooling increases students’ interests and self-efficacy in math and science subjects and their expectations to major in a STEM area when they enter college. We expect that increased students’ STEM interests, self-efficacy, and expectations are related to their enhanced performance in math and ultimately to the probabilities that they will pursue STEM careers. Finally, we investigate whether those who graduated from single-sex high schools are more likely to attend university with STEM college majors within two years after high school than their counterparts who graduated from coeducational schools.

We investigate these questions for Korea because of the random assignment of students into single-sex and coeducational high schools in Seoul (capital of Korea with population of 10 million) that will be described below in more detail. The unique setting of Seoul high schools provides an exceptional opportunity of estimating causal effects of single-sex schools on students' STEM outcomes. Our analyses of math test scores and the choice of the science-math test are based on administrative data that contain information on all high school seniors in Seoul who took the national entrance examinations for the period 2004-2011. In Korea, more than 95 percent of students in academic high schools take this examination that is given once a year in November.

We, furthermore, attempt to address possible mechanisms through which single-sex schools affect students' math test scores and choices whether to take the science-math test. First, we present single-sex school effects on Korean and English test scores as well as STEM outcomes. Even though this exploration does not directly identify a mechanism for single-sex school effects, the comparison between non-STEM and STEM outcomes can help us to understand to what extent single-sex school effects are specific to STEM outcomes or general across different subjects. In other words, we can address the extent to which separating female and male students is particularly conductive to enhancing STEM outcomes. Second, using the same administrative data of high school seniors in Seoul linked with school-level information on the numbers of female and male math teachers, we investigate how the gender composition of math teachers may account for single-sex school effects on math-related outcomes. In order to assess to what extent the role of the gender composition of teachers in accounting for single-sex school effects is specific to STEM outcomes, we repeat the analysis for Korean and English test scores as well using *subject-specific* numbers of female and male teachers (i.e., the share of male teachers in each subject of Korean and English).

There are many claims that single-sex schools (or classrooms) enhance educational outcomes, particularly in STEM for female students, because of the absence of social interactions with boys that divert attention from academic activities and because of the absence of competition from boys for teachers' attention (Mael et al., 2004; Riordan, 1990). However, some other studies question any benefits of single-sex schools, highlighting the likelihood that better educational outcomes among students in single-sex than their peers in coeducational schools may simply reflect prior differences in ability, motivation and other background factors between students in single-sex and coeducational schools before entering the schools (Jackson, 2012; Lavy & Schlosser, 2011; LePore & Warren, 1997; Marsh, 1989). If students, or their families, choose between single-sex schools and coeducational schools, students attending the two types of schools probably differ in their characteristics, including those difficult to measure such as ability, motivation, effort, and parental involvement in children's education that could potentially affect student's educational outcomes. This self-selection may lead to biased estimates of the single-sex school effects from observational data (Mael et al., 2005; Sax, 2009).

Although there has been an increasing body of studies that attempt to estimate causal effects of single-sex education or effects of gender composition on educational outcomes, the results are quite mixed. Booth, Cardona-Sosa, and Nolen (2013) conduct an experiment in a coeducation university to examine the effect of single-sex classes on performance of college students taking economics courses (also see Booth & Nolen, 2012a, 2012b). They find positive effects of single-sex classes for females and no effects for males, and they suggest that their findings are consistent with a reduction in stereotype threat for females. Investigating the impact of single-sex education on math achievement at the top of the distribution in Ireland, Doris, O'Neil, and Sweetman (2013) find that boys in single-sex schools are more likely to show better performance than their counterparts in coeducational schools with little evidence of a similar effect for girls. Schneeweis and Zweimuller (2012) study the causal impact of the gender composition in coeducational classes on the choice of school type for girls in Austria. They find that if girls were exposed to a higher share of girls in earlier grades, they were more likely to choose a male dominated school type at the age of 14. In contrast, some recent studies find little evidence for positive effects of single-sex schooling on STEM outcomes (Jackson, 2012; Nagengast, Marsh, & Hau, 2013; Sohn, 2016). In sum, despite recent attempts to identify causal effects of single-sex schooling by addressing selection bias using various methods and research designs, we still need more evidence on relevant outcomes under various contexts to better assess the potential costs and benefits of single-sex schooling.

According to the national policy for high school equalization in Korea, especially Seoul, middle school graduates, who advance to academic high schools (the major form of high schools in Korea), are randomly assigned into high schools within residential school districts regardless of whether schools are single-sex or coeducational, and also whether schools are private or public. In Seoul for the time period for which we have data, students attending academic high schools could not choose their schools, and academic high schools had to receive students who were assigned by lottery. It is notable that this policy of random assignment has been implemented for a long time, since 1974, and so single-sex schooling due to random assignment is not a novelty but instead a long-established institution. Therefore, a potential bias in estimating the effect of a novel and innovative program, caused by participants' 'novelty-based enthusiasm' or interest in innovation, is not of serious concern for evaluating the impacts of single-sex school effects in Korea (cf. Halpern et al., 2011; Behrman & King, 2008; King & Behrman, 2009). Moreover, the number of students attending single-sex high schools is considerable, suggesting the broad relevance of single-sex schooling.

In an earlier study Park et al. (2013) used this unique random assignment to assess the effect of single-sex schools in Korea on students' scores on Korean and English subjects for a high school senior cohort without examining any outcomes directly related to STEM. They found that both boys and girls attending single-sex schools showed better performance on Korean and English tests than their counterparts attending coeducational schools. However, it is notable that the effects of single-sex schools were more substantial among boys than girls. Park et al. (2013) also used school-level data on the number of graduates who transitioned to college to investigate the effects of single-sex schools on overall college attendance rates but did not examine students' choices of STEM college majors. Our current study significantly extends the previous study not only by focusing on a set of explicit STEM-related outcomes, but also by assessing the role of gender composition of teachers in accounting for single-sex school effects. By presenting the results for Korean and English test scores as well as STEM outcomes, we address the extent to which single-sex school effects and the roles of gender composition of teachers to explain such single-sex school effects are specific to STEM outcomes. Also, by examining the effects of single-sex schools across seven different cohorts of high school seniors, our estimates of the single-sex school effects should be more robust than those based on only one cohort in Park et al.'s (2013) study.

Do Single-Sex Schools Help?

All-Girls Schools

In contrast to the common assumption that coeducational schools should promote gender equity in learning experiences, numerous studies of primary and secondary schools in the United States have presented associations that they interpret to suggest that coeducational schools may work as social institutions to reinforce, rather than to reduce, traditional gender role socialization, provide gender-differential experiences of learning in classrooms, and thus potentially constrain female students' opportunities to pursue mathematics and science (AAUW, 1992; Oakes, 1990; Thompson, 2003). Gender-biased teaching and counseling practices, due to pervasive sex stereotypes among school teachers and counselors in coeducational schools, are often thought to discourage female students' interest and participation in mathematics and science. Several studies report 'warm' classroom climates that teachers make for boys but 'chilly' climates for girls in studying math and science subjects with gender-differential expectations for and interactions with boys and girls (Hall & Sandler, 1982; Lee, Marks, & Byrd, 1994; Sadker & Sadker, 1994). Moreover, the influence of adolescent culture in coeducational settings, which often emphasizes physical attractiveness and interpersonal relationships over academic activities, may discourage female students' interest in traditionally male-dominant math and science (Coleman, 1961; Riordan, 1990).

