Gender Composition in classroom: Influences on Post-Secondary Schooling Choices

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Abstract

This paper analyzes a Colombian policy transitioning female single-sex secondary schools to co-educational settings. Using a staggered difference-in-differences approach, we find this structural change significantly increased female students' enrollment in STEM fields by 6.43 percentage points. Notably, this increase was accompanied by a shift in educational pathways: enrollment in bachelor's degree programs declined, while uptake of shorter-cycle tertiary and vocational STEM programs rose. These findings highlight the multifaceted consequences of altering single-sex school environments on female educational trajectories beyond just major choice.

JEL Codes: I21, J16, J24.

Keywords: STEM Education, Single-sex Schools, Gender Gap, Higher Education

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1 Introduction

The underrepresentation of women in science, technology, engineering, and mathematics (STEM) fields is a persistent global challenge with significant economic consequences. Despite evidence of substantial financial rewards associated with STEM careers (Jang and Lawrence, 2014; Neal, 2014; Rothwell, 2013), women remain less likely than men to pursue these paths, contributing to gender inequality in the labor market and potentially hindering innovation and economic growth. Understanding the factors that influence women's STEM choices is therefore crucial for designing effective policies to promote gender equality and maximize economic potential.

One potential influence often overlooked is the gender composition of the classroom. While prior research has examined peer effects and broader societal factors, the impact of the immediate learning environment – specifically, the proportion of male and female students in a classroom – on female students' academic decisions remains underexplored, especially concerning the choice of university majors in STEM disciplines. This is particularly relevant as many countries have transitioned from single-sex to coeducational schooling, altering the gender dynamics within classrooms.

It is unclear how classroom gender composition affects female students' choices of university majors, especially in STEM disciplines. Existing studies provide conflicting insights. Some suggest that women thrive in mixed-gender environments due to increased competition (Böheim et al., 2017; Niederle and Vesterlund, 2011), while others highlight the potential for stereotype threat and decreased confidence in male-dominated settings (Spencer et al., 1999). Moreover, the evidence on the effects of single-sex versus coeducational schooling on academic outcomes is mixed and often lacks causal identification (Eisenkopf et al., 2015; Pahlke et al., 2014). This leaves a significant gap in our understanding of how classroom gender dynamics shape female students' STEM aspirations.

In this paper, we provide new causal evidence on the impact of classroom gender composition on female students' STEM choices by exploiting a unique natural experiment in Colombia: a staggered transition from single-sex to coeducational schooling. Unlike previous studies that rely on observational data or small-scale experiments (Buser et al., 2014; Niederle and Vesterlund, 2011), our setting allows us to isolate the causal effect of coeducation on major selection. To mitigate potential confounding factors related to pre-existing differences in academic content, we leverage the fact that Colombian public schools follow a standardized national curriculum through all the years of secondary education.

We focus on Colombia, where a significant gender gap in STEM persists despite women achieving higher overall university graduation rates. Only 16% of female university graduates choose STEM careers, compared to 24% of male graduates (ICFES, 2019). The Colombian context is particularly relevant, since, similar to many developed countries, higher university graduation rates coexist with substantial gender gaps in STEM fields. This setting enables us to examine the specific role of classroom gender dynamics, independent of broader societal influences that could otherwise confound the relationship between gender and major selection.

We investigate the hypothesis that a higher proportion of male students in a classroom increases the likelihood of female students choosing STEM-related majors at the university level. This hypothesis is grounded in research suggesting that women tend to respond favorably to competition in mixed gender environments (Böheim et al., 2017; Niederle and Vesterlund, 2011). Laboratory experiments have shown that men are more inclined to compete, which can motivate women to enter and succeed in competitions. Furthermore, evidence suggests that while girls exhibit greater competitiveness in verbal tasks, boys tend to dominate in motor and spatial domains, which are frequently related to STEM fields (Gindi et al., 2019). We also consider the possibility that in traditionally female-dominated fields like the humanities and social sciences, increased male presence could intensify competition and narrow the participation gap between genders in STEM.