In contrast, single-sex schools may provide better environments for female students with regard to both teacher-student and peer-group interactions, which may encourage them to pursue their educational careers in STEM. In single-sex environments, students do not need to compete with the opposite sex for teachers' attention and time. In all-girls schools, leaders and top performers in all classes, including math and science, are female students, which may provide good female role models for other girls (Thompson, 2003). The absence of the opposite sex in the classroom may reduce the influence of adolescent culture, and thus increase female students' participation in math and science classrooms and ultimately their confidence in their abilities in the subjects. Comparing single-sex and coeducational Catholic schools in the United States, for instance, Lee and Bryk (1986) showed that girls attending single-sex schools expressed more interest in math than girls attending coeducational schools. Girls (and boys) in single-sex schools also took more math courses than did their peers in coeducational schools. Studying private high schools in the National Educational Longitudinal Study (NELS), Billger (2009) found much less segregated college major choices among those who went to single-sex high schools than their peers who went to coeducational high schools. Using data from the High School and Beyond Study, Thompson (2003) also showed that the likelihood for girls to choose a sex-integrated college major over a female-dominant major was significantly higher among girls who attended all-girls high schools than girls who attended coeducational high schools.

Another possible mechanism may operate through interactions between teachers and students. Some studies have found that students benefit from having a same-gender teacher. Using the National Longitudinal Survey of Youth, Nixon and Robinson (1999) found that the higher share of female teachers and professional staff in high school was significantly associated with higher levels of educational attainment of young women. Studying 8th-grade students and their teachers using data from the National Education Longitudinal Study (NELS: 88), Dee (2006, 2007) also found that "… girls have better educational outcomes when taught by women and boys are better off when taught by men" (2006: 71). By analyzing data from the U.S. Air Force Academy, where students are randomly assigned to professors, Carrel, Page, and West (2010) found that gender of a professor has a strong effect on female students' performance in math and science classes, and high-performing female students' likelihood of taking future math and science courses, and graduating with a STEM degree.

One possible reason for the significant effect of same-gender teachers on STEM outcomes is that such teachers provide better role models (Bettinger & Long, 2005; Nixon & Robinson, 1999; Riordan, 1990). Having role models of the same-gender teachers may be particularly important for girls to become interested in math and science. Another possible explanation is reduced stereotype threat. If girls have a female math teacher, it can reduce students' worry that they will confirm the negative stereotype on girls' math ability (Dee, 2007; Steel, 1997). Therefore, if all-girls schools tend to have more female teachers in math and science than do coeducational schools, female students in all-girls schools are likely to have more exposures to female teachers than female students in coeducational schools, leading to better outcomes for the former.

The arguments so far, which focus on interactions between teachers and students, and among students, emphasize pervasive school environments that shortchange girls in coeducational schools especially in regard to math and science education, and therefore lead to an expectation of potentially positive effects of all-girls schools for girls. However, this argument that single-sex schools may provide better environments for females than coeducational schools seems somewhat outdated given evidence that at least in the United States, where most students attend coeducational schools, "[n]ow boys and girls take equally demanding math classes in high school…and girls get better grades in those classes…" (Buchmann et al., 2008: 323). The situation seems similar in Korea where girls have increasingly outpaced boys in both general-math test and science-math test scores. In 2005, female high school seniors had the same or slightly higher average scores as male seniors in the general-math test and science-math test, respectively.[1] In 2011, however, female seniors scored 0.09 standard deviations higher in both tests.

All-Boys Schools

In the context where girls tend to surpass boys academically, discussion of single-sex schooling perhaps should pay more attention to the question of whether all-boys schools can help boys. There are some arguments that may carry over from all-girls to all-boys schools.

[1]In 2004, female seniors showed substantially higher performance than male seniors in the science-math test (0.15 standard deviations higher) and somewhat less higher performance in the general-math test (0.04 standard deviations).

For instance, as all-girls schools may reduce influences of adolescent culture that are perceived often to interfere with girls' academic work, separating boys and girls may also help boys focus on academic work, and thus contribute to their better academic achievement in math and science as well as in other subjects (Coleman, 1960; Riordan, 1990).

All-boys schools may also provide better environments for teacher-student interactions. If all-boys schools tend to have more male math and science teachers (see Riordan, 1990) like all-boys schools in Seoul where the majority (81%) of teachers are male, the possibly positive effect of student-teacher gender matching may account for at least some of all-boys school effects on STEM outcomes. Male teachers may impose a 'positive' stereotype for boys with respect to math and science ability, which may enhance boys' performance in math and science (Shih et al., 1999). The effect of 'positive' stereotypes by male teachers on boys' performance may be strengthened when all the students in a school or classroom are boys who tend to expect to enter STEM college majors more than do girls.

An alternative explanation of the positive effect of same-gender teachers may pertain to possible advantages for same-gender teachers for managing student discipline and classroom order, especially for boys (Sullivan, Joshi, & Leonard, 2010). As suggested in Lavy and Schlosser (2011), if male teachers are able to handle boys' discipline better, then in all boys-schools, with their higher proportion of male teachers, academic outcomes of boys would be better than their counterparts in coeducational schools. Furthermore, teachers' management of classroom discipline and order may be even more effective when they deal with only boys or only girls, and not a mixture.

However, it is worth noting that particularly with respect to STEM outcomes, theoretical arguments and empirical evidence are thin in regard to how all-boys schools may enhance boys' outcomes, which contradicts various insights into how all-girls schools may help girls' STEM outcomes. Therefore, our study of the effects of both all-girls' and all-boys' schools on STEM outcomes and the extent to which such effects are due to the gender composition of teachers can provide useful insights.

Random Assignment of Students to High Schools in Korea

The 'High School Equalization Policy' (*P'yŏongjunhwa Chŏngch'aek*) in Korea, which has been in effect since 1974, randomly sorts entering high school students into either single-sex or coeducation schools within school districts by lottery (Kim, 2003). Before the policy, students had to apply to high schools and take entrance examinations administered by each high school, which resulted in considerable between-school differences in socioeconomic and academic compositions of student bodies. Importantly, this equalization policy is applied to all schools within a school district, regardless of whether they are single-sex or coeducational and regardless of whether they are public or private. After middle school, students can go to either academic high schools or vocational high schools and the random assignment is applied to only academic high schools. In 2012, almost 83 percent of high school students in Korea attended academic high schools (KEDI, 2012). Although the random assignment policy had been applied to other metropolitan areas besides Seoul, however, in the last decade or so the policy has been modified to introduce some element of individual family choice in the other major metropolitan areas (see below). Therefore, we focus on Seoul for this study because in Seoul it was applied in unmodified form for the time period that we consider.

Non-compliance with the initial school assignment is not a major concern for this study. Students have to accept the random assignment unless they move to a different school district. If they move to another school district, they are subject to another lottery in the new district. Students (and families) may also move to another school district in the middle of the school year if they are not satisfied with the randomly-assigned school. However, the movement does not necessarily increase the likelihood for a student to attend a single-sex school (or a coeducational school) because the assignment of a moving-in student into a school within a school district is close to be random on the basis of availability of open seats in a specific school district. Discussing possibilities of non-compliance, moreover, Park et al. (2013) showed that the actual percentage of households moving into a different school district during the ages for transition to high schools is very small and consequently concluded that non-compliance is not likely to cause serious distortions in the estimates of the causal effect of single-sex schools in Seoul .