Our analysis uses a comprehensive dataset combining administrative records from the Integrated School Enrollment System in Colombia (SIMAT), and the National Higher Education Information System (SNIES). This rich dataset provides detailed information on students' educational trajectories, school characteristics, and demographic backgrounds, allowing us to track the impact of coeducation on a large and representative sample of female students. The longitudinal nature of the data enables us to examine the effects of the transition.

We employ a staggered difference-in-differences (S-DiD) approach (Goodman-Bacon, 2021) to estimate the causal effect of changing gender composition on post-secondary schooling decisions of female students. This method allows us to compare trends in schools that transitioned to coeducation with those that have not transitioned yet, effectively isolating the effect of classroom gender composition from other confounding variables. We address potential biases arising from non-random timing of the transitions based on Callaway and Sant'Anna (2021) estimator.

We contribute to the literature in several key ways. First, this paper provides, to our knowledge, the first rigorous causal evidence on the impact of classroom gender composition on female students' STEM choices, a departure from prior studies like Bernal (2021); Pahlke et al. (2014); Pregaldini et al. (2020) that primarily focus on peer effects on vocational math schools or the effect on academic performance. Utilizing a unique natural experiment in Colombia, we isolate the causal effect of coeducation on major selection using a staggered difference-in-differences approach. Second, we move beyond binary comparisons of single-sex versus coeducational environments by uncovering nuanced heterogeneous impacts across STEM fields, educational pathways, and the speed of transition to coeducation, providing a more granular understanding of the effects of classroom gender dynamics. Third, we offer valuable insights from a developing country context, Colombia, where the interplay between gender, education, and career choices may differ from developed nations. Finally, we rigorously address potential selection biases and endogeneity concerns using Callaway and Sant'Anna (2021) estimator and extensive robustness checks, strengthening the validity of our findings and offering actionable insights for policymakers seeking to promote gender equality in STEM.

Our findings reveal that coeducation significantly increases female students' participation in STEM majors by 6.43 percentage points, with a particularly pronounced impact on technology and engineering. This effect strengthens over time and leads to changes in educational pathways, increasing enrollment in shorter-cycle tertiary programs while decreasing enrollment in bachelor's degrees. These results suggest that coeducation can serve as a policy tool for fostering gender equality in STEM, but also highlight the need to consider the potential impact on students' choices of different types of post-secondary education.

These results are robust to a range of sensitivity checks, including alternative control groups, different specifications of the S-DiD model, and adjustments for potential confounding factors. We also explore heterogeneous effects across different types of schools and demographic groups to provide a more nuanced understanding of the impact of coeducation. Our findings contribute to a growing literature on the role of gender in education and have important implications for policymakers seeking to promote gender equality in STEM fields.

The remainder of the paper is organized as follows. Section 2 provides an overview of the policy context surrounding the transition from single-sex to coeducational schooling in Colombia. Section 3 discusses the potential mechanisms through which classroom gender composition may shape female students' university major choices. Section 4 describes the data and descriptive statistics, and Section 5 details our empirical strategy. Section 6 presents the main results of our analysis, including robustness checks. Section 7 further investigates the heterogeneous effects of coeducation. Finally, Section 8 concludes the article, summarizing our key findings, discussing their policy implications, and suggesting avenues for future research.

2 The Transition to Coeducation: A Policy Overview

This section outlines the institutional context of our study, focusing on the transition from single-sex to coeducational public schools in Colombia. We provide an overview of the policy rationale and its implementation, emphasizing the key factors driving this shift.

The Colombian education system mandates a standardized national curriculum for all students through the penultimate year of secondary school. As illustrated in Figure 1, the system is structured as follows[1]: Primary School (5 years, ages 6-10), Basic Secondary School (4 years), and Middle Secondary School (2 years). Crucially, the uniform curriculum during the compulsory years implies that students across different schools are exposed to similar academic content and pedagogical approaches prior to the senior year, when curriculum differentiation may begin. This standardization helps to minimize pre-existing differences in academic preparation that could confound our analysis. Our study focuses on students in their final year of middle secondary school, as this is the point at which students make critical decisions about their

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[1] For a detailed overview of the Colombian education system, including its alignment with the International Standard Classification of Education (ISCED), please refer to Table 7.

post-secondary education pathways.