Although the assignment of students into schools is random, it is important to note that single-sex and coeducational schools may differ in other school characteristics, though probably less so in Korea than in most countries. The Korean school system is highly standardized and centralized by the government (Park, 2010) and therefore variation across schools (even between public and private schools) in formal curricula and most other basic school resources generally is minimal. However, public and private schools differ in hiring and retention of teachers. To become a teacher in public schools, candidates have to pass the National Teacher Employment Test and those who pass the exam are eventually assigned to a school in the city or province to which they applied (Kang & Hong, 2008). The hiring process in private schools is, however, dependent upon each school' s own procedures and decisions. Once hired, moreover, public school teachers are rotated to a different school within the city or province every 4-5 years, while such rotation does not exist for private school teachers for whom tenure is decided at the school level. These differences in teacher recruitment and tenure systems may yield some differences in teacher-related characteristics between public and private schools. Given that the share of private schools is higher for single-sex schools than for coeducational schools in Seoul,[2] we include a dummy variable for private schools to control for the influence that potential differences in teacher-related characteristics between private and public schools may impose in estimating the effect of single-sex schools.

Following the strategy of the previous study by Park et al. (2013), in the current study we limit our analysis to schools in Seoul where the random assignment policy was introduced at the start of the equalization policy in 1974 and remained more or less intact until 2009.[3]

[2]In our pooled sample across all seven cohorts, 84 percent of all-boys schools and 84 percent of all-girls schools are private, whereas only 28 percent of coeducational schools are private.

[3]Strictly speaking, the random assignment in Seoul is not entirely 'intact' in that among 11 school districts, one school district in downtown Seoul considers student preferences to some extent in school assignments to deal with the small number of residents. The results with and without this school district, however, do not differ substantially or significantly.

Since the mid-1990s, school districts in other metropolitan areas modified the original random assignment procedure in response to growing criticism on the lack of school choices. Specifically, schools outside Seoul began to allow students to list their preferred 2-3 schools before assignment.[4] Then, about 30 – 40% of enrollments in each school are randomly selected among those students who preferred the school and the remaining enrollments are determined by lottery without consideration of students' preferences. It is an open question to what extent this modification affects selection into single-sex schools by observed and unobserved characteristics of students and families. However, we acknowledge that some other observed and unobserved characteristics of students and their families could still affect students' selection into single-sex schools in areas of the modified random assignment, even though selection may not be as substantial as in the context where students "freely" choose single-sex schools over coeducational schools. Therefore, we focus our analysis on students and schools in Seoul only.

Data and Variables

Data

We use two different data sources: 1) administrative data on math test scores of all high school seniors (12th graders; 3rd-year in high school) who took the national college entrance exam in each year from 2004 to 2011 (except for 2007); and 2) a longitudinal survey of high school seniors, the 2004-06 Korean Education and Employment Panel (KEEP). The administrative data for the 2007 high school seniors do not contain math test scores and therefore are excluded from the analysis. To apply to college, high school seniors take the national college entrance exam, College Scholastic Ability Test (CSAT), at the end of their high school senior year, which is a standardized test administered only once a year by the government. CSAT consists of several subjects including math. As a nationally standardized test that most students seriously take for college admission, CSAT is a "high-stakes" test that probably is the most reliable measure of academic achievement of high school seniors in Korea. The large number of students contained in the administrative data allows us to focus on students in Seoul where the intact random assignment still took place during the years considered. For seven years, math scores are available for a total of 248,885 female and 290,627 male seniors in Seoul high schools across 11 school districts (see Appendix for distributions of students and schools by school types).[5]

We also examine whether single-sex schools increase students' interests and self-efficacy in math and science, and also students' expectations of majoring in a STEM field in university and their actual selection of a STEM major in university by two years after high school. For this purpose, we use the Korean Education and Employment Panel (KEEP), which is a nationally representative, longitudinal survey that began in 2004 by interviewing 2,000 academic high school seniors across 100 schools (Chae et al., 2006). In the 2004 baseline survey, KEEP collected a variety of information on high school seniors' attitudes toward

[4]Seoul also introduced a kind of modified version of the random assignment in 2010. However, our analysis below deals with high school entrants before 2010 to which the modified version was not applied yet.

[5]Unfortunately, the CSAT administrative dataset does not include any individual or family background variables except for the gender of students.

study generally and interest in specific subjects, their educational and occupational plans, their demographic and family background characteristics, and other data. In each year since the baseline, KEEP reinterviewed respondents to collect information on educational transitions. In this study, we utilize the data from the baseline to the second follow-up conducted in 2006.[6] Using these data over three years, we can determine who expected to major in STEM in college during their final year of high school, and who actually chose a STEM college major within two years after high school. When students apply for college in Korea, they apply to a specific major (department) (or a group of majors) within a college and they are accepted or rejected by the department. Therefore, with only two years of data after high school graduation, we can still identify students' college majors. Students' actual choice of a STEM major in university is an important STEM outcome, along with math test scores and choice of the science-math test, that may be predicted by single-sex schooling status. School administrators provided information on whether the schools are single-sex or coeducational school. A parent of each student respondent filled in the questionnaire to provide information on the student's family environment.

A limitation of this longitudinal dataset is the small size of the sample. When we consider students only in Seoul, we have a total of 440 students: 232 female students in 15 schools and 208 male students in 14 schools (see Appendix for distributions of students and schools by school types). Because this sample of students is small, our inferences from the analysis of these data must be qualified. Our goal with this additional analysis is to see whether the pattern of single-sex school effects for an additional set of variables is generally consistent with the pattern found in the analysis with large-scale administrative data.

Variables

The CSAT data provide each student's score on a math test. In CSAT, students choose between the general-math and science-math tests. Although the science-math test includes three different sub-types – calculus, probability and statistics, and discrete math, the share of students taking a probability or discrete math is usually negligible[7]. More students tend to choose the general-math test over the science-math test: across all seven years in our data 17 percent of female high school seniors took the science-math test, while 32 percent of male high school seniors did so. One major question for our study is whether students in single-sex and coeducational schools significantly differ in their choice of the science-math test that is required for application to STEM college majors. There are a small number of students who did not take either math test. We combine them with students who took the general math test to distinguish from those who took the science-math test. In addition to whether students took the science-math test or not, we assess differences between students in single-sex and their counterparts in coeducational schools in their average general-math test score and science-math test score, respectively, among those who took each type of math test.[8] We

[6]Military service is mandatory for Korean males. Most male college students complete their military service before starting their third year in college. Therefore, most longitudinal data including KEEP suffer from considerable attrition of male respondents after the second year in college.

[7]For the 2011 high school senior cohort, only two types – the general-math and (combined) science-math – of math tests were given. For the pooled sample across six years from 2004-2010 high school senior cohorts, only 0.3 percent of female high school seniors (among those whose test scores were reported) and 0.6 percent of male high school seniors took either a probability or a discrete math test.

standardize each of the general-math and science-math test scores to have a mean of 0 and standard deviation of 1 in each year.

As a potential mechanism for single-sex school effects, we examine the extent to which the proportion of male teachers among total math teachers in schools accounts for the effect of single-sex schools on math test scores and choice of the science-math test. We attached a school-level variable of the proportion of male math teachers in a school, obtained from the Korean Educational Statistics Service by submitting an official request to get subject-specific number of teachers by gender for each school (http://kess.kedi.re.kr), to student-level data of math test scores and choice of the science-math test using the school names. As seen in the appendix, in the pooled data from 2004 to 2011 the average percentage of male math teachers across high schools in Seoul was 64.5 percent. However, this average percentage masks the considerable difference in the percentages by school type. The average percentage of male math teachers was 81 percent among all-boys schools, while it was 55 percent among coeducational schools and 54 percent among all-girls schools.