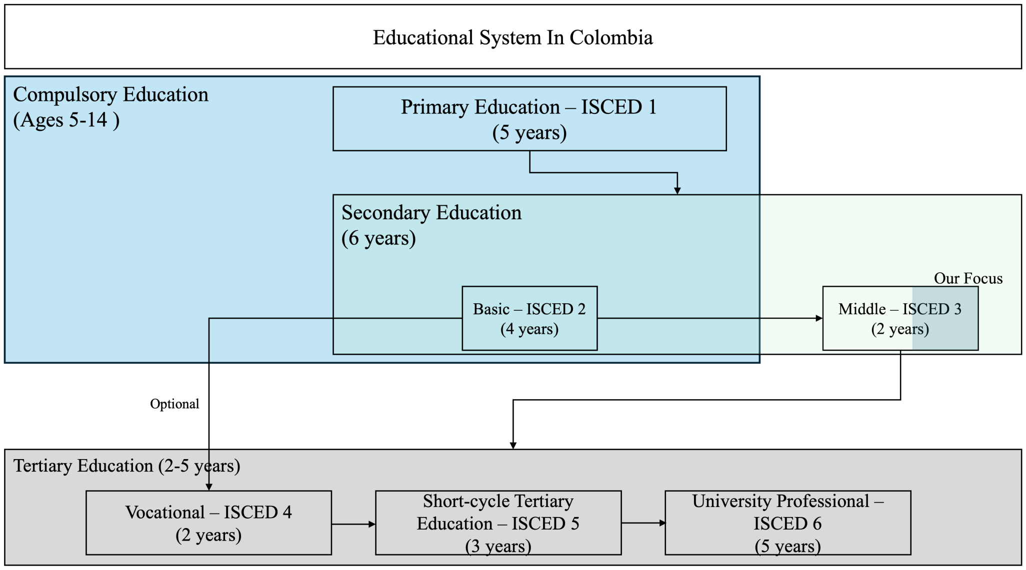

Figure 1: Structure of Colombia's education system, including its alignment with the International Standard Classification of Education (ISCED)

Exogeneity

This transition from single-sex to coeducational schooling was primarily driven by economic and logistical factors, as evidenced by interviews by Herran (2023); Pachon (2023). Both emphasized the government's rationale for the policy: to ensure that students could choose a school based on distance and not be limited by gender-specific admissions. This suggests that the timing of the transition was largely driven by exogenous factors related to resource constraints and not by school performance or post-secondary schooling preferences of students. As shown in Table 6, the socio-demographic characteristics of families remain constant over time, with no variation linked to the proportion of female students in the classroom. This consistency further supports the exogeneity of the transition. This trend is consistent across different cohort periods for all schools that transitioned from single-sex female schools to coeducational settings (see Table 1).

While this policy-driven approach supports the exogeneity of the transition, it is important to acknowledge potential endogeneity concerns. For instance, the selection of schools for transition might not have been entirely random. Factors such as school size, budget constraints, or existing infrastructure could have influenced which schools transitioned first. To address this, our empirical strategy employs a staggered difference-in-differences (S-DiD) design that compares schools transitioning to coeducation at different times. This allows us to control for time-invariant school characteristics and isolate the effect of the transition itself.

Similarly, families could potentially choose their residence based on the availability of single-sex or coeducational schools. However, this concern is mitigated by the fact that new students are assigned to the nearest school with available space, limiting families' ability to strategically select school types. Additionally, we control for student characteristics in our analysis to minimize potential bias from self-selection.

Finally, it is conceivable that the transition to coeducation affected teacher assignments or quality. However, since teachers are assigned by administrative education entities and not individual schools, it is unlikely that the transition directly impacted teacher quality. Furthermore, our school fixed effects control for any systematic differences in teacher quality across schools.

We acknowledge that the curriculum and extracurricular activities designed by the school may impact educational choices made by female students in the last year of secondary school. However, these elements are largely standardized across public schools in Colombia and are unlikely to change in the short term with the transition to coeducation due to limited school resources. Furthermore, our empirical strategy, which includes school fixed effects, accounts for any time-invariant differences in these factors between schools.