In addition to math test scores and selection of the science-math test, we analyze Korean and English test scores from the CSAT. Furthermore, using the number of female and male teachers in each subject of Korean and English, we examine how a subject-specific male teacher ratio accounts for the effect of single-sex schools on Korean and English scores, respectively. By comparing the extent to which the proportion of male teachers accounts for the effect of single-sex schools on non-STEM outcomes in a comparison with STEM ones, we can examine whether student-teacher gender matching would have differential impacts between STEM and non-STEM subjects, which can help us better understand the mechanism of single-sex schools on STEM outcomes.

We turn to KEEP data for the analysis of students' interests and self-efficacy in math and science subjects. The baseline survey of KEEP asked high school seniors to indicate the extent to which they agree with the following two statements for each of math and science subjects: 1) I am interested in this subject; and 2) I am good at this subject. The first item is related to the student's interests in math and science, while the second measures the level of self-efficacy with regard to math and science. Students indicated the degree of agreement on a five-point scale from "strongly disagree (1)" to "strongly agree (5)." In multivariate analysis, we treat each measure of interests and self-efficacy as a continuous variable. KEEP also asked high school seniors to report whether they expect to go to a university, and which majors they expect to choose if they enter a university. We classify expected college majors into two groups: STEM majors and non-STEM majors. The STEM majors include engineering, computer science, natural science, biological science, mathematics, physics, and other related majors.[9] For the analysis, we use a dependent variable that has three categories: 1) expecting university and a STEM major; 2) expecting university and a non-

[8]We exclude a small number of students who took either a probability-statistics or discrete math test for this analysis because of non-comparability of the probability-statistics or discrete math test with the calculus test. In other words, the analysis of the science-math test score basically refers to the analysis of the calculus test score.

[9]In the Korean higher educational system, medicine, nursing, and pharmacy are undergraduate colleges, not professional schools as in the United States. However, following the common definition of STEM in the United States (NCES 2009), we excluded medicine, nursing, pharmacy from STEM majors. We also estimated the same models by including medicine, nursing, and pharmacy in STEM majors and there were no significant differences from the results reported in the current paper.

STEM major; and 3) expecting no university (i.e., high school graduation only or two- or three-year junior colleges).

Because the KEEP survey followed high school seniors over two years after high school graduation, using longitudinal information we can identify who actually enrolled in a university within two years after high school graduation. Because Korean students apply to specific majors (departments) for college admission as noted above, we can also identify their majors (departments) even with the data on sophomore college students. We use this longitudinal information to examine the effect of single-sex schools on actual attendance at a university and actual choice of a STEM major given attendance at a university. Along with math test scores and choice of the science-math test, our examination of actual choice of a STEM major in a university increases knowledge of how robust are the single-sex school effects across different STEM outcomes. Similar to the variable for expectations, we construct a categorical dependent variable that has three different statuses: 1) attending university with a STEM major; 2) attending university with a non-STEM major; and 3) not attending a university. Means and standard deviations of mathematics and science interest and self-efficacy measures as well as the distributions (%) of STEM expectation and actual attendance measures are shown in the Appendix.

Methods

Analysis of Math Test Scores and the Type of Math Test Taken

Because the CSAT dataset provides students' high school names, we can identify schools and school districts. This allows us to estimate the school district-fixed effect model by including school district dummies in equations predicting students' scores on the general-math test and the science-math test, respectively. As mentioned before, the random assignment occurs within a school district and school districts can differ in various district-related characteristics. Therefore, the school district-fixed effect model should control for possible differences across districts by producing within-district estimates. For the analysis of math test scores, we estimate the following regression model for boys and girls, separately:

$$Y_{ijk} = \beta_0 + \beta_1(\mathrm{Sin}\,gle - Sex)_{jk} + \beta_2(\mathrm{Pr}\,ivate)_{jk} + \mu_k + e_{ijk} \quad (1)$$

where Y_{ijk} is the (either general-math or science-math) test score of student i in school j and district k. Our main focus is the coefficient β_1 indicating the causal effect of single-sex schools, controlling for the effect of private schools. μ_k stands for school district-fixed effects absorbed by 10 school district dummy variables. e_{ijk} is a student-specific error term. To take into account the data structure in which students are nested within schools, we report robust standard errors clustered by schools. We first estimate this regression model for a math test score in each high school senior cohort (i.e., year), separately. Then we pool the sample across all seven years and run the same regression model with high school senior cohorts included as dummy variables. We estimate the same equation for Korean and English test scores, respectively, to see how single-sex school effects vary across subjects. For the analysis of whether a student took the science-math test over the general-math test, we apply a logit model for the dichotomous variable with the same specification as Equation (1).

We, then, include a school-level variable, the proportion of male math teachers in school, in Equation (1) to see the extent to the effect of single-sex school changes after controlling for the proportion of male math teachers. By comparing the coefficient estimate of single-sex schools in Equation (1) and the coefficient estimate in the following Equation (2), we address the extent to which the share of male math teachers in school accounts for the estimated effects of single-sex schools on math test scores and choice of the science-math test. We estimate the same equation for Korean and English test scores, respectively, using each subject-specific proportion of male teachers.

$$Y_{ijk} = \beta_0 + \beta_1(\mathrm{Sin}\,gle - Sex)_{jk} + \beta_2(\mathrm{Pr}\,ivate)_{jk} + \beta_3(Male\,Teacher\ Ratio)_{jk} + \mu_k + e_{ijk} \quad (2)$$

Analysis of Mathematics and Science Interests and Self-Efficacy

We use data from the baseline KEEP survey to examine the effect of single-sex schools on mathematics and science interests and self-efficacy among high school seniors. As noted, KEEP does not provide identification numbers for school districts (except that we can identify whether schools are in Seoul). Therefore, we are not able to estimate district fixed-effects regressions.[10] Moreover, because school identifiers are not available, we cannot use school-level variables other than private school status in estimating the effect of single-sex schools. We use ordinary least square regressions to predict students' mathematics and science interests and self-efficacy, which are scaled from 1 to 5, by a dichotomous variable of single-sex schools (vs. coeducational) and an additional school-level variable for private schools (vs. public) schools.[11] As we do for the analysis of mathematics test scores, we report robust standard errors clustered by schools.

$$Y_{ij} = \beta_0 + \beta_1(Single - Sex)_j + \beta_2(\mathrm{Pr}ivate)_j + \varepsilon_{ij} \quad (3)$$

Analysis of Expectations and Actual Choices of a STEM College Major

Given that the expectation outcome variable during the high school senior year has three categories (1 – expecting university and a STEM major; 2 – expecting university and a non-STEM major; 3 – expecting no university), we use multinomial logit models to predict the likelihood of expecting university and a STEM major or expecting university and a non-STEM major relative to expecting no university, by whether the respondent is attending a single-sex high school (vs. coed) and whether attending a private school (vs. public).

[10]Following the suggestion from a reviewer, we run the specifications without districts fixed effects using the CSAT dataset. We find that not controlling for districts fixed effects leads the coefficient of the indicator for single-sex school status to move downward with increased standard errors, resulting in statistical insignificance. For boys we find the size of each coefficient is reduced for all three outcomes: general-math test score, science-math test score, and choice of the science-math test. Although we are very cautious, this result suggests that the results for boys using KEEP might underestimate the true effects, if there is any bias.

[11]Following a reviewer's suggestion, we also estimated ordered logit and ordered probit model and found that the results were qualitatively similar.

Similarly, we analyze actual attendance at university after two years from high school graduation using multinomial logit models that compare the likelihood of actual attendance at university with a STEM major or the likelihood of actual attendance at university with a non-STEM major relative to the likelihood of attending no university, by single-sex school status and private school status.

Results

Checking Randomness of Student Assignment: Differences in Students' Socioeconomic Backgrounds between Single-Sex and Coeducational Schools

Given the importance of random assignment into single-sex or coeducational schools for our analysis, it is critical to confirm the randomness from the survey data by checking for balance on observed characteristics of parents between students in single-sex and coeducational schools. Therefore, before discussing the effects of school type on STEM outcomes, we examine the extent to which students attending single-sex and coeducational schools are similar in their socioeconomic backgrounds. An earlier study by Park et al. (2013) already showed the balance on observed family characteristics and prior achievement between students attending single-sex and coeducational high schools using a different dataset. Assessing the balance with our current data, which are different from those used in the Park et al.'s study, increases our knowledge about the nature of random assignment.

To represent family background, we use parent's completed grades of schooling attainment (the higher one between father's and mother's), (logged) monthly household income, and number of books at home.[12] Each of these three variables has been widely used to measure a specific aspect of family environment in the literature on educational stratification (Buchmann 2002). Note that our KEEP data do not have a prior achievement measure that represents levels of academic achievement before entering high schools so we are not able to control for achievement before entering high school. We run a logistic regression for predicting single-sex school attendance by these three background measures for boys and girls, separately. Our expectation is that if students are randomly allocated into single-sex and coeducational schools, family background measures will not have significant associations with students' enrollments in single-sex schools.

Table 1 shows the logistic regression results of attending a single-sex school separately for boys and girls in Seoul. None of the three background measures is significantly associated with attendance at single-sex schools for either girls or boys. These results showing no significant relationships between family background and students' enrollment at single-sex schools increase our confidence regarding the random assignment in Seoul high schools.

Causal Effects of Single-Sex Schools on Math Test Scores

In Panel A and Panel B of Table 2 we present the results of school district-fixed effect model for the general-math and the science-math test scores for girls in Seoul high schools for each high school senior cohort from 2004 to 2011 and also for the pooled sample across all seven

[12]The number of books at home has eight ordered categories.

cohorts. For the general-math test score, female high school seniors in all-girls schools show test scores higher by 0.03-0.07 standard deviations than female seniors in coeducational schools. For the pooled sample, the effect size of single-sex schools is about 5 percent of one standard deviation. However, none of the effects is statistically significant. The same pattern is found for science-math test scores: the coefficient of single-sex schools is generally positive, except for the 2011 cohort, but none of them shows statistical significance. In short, girls attending all-girls schools do not show significantly better performance in either math test than girls attending coeducational schools.

Turning to Panel C and Panel D of Table 2 for boys, we find that male seniors who attend all-boys schools show a significantly higher level of performance on the general-math test than their counterparts who attend coeducational schools for five of the seven cohorts (except for the 2005 and 2010 cohorts). For these five cohorts, the effect sizes are about 7-9 percent of one standard deviation. When data for all seven cohorts are combined, the effect of single-sex schools is statistically significant at about 8 percent of one standard deviation. Although the effect of single-sex schools on the science-math test score seems similar to the effect on the general-science test score in its size for several cohorts, the effect is only significant for the 2005 senior cohort at about 10 percent of one standard deviation. In short, in contrast to the results for female students, single-sex schools have a significantly positive effect on the general-math test score for male students, though the evidence is much weaker for the science-math test score.

One concern regarding the interpretation of our results on test scores is students' self-selection into different types of math tests. As discussed below, we find that boys in all-boys schools are more likely to take the science-math test than boys in coeducational schools. Supposedly, those who are good at math are more likely to select into the science-math test. Based on the random school assignment and the evidence that all-boys schools enhance mathematics performance, we expect that those who take the general-math test in all-boys schools would not be better in their prior math achievement than corresponding boys in coeducational schools. Hence, the finding of better performance in the general-math test of boys in all-boys schools than boys in coeducational schools suggests that if our estimation results are biased due to the positive selection into science-math test, they are likely to underestimate the true gap in general-math test between boys in all-boys schools and their counterparts in coeducational schools.

Causal Effects of Single-Sex Schools on Choosing the Science-Math Test

Given that the science-math test score is required for application to STEM college majors, it is useful to examine whether students in single-sex and coeducational schools differ in the degree to which they choose the science-math test. Table 3 presents the results of the logit model that assesses the likelihood for students to take the science-math test relative to the general-math test. Similar to the regression analysis for math test scores, we run a logit model with private schools controlled for each separate cohort as well as for all samples pooled across seven cohorts with cohort dummies added.

The result in Panel A of Table 3 shows that single-sex schools make no significant difference in student's choice of the science math test for girls. However, there is some limited evidence that male senior students in all-boys schools are more likely to take the science-math test than male senior students in coeducational schools (Panel B of Table 3). The effect of all-boys schools is significant for the 2006 and 2010 cohorts. Specifically, the odds of taking the science-math test among male senior students attending all-boys schools are 1.13 times (exp(0.118) = 1.13) and 1.16 times (exp(0.145) = 1.16) the odds among male senior students attending coeducational schools in 2006 and 2010, respectively. When all seven cohorts are pooled together, students in all-boys schools show a significantly higher likelihood of taking the science-math test than their counterparts in coeducational schools (exp(0.081) = 1.08, at least at the 90% level).

The Share of Male Math Teachers and the Effect of Single-Sex Schools

In the literature review, we discussed the potential of gender matching between students and teachers to enhance students' STEM outcomes. If this student-teacher gender matching is important and if single-sex schools are more likely to have same-gender teachers, the higher percentage of same-gender teachers may account for some of single-sex school effects. As we described in the data section, eight out of ten math teachers in all-boys schools are male, while 46 percent of math teachers are female in all-girls schools.

Table 4 presents the results of regression analysis of math test scores and the logit analysis of students' choice of the science-math test before and after controlling for each school' s proportion of male teachers for math, using the sample pooled across all seven years. For girls, the proportion of male teachers in math is not significantly related to either students' math test scores or their choice of the science-math test (Panel A). The coefficient estimates of single-sex schools also do not change much after controlling for the proportion of male teachers.

However, we do see different patterns for boys in Panel B of Table 4. First of all, the proportion of male math teachers is significantly associated with the increased general-math test scores and choice of the science-math test. More importantly, controlling for the proportion of male teachers in math reduces the size of coefficient estimates for all-boys schools. For the general-math test score, the coefficient estimate for all-boys schools is reduced from 0.077 to 0.058 and for the choice of the science-math test the coefficient estimate of all-boys schools is reduced from 0.081 to 0.053 and becomes insignificant.

Single-Sex Schools and Gender Composition of Teachers for Korean and English

In addition to STEM outcome variables, we also analyze Korean and English test scores. The results in Columns (4) and (5) in Table 4 show that boys attending all-boys schools show better performance in Korean and English tests as well as STEM outcomes, while the difference between female students attending all-girls schools and those attending coeducational schools is not statistically significant for Korean and English, similar to STEM outcomes.[13]. In other words, we find a similar pattern of the positive effects of all-boys schools across Korean, English, and STEM outcomes, while estimates of all-girls

[13]We note that our results do not show significant effects of all-girls schools on any of Korean, English, and STEM outcomes, which is somewhat inconsistent with findings in Park et al. (2013) of the positive effects of all-girls schools. However, it is worth noting that our estimation method is different from Park et al.'s hierarchical linear models and in this study we use multiple years of CSAT data to

schools across Korean, English, and STEM outcomes are not statistically significant. These results seem to suggest that all-boys schools improve male students' academic performance across all subjects by separating them from girls.