3 Mechanisms

Following the policy shift described in the previous section, this section explores the specific mechanisms through which the transition to coeducation might influence female students' university major choices. The unexpected introduction of male students into formerly all-female learning environments has the potential to disrupt established social dynamics and academic norms, with implications for how female students perceive their capabilities and aspirations. This section focuses on mechanisms directly related to the change in classroom gender composition such as competitiveness, peer influence, self-efficacy, and teacher expectations.

The presence of male students introduces a new competitive dynamic into the classroom.

Historically, female education in Colombia emphasized traditional feminine roles and often fostered a less competitive learning environment (Pedraza, 2011). The transition to coeducation might disrupt these established norms and expose female students to different competitive pressures. For instance, Urbano Bernal (2023), in their ethnographic study of a formerly all-girls private school, observed that the introduction of male students led to increased competition for grades and academic recognition, with some girls feeling pressured to adapt to what they perceived as a more assertive male learning style. Although their study focused on a private school context, similar dynamics could be at play in public schools as well.

Furthermore, research suggests that males, on average, exhibit higher levels of competitiveness than females from a young age (Gindi et al., 2019; Sutter and Rützler, 2010). This difference extends to academic settings, where boys are often more competitive in tasks involving motor and spatial skills, which are frequently associated with STEM fields (Gindi et al., 2019). This disparity in competitiveness is linked to career aspirations, with more competitive individuals, particularly males, demonstrating a preference for STEM disciplines (Buser et al., 2014).

As illustrated in Figure 2, the increased competition in newly coeducational classes may have two effects, considering the implications of the Colombian policy change. For some female students, particularly those who are already confident in their abilities, the presence of male competitors might serve as a motivation to pursue STEM fields, aligning with a desire to prove their competence in a traditionally male-dominated domain (Niederle and Vesterlund, 2011). However, for others, the increasing competitiveness may create a disadvantage that decreases interest in STEM professions (Böheim et al., 2017).

Beyond direct competition, as shown in Figure 2, the transition to coeducation alters peer networks and social dynamics. Exposure to male peers interested in STEM could introduce female students to new academic and career possibilities, potentially encouraging them to consider STEM fields. Conversely, peers who reinforce traditional gender stereotypes could have a deterring effect (Liu et al., 2023). This peer influence is closely related to self-efficacy, which is an individual's belief in their ability to succeed in specific tasks or situations (Bandura, 1997; Lent et al., 1994). While girls in single-sex environments often report higher confidence in mathematics and science (Eisenkopf et al., 2015), coeducation can introduce social comparison with male peers, potentially leading to stereotype threat – a fear of confirming negative stereotypes about one's group, which can hinder performance (Steele and Aronson, 1995). However, coeducation can also offer positive role models in the form of male peers who excel in STEM, potentially boosting female students' confidence and aspirations (Schunk and Hanson, 1989).