However, we do find another, although weak, evidence for STEM-specific patterns. In the analyses that assess the extent to which proportion of subject-specific male teachers account for the effects of single-sex schools, only the proportion of male teachers in math is significantly associated with general-math test scores and choice of the science-math test. Male teacher ratios in Korean and English are not significantly associated with Korean or English test scores. Along with our previous finding that all-boys schools significantly improve general-math test scores and increase students' choice of the science-math test, this finding of positive relationships between the male teacher ratio in math and two STEM outcomes -- general-math test scores and choice of the science-math test suggests that the larger share of male teachers in math may account for better STEM outcomes. However, we are cautious about this statement in that the coefficient of male teacher ratios for English test scores is similar to the coefficient of male teachers in general-math test scores in terms of the size, although it is not statistically significant.

Single-Sex Schools and Students' Math and Science Interest and Self-Efficacy, and Expectation and Actual Choice of a STEM College Major

In the literature review, we noted the possibility that interactions among boys, who tend to have higher expectations of a STEM college major than do girls, may reinforce each one's STEM interests, self-efficacy, and expectations, all of which may enhance their performance in math and science. Although these kinds of peer group effects could also operate among girls, the overall low level of girls' expectations of a STEM career may mean that such peer group effects are relatively weak for girls' STEM outcomes, combined with negative stereotypes on girls' math performance that girls may face in front of male teachers who are the majority even in all-girls schools in Korea. We compare levels of STEM interests, self-efficacy, and expectation between students attending single-sex and coeducational schools, and expect that students in single-sex schools, particularly in all-boys schools should have higher levels than their counterparts in coeducational schools, possibly due to peer group effects, combined with supportive teacher-student interactions.

We now discuss the results for math and science interests and self-efficacy, and expectations of a STEM college major among high school seniors using data from KEEP. As mentioned before, we also examine the extent to which students actually attend university and select a STEM college major within two years after high school graduation by following up KEEP high school seniors as a STEM outcome in addition to students' math test scores and choice of the science-math test. In Panel A of Table 5 we present the results of OLS regression and multinomial logit models for girls. The results show that none of the single-sex school coefficient estimates is significant for females. This result is consistent with no significant

get more robust findings. Moreover, although the effects of all-girls schools were significant in Park et al., the size of the effect of all-girls schools was less than half of the size of the effect of all-boys schools in that study. In fact, all-girls schools were not significantly associated with girls' English test scores in Park et al.'s. The effect became significant only after controlling for other school-level variables. However some of the school-level variables are not available for the sample periods we analyze in this study.

effect of all-girls schools on math test scores (Table 2) and on choice of the science-math test (Table 3).

For male seniors in Panel B of Table 5, however, we see a different pattern in regard to effects of all-boys schools compared to those of all-girls schools. Students attending all-boys schools show higher levels of interests and self-efficacy in science subjects than do their counterparts attending coeducational schools. The positive effect of all-boys schools is also found for expectations of a STEM college major. Compared to male seniors who attend coeducational schools, those who attend all-boys schools show higher odds of expecting attendance at university with a STEM major (relative to expecting no university). Note that all-boys schools make no difference in expecting university attendance with a non-STEM major compared to expecting no university. In short, our findings are consistent with our expectation that all-boys schools are conducive to enhancing students' interests in and expectations of a STEM college major. Finally, we find that students who graduated from all-boys schools have higher odds of attending university with a STEM major within two years after graduating from high school than their counterparts who graduated from coeducational schools. This positive effect of all-boys schools is consistent with the finding of the positive effect of all-boys schools on the general-math test score (Table 2) and choice of the science-math test (Table 3).

Conclusion

There has been long-standing interest in the possible positive effects of all-girls schools for improving girls' education in general and in STEM specializations in particular. But the positive associations presented in the previous literature do not permit identifying the effects of selection into all-girls schools versus the effects of the gender composition of those schools per se. Using the unique experience of random assignment of students into high schools in Seoul, we have assessed the causal effects of single-sex schools for girls and boys, separately, without confounding due to selection of schools by students or their families. Our comparison of students' socioeconomic backgrounds demonstrates balance between students attending single-sex and coeducational high schools, increasing the credibility that student assignment in Seoul high schools really is random.

In estimating causal effects of single-sex schools, we use both cross-sectional and longitudinal data to examine various STEM outcomes including high school seniors' math test scores, choice of the science-math test (over the general-math test), and students' actual attendance at university with a STEM college major within two years of graduating from high school. The previous literature has mostly focused on the potential of all-girls schools for girls' STEM outcomes. In this study we also investigate the possibility that all-boys schools may enhance boys' STEM outcomes, which is of increasing interest given the rising trend of female advantage in education (Buchmann & DiPrete, 2013). As girls now excel boys even in math test scores in Korea as well as in the United States, it is reasonable to ask if all-boys schools can improve boys' educational outcomes.

Our investigation of students' math test scores, their choice of the science-math test, and the actual STEM university major consistently shows that all-girls schools do not make significant differences in those STEM outcomes. This contrasts with some previous studies that showed some positive effects of single-sex schooling on girls' STEM outcomes. However, our findings of insignificant effects for girls are not contaminated by upward bias caused by positive selection into single-sex schools, which many previous studies based on observational data may have suffered. Moreover, overall performance of girls in math has improved over time in Korea and currently girls do better in math than boys overall and particularly within coeducational schools, which suggests that girls nowadays may be less affected by different types of schools than in the past.

In contrast to the insignificant effects of all-girls schools, our results suggest generally positive significant effects of all-boys schools for several STEM outcomes. All-boys schools in Seoul are associated with better scores on the general-math test, although the effect is definitely weaker for the science-math test score. Boys in all-boys schools are also more likely to choose the science-math test, which is required to apply for a STEM college major. Importantly, boys who graduated from all-boys schools actually have higher odds of attending university with a STEM major (relative to attending no university) by two years after high school. The consistently positive effect of all-boys schools across different STEM outcomes and also from two different datasets increases our confidence in these findings.

What are the mechanisms through which these positive effects of all-boys schools are generated? Although we fully acknowledge that limitations of our data considerably constrain our tests of the suggested mechanisms, within our limitations we have attempted to address plausible channels. First, our comparison of the effects of single-sex schools across STEM and non-STEM (i.e., Korean and English test scores) shows that the positive effect of all-boys schools is found for both STEM and non-STEM outcomes, suggesting that possibly the effect of all-boys schools is general due to separating boys and girls. However, our mediation analysis controlling for school's proportion of male math teachers reduces the positive effect of all-boys schools on the general-math test score and choice of the science-math test. The proportion of math male teachers is also significantly related to the increased general-math test scores and choice of the science-math test for boys. Notably the proportion of male teachers in Korean and English, respectively, does not show a significant relationship with Korean and English test scores. The significant association of the share of math male teachers with two STEM outcomes -- general-math test scores and choice of the science-math test suggests possibly STEM-specific effects of all-boys schools. In comparison to all-boys schools, controlling for male math teachers produces little change in the estimated coefficients of all-girls schools. Interestingly, an increase in the proportion of male teachers in math reduces test scores in math and probability of choosing science-math test for girls, although not significant. These findings suggest that student-teacher gender matching could play a role in determining students' STEM outcomes in an educational setting.

Although students were randomly assigned to schools within districts during our study periods, not being able to address teacher sorting can be a major limitation, which is an important factor that determines school quality. However, as demonstrated in Park et al. (2013), all-girls and all-boys schools are disadvantaged, not advantaged, with respect to observable teacher characteristics such as teaching experiences and average years of schooling, which implies that if there can be any bias due to the teacher sorting, the positive impacts of single-sex schools would be downward biased. We are also aware of the difficulty of estimating the effect of a mediating variable even when the outcome is manipulated randomly but not the mediating variable itself, proportion of male teachers in our study context (Bullock, Green, and Ha 2010; Green, Ha, and Bullock 2010). Therefore, our mediation analysis should be interpreted with caution. However, our findings suggest that gender matching between students and teachers, facilitated by single-sex schools (especially, all-boys schools), could be a good candidate for a potential mechanism through which single-sex schools affect students' STEM outcomes.

Lastly, we do find that male high school seniors attending all-boys schools show higher levels of science interests and self-efficacy and higher odds of expecting university with a STEM college major than their counterparts attending coeducational schools. Similar to math test scores and choice of the science-math test, we consider the positive effect of all boys' schools on these additional STEM outcomes to reflect peer group interactions and teacher-student interactions within all-boys schools conducive to enhancing male students' STEM outcomes. Along with the finding that the share of male math teachers is significantly related with the general-math test scores and choice of the science-math test but the share of male teachers in Korean or English subject is not related to its test scores, the significant effects of all-boys schools on a variety of STEM outcomes provides evidence suggesting STEM-specific effects of all-boys schools besides the general effect across subjects. Future research with better data is warranted to better understand the process through which single-sex school environment has caused positive impacts on STEM outcomes for boys and the reason why the impacts are weaker for girls.

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Appendix.: Descriptive Statistics of CSAT and KEEP

	CSAT (Seoul)	KEEP (Seoul)
Panel A. Students	N = 539,512	N = 440
School Type (%)		
All-boys schools	36.1	27.3
Private schools	30.0	27.3
Public schools	6.1	0.0
All-girls schools	30.5	36.4
Private schools	25.4	27.3

		CSAT (Seoul)	KEEP (Seoul)
Public schools		5.1	9.1
Coed schools		33.4	36.4
Private schools		10.1	9.1
Public schools		23.4	27.3
Mathematics Exam Type (%)			
General-math test		75.2	
Science-math test		24.8	
Math Interest			3.05 (1.28)
Math Self-Efficacy			2.37 (1.08)
Science Interest			2.94 (1.41)
Science Self-Efficacy			2.47 (1.17)
During High School Senior, Expecting (%)			
university and a STEM major			20.2
university and a non-STEM major			69.1
no university			10.7
2 Years After High School, Attending (%)			
university and a STEM major			18.9
university and a non-STEM major			27.7
no university			53.4
Panel B. Schools		N= 1,390	N = 22
School Type (%)			
All-boys schools		34.5	27.3
Private schools		28.9	27.3
Public schools		5.5	0.0
All-girls schools		30.8	36.4
Private schools		25.8	27.3
Public schools		5.0	9.1
Coed schools		34.8	36.4
Private schools		9.6	9.1
Public schools		25.2	27.3
Panel C. Proportion of male teachers in each subject			
School Type (%)	Math	English	Korean
All-boys schools	80.9	70.6	80.0
Private schools	85.1	75.6	85.4
Public schools	59.7	47.3	54.2
All-girls schools	54.5	39.0	47.1
Private schools	58.2	41.6	50.1
Public schools	36.2	26.2	32.7
Coed schools	55.0	39.8	45.0
Private schools	74.5	58.0	69.5
Public schools	47.2	32.7	35.3

Note : Values in parentheses are standard deviations. The number of students and schools for CSAT data indicates the number of students and schools in the pooled sample across all seven cohorts (the sample used for the analysis of math test scores).

Source : Authors' own calculations

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Table 1.

Predicting Single-Sex School Attendance by Students' Socioeconomic Backgrounds

	Girls All-girls schools (vs. coed schools)	**Boys All-boys schools (vs. coed schools)**
Parent’s completed grades of schooling attainment	0.033 (0.057)	0.019 (0.056)
Monthly household income	0.04 (0.292)	−0.149 (0.208)
Number of books at home	0.096 (0.096)	−0.03 (0.085)
Constant	−0.139 (1.527)	1 (1.213)
N	232	208
Log pseudolikelihood	−142.6	−141.4

Note : Standard errors are reported in parenthesis.

*significant at 10%

**significant at 5%

***significant at 1%.

Table 2.

Causal Effects of Single-Sex Schools on Math Test Scores

	Math Test Score							
	2004	**2005**	**2006**	**2008**	**2009**	**2010**	**2011**	**2004-11**
Panel A. Girls - General-math test score								
All-girls schools (vs. coed)	0.055 (0.048)	0.042 (0.048)	0.060 (0.049)	0.066 (0.047)	0.048 (0.047)	0.031 (0.051)	0.035 (0.045)	0.048 (0.044)
Private schools (vs. public)	0.014 (0.052)	0.045 (0.054)	0.038 (0.053)	0.028 (0.049)	0.009 (0.045)	0.024 (0.050)	0.046 (0.042)	0.030 (0.045)
Constant	0.020 (0.085)	−0.038 (0.098)	0.036 (0.089)	−0.019 (0.084)	0.068 (0.083)	0.055 (0.098)	0.036 (0.082)	0.005 (0.082)
N	26,266	26,716	28,229	28,264	33,748	33,057	31,256	207,536
Panel B. Girls - Science-math test score								
All-girls schools (vs. coed)	0.039 (0.054)	0.042 (0.055)	0.077 (0.054)	0.032 (0.057)	0.053 (0.066)	0.068 (0.060)	−0.006 (0.072)	0.046 (0.047)
Private schools (vs. public)	0.017 (0.067)	−0.052 (0.065)	−0.048 (0.061)	−0.083 (0.066)	−0.049 (0.068)	−0.099 (0.064)	0.035 (0.072)	−0.036 (0.053)
Constant	0.109 (0.116)	0.070 (0.087)	−0.111 (0.092)	−0.031 (0.118)	0.031 (0.106)	0.086 (0.109)	−0.000 (0.102)	0.099 (0.097)
N	6,919	6,035	5,316	5,310	5,881	5,822	6,066	41,349
Panel C. Boys - General-math test score								
All-boys schools (vs. coed)	0.071 * (0.043)	0.057 (0.038)	0.086 ** (0.039)	0.085 ** (0.040)	0.089 ** (0.041)	0.049 (0.035)	0.094 ** (0.038)	0.077 ** (0.033)
Private schools (vs. public)	0.029 (0.043)	0.023 (0.047)	0.046 (0.042)	0.028 (0.040)	0.061 (0.043)	0.037 (0.040)	0.010 (0.043)	0.034 (0.037)
Constant	−0.027 (0.060)	−0.087 (0.063)	−0.122 ** (0.061)	−0.090 (0.064)	−0.084 (0.074)	−0.048 (0.062)	−0.064 (0.051)	−0.071 (0.057)
N	25,019	25,260	27,970	27,080	31,429	31,371	30,161	198,290
Panel D. Boys - Science-math test score								
All-boys schools (vs. coed)	0.064 (0.053)	0.099 ** (0.047)	0.060 (0.052)	0.084 (0.060)	0.020 (0.053)	0.024 (0.046)	0.067 (0.059)	0.059 (0.041)
Private schools (vs. public)	0.034 (0.058)	−0.025 (0.058)	0.026 (0.059)	0.020 (0.060)	−0.014 (0.056)	0.001 (0.047)	0.026 (0.052)	0.012 (0.045)
Constant	−0.024 (0.087)	0.054 (0.083)	0.018 (0.067)	−0.083 (0.090)	0.050 (0.094)	0.020 (0.085)	−0.037 (0.099)	−0.027 (0.076)
N	14,901	12,578	10,925	11,619	13,731	13,902	14,681	92,337

Note : Each math test score is standardized to have a mean of 0 and a standard deviation of 1 in each year. We control for dummy variables for school districts and cohorts but not reported here.