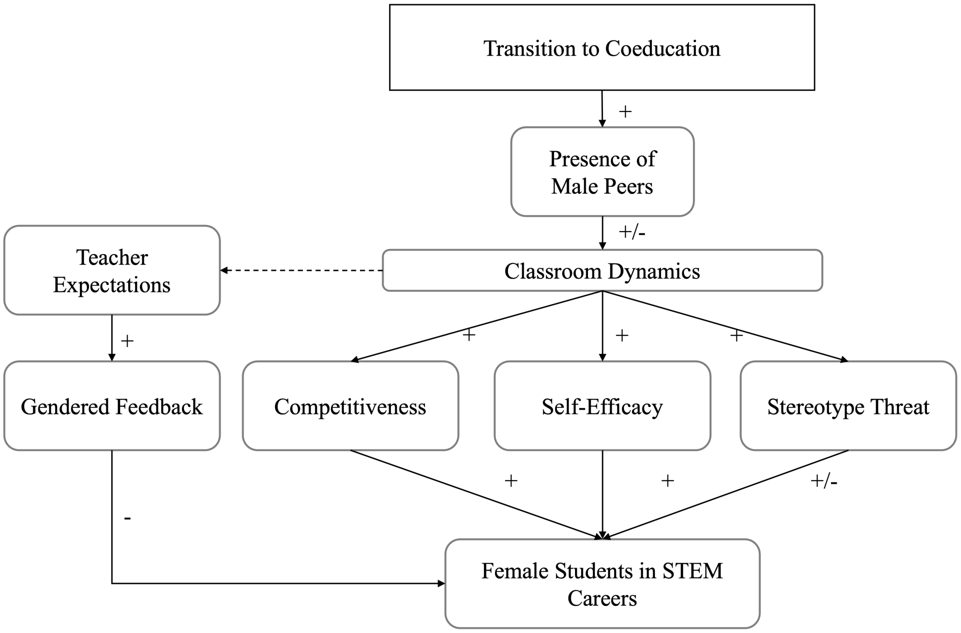

Figure 2: Mechanisms Influencing Female Students' STEM Major Choices.

Even though teachers are assigned centrally, as shown in Figure 2, the transition to coeducation might influence teacher behavior. Teachers, often unconsciously, might hold different expectations for male and female students or reinforce traditional gender roles in coeducational settings, inadvertently affecting students' choices (Beilock et al., 2010). Such biases can manifest in various ways, from the types of questions posed to different genders to the level of encouragement provided. For instance, teachers might subconsciously offer more challenging problems to male students in mathematics or physics, implicitly communicating higher expectations for their performance. This, in turn, could discourage female students from pursuing these subjects at a higher level. While our school fixed effects control for pre-existing differences in teacher characteristics between schools, they cannot account for potential changes in teacher behavior within the same school following the transition.

4 Data and Descriptive Statistics

This study investigates the causal impact of schools transitioning from single-sex (female) to coeducational settings on female students' major choices. To conduct this analysis, we leverage data from two primary sources in Colombia: the Integrated School Enrollment System (SIMAT), and the National Higher Education Information System (SNIES).

SIMAT provides detailed longitudinal records of student enrollment and academic progress throughout their educational journey in Colombian schools. This dataset enables us to track individual students over time and analyze trends in educational outcomes. From SNIES, we obtain data on students' post-secondary enrollment, with a particular focus on their choice of STEM or non-STEM careers. By examining enrollment patterns across different fields of study, we can assess the impact of coeducation on female students' post-secondary decisions.

Variable Construction and Data Cleaning

Our primary data source for post-secondary outcomes is the National Higher Education Information System (SNIES). However, not all students in our secondary school sample appear in the SNIES database, as some may choose not to pursue any form of higher education, enroll in institutions not covered by SNIES, or attend institutions outside of Colombia. To account for these individuals, we create a "Not Continuing Education" category in our outcome variable, indicating students who are present in the SIMAT secondary school data but do not have a corresponding record in SNIES within two years of expected graduation. This approach allows us to include all students in our analysis and examine the effect of coeducation on the decision to pursue higher education, as well as the type of higher education pursued.

Our analysis is necessarily limited to formally accredited post-secondary pathways tracked by the Ministry of Education. We recognize that some students may pursue education outside this system, such as unregistered private institutions, informal "learning by doing" programs, or institutions abroad. However, these limitations are unlikely to significantly bias our findings.

Enrollment in unregistered programs within Colombia is relatively limited and unlikely to be systematically correlated with the transition to coeducation. Furthermore, while some students, particularly those from higher socioeconomic backgrounds, may choose to pursue post-secondary education outside of Colombia, the available data suggests that this is a negligible fraction of our sample. According to the - Ministry of Education (2015), between 2001 and 2015, only 9,427 applications were received to validate higher education degrees obtained abroad. This equates to approximately 628 students per year, compared to the more than 550,000 students who complete secondary school annually in Colombia. Thus, the proportion of students studying abroad is approximately 0.1%, a quantity that is insignificant for our analysis.