* significant at 10%

** significant at 5%

*** significant at 1%.

Table 3.

Causal Effects of Single-Sex Schools on Students' Choice of the Science-Math Test (over the General-Math Test)

	Choice of Science-Math Test							
	2004	**2005**	**2006**	**2008**	**2009**	**2010**	**2011**	**2004-11**
Panel A. Girls								
All-girls schools (vs. coed)	−0.003 (0.054)	0.004 (0.070)	0.007 (0.070)	0.000 (0.062)	−0.031 (0.070)	−0.013 (0.070)	0.028 (0.061)	−0.005 (0.049)
Private schools (vs. public)	0.048 (0.061)	0.074 (0.074)	0.077 (0.068)	0.050 (0.065)	0.045 (0.069)	0.044 (0.060)	0.033 (0.056)	0.051 (0.048)
Constant	−1.486 *** (0.080)	−1.642 *** (0.109)	−1.808 *** (0.101)	−1.707 *** (0.085)	−1.766 *** (0.087)	−1.734 *** (0.091)	−1.634 *** (0.095)	−1.441 *** (0.072)
N	38,711	38,547	38,798	37,497	43,335	42,542	40,644	280,074
Panel B. Boys								
All-boys schools (vs. coed)	0.036 (0.057)	0.073 (0.058)	0.118 * (0.064)	0.083 (0.052)	0.042 (0.052)	0.145 ** (0.059)	0.084 (0.055)	0.081 * (0.042)
Private schools (vs. public)	−0.003 (0.057)	0.080 (0.062)	−0.012 (0.064)	−0.001 (0.052)	0.124 ** (0.050)	0.028 (0.058)	0.033 (0.051)	0.035 (0.044)
Constant	−0.676 *** (0.095)	−0.889 *** (0.089)	−0.970 *** (0.114)	−0.761 *** (0.069)	−0.849 *** (0.078)	−0.799 *** (0.085)	−0.707 *** (0.091)	−0.583 *** (0.075)
N	43,801	42,189	42,561	41,085	47,639	47,629	47,090	311,994

Note: We control for dummy variables for school districts and cohorts but not reported here.

* significant at 10%

** significant at 5%

*** significant at 1%.

Table 4.

Comparing STEM and Non-STEM Outcomes with Subject-Specific Male Teacher Ratios (CSAT)

	General-Math Test Scores (1)		Science-Math Test Scores (2)		Choice of Science-Math Test (3)		Korean Test Score (4)		English Test Scores (5)	
Panel A. Girls										
All-girls schools (vs. coed)	0.048 (0.044)	0.043 (0.046)	0.046 (0.047)	0.039 (0.049)	0.048 (−0.044)	0.043 (0.046)	0.033 (0.037)	0.024 (0.039)	0.048 (0.049)	0.037 (0.050)
Private schools (vs. public)	0.030 (0.045)	0.038 (0.048)	−0.036 (0.053)	−0.024 (0.053)	0.030 (−0.045)	0.038 (0.048)	0.031 (0.037)	0.047 (0.043)	0.033 (0.051)	0.054 (0.056)
Proportion of male teachers		−0.035 (0.066)		−0.049 (0.086)		−0.035 (0.066)		−0.066 (0.067)		−0.099 (0.086)
Constant	0.005 (0.082)	0.022 (0.088)	0.099 (0.097)	0.123 (0.105)	0.005 (0.082)	0.022 (0.088)	0.157 ** (0.062)	0.182 *** (0.064)	0.100 (0.094)	0.130 (0.098)
N	207,536		41,349		280,074		278,704		277,756	
Panel B. Boys										
All-boys schools (vs. coed)	0.077 ** (0.033)	0.058 * (0.033)	0.059 (0.041)	0.048 (0.042)	0.081 * (0.042)	0.053 (0.043)	0.072 ** (0.034)	0.052 (0.036)	0.101 ** (0.042)	0.076 * (0.041)
Private schools (vs. public)	0.034 (0.037)	−0.005 (0.042)	0.012 (0.045)	−0.012 (0.049)	0.035 (0.044)	−0.024 (0.052)	0.031 (0.040)	−0.002 (0.045)	0.026 (0.048)	−0.013 (0.057)
Proportion of male teachers		0.152 ** (0.065)		0.093 (0.078)		0.226 ** (0.102)		0.106 (0.075)		0.149 (0.097)
Constant	−0.071 (0.057)	−0.152 ** (0.065)	−0.027 (0.076)	−0.078 (0.086)	−0.583 *** (0.075)	−0.706 *** (0.094)	−0.104 * (0.055)	−0.154 ** (0.067)	−0.104 (0.076)	−0.165 * (0.095)
N	198,290		92,337		311,994		309,233		307,661	

Note : We control for dummy variables for school districts and cohorts but not reported here.

* significant at 10%

** significant at 5%

*** significant at 1%.

Table 5.

Causal Effects of Single-Sex Schools on STEM Outcomes (KEEP)

	OLS Regression				Multinomial Logit Model			
					Expecting university &		Actually attending university &	
	Math		Science		a STEM major	a non-STEM major	a STEM major	a non-STEM major
	Interest	Self-efficacy	Interest	Self-efficacy	(vs. expecting no university)		(vs. no university attendance)	
Panel A. Girls								
All-girls schools (vs. coed)	−0.163 (0.438)	−0.063 (0.279)	−0.110 (0.306)	−0.198 (0.178)	−0.100 (0.712)	0.411 (0.447)	−0.154 (0.596)	0.347 (0.286)
Private schools (vs. public)	−0.192 (0.339)	−0.047 (0.224)	−0.214 (0.302)	−0.115 (0.167)	−0.100 (0.755)	−0.382 (0.433)	0.105 (0.652)	−0.044 (0.309)
Constant	3.487 *** (0.246)	2.464 *** (0.207)	3.141 *** (0.371)	2.636 *** (0.230)	0.336 (1.124)	2.261 *** (0.589)	−1.429 (0.880)	−0.587 (0.435)
R^2 (or Log pseudolikelihood)	0.014	0.002	0.010	0.012	−164.2		−225.6	
Panel B. Boys								
All-girls schools (vs. coed)	0.011 (0.150)	−0.067 (0.438)	0.978 *** (0.302)	0.719 ** (0.301)	0.910 (0.444)	−0.050 (0.430)	0.897 *** (0.263)	0.255 (0.444)
Private schools (vs. public)	0.056 (0.182)	0.186 (0.420)	−0.683 ** (0.420)	−0.487 * (0.262)	−0.288 (0.520)	0.123 (0.347)	−0.095 (0.304)	−0.642 (0.537)
Constant	2.944 *** (0.359)	2.129 *** (0.449)	3.754 *** (0.375)	3.030 *** (0.393)	0.981 (0.949)	1.627 ** (0.687)	−1.196 ** (0.570)	−0.103 (0.347)
R^2 (or Log pseudolikelihood)	0.001	0.003	0.040	0.031	−183.2		−203.6	

Note : We use 232 female students in 15 schools and 208 male students in 14 schools.

* significant at 10%

** significant at 5%

*** significant at 1%.