Moreover, this small number is predominantly those from higher socioeconomic backgrounds who often attend private secondary institutions, making them less relevant to our analysis of students transitioning from public schools. More importantly, the decision to pursue studies abroad it's plausible to assume that it is not associated with the coeducation policy. Our research question focuses on how gender composition influences the choice of major within the framework of formal, domestic higher education. Therefore, while we acknowledge these alternative pathways, we are confident that our focus on accredited programs provides a valid and policy-relevant analysis of the impact of coeducation on STEM choices within the Colombian context.

The final dataset includes students enrolled in the last year of secondary school between 2012 and 2020 and their post-secondary major choices up to two years after graduating from secondary school. We cleaned the data by addressing missing values, outliers, and inconsistencies. Outliers in continuous variables, such as age, were winsorized at the 1st and 99th percentiles. Inconsistencies in school identification codes were resolved through manual inspection and cross-referencing with official school registries.

Figure 3 presents the distribution of female students across secondary schools in Colombia for each year of our sample period. Figure 3 shows the distribution of female students across secondary schools in Colombia for each year of our sample period. Each facet represents a year, and the distribution within each facet shows the proportion of female students in secondary schools during that year. The proportion of female students ranges from 0 (all-male schools) to 1 (all-female schools), with an overall average of 53.3% female students per classroom. Over the years, the gender composition in classrooms has remained stable with not significant changes observed.

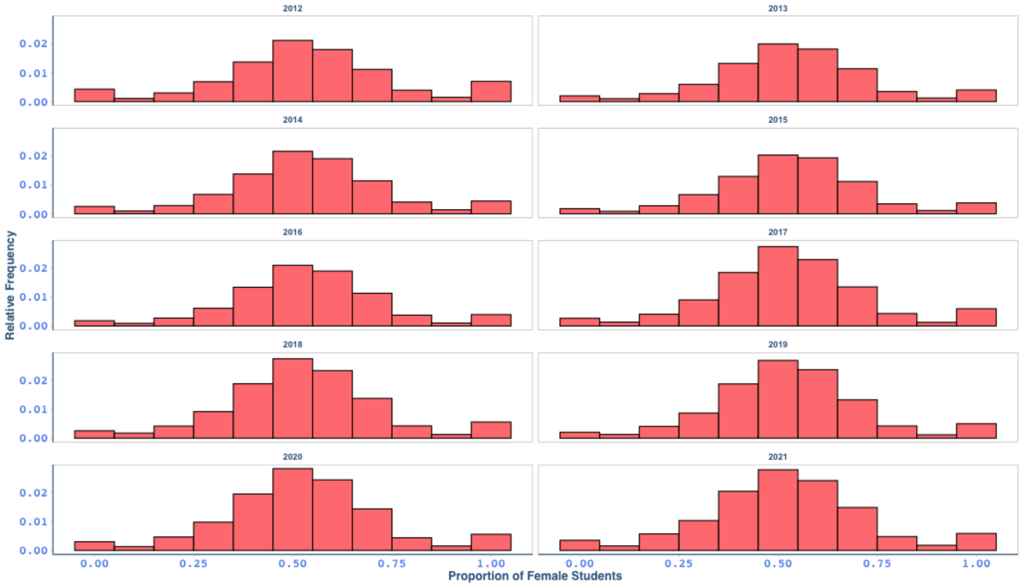

Figure 3: Distribution of Female Student Proportion by Year with Summary Statistics

School Transitions to Coeducation

Our study evaluates a natural experiment created by the staggered transition of 459 Colombian public schools, each with a unique classroom in the final year of secondary education, from single-sex (female) to coeducational settings between 2013 and 2019. We excluded schools that transitioned in 2012 due to insufficient pre-2012 data. Additionally, we omitted schools that transitioned in 2020 and later because of pandemic-related disruptions that altered classroom dynamics beyond the scope of this study.

Figure 4 illustrates the distribution of these transitions over time. The figure shows the proportion of 459 schools that transitioned to coeducation in each year. The staggered nature of these transitions, with varying adoption years across schools, allows us to employ a staggered difference-in-differences (S-DiD) approach. This staggered adoption approach leverages the variation in the timing of transitions from single-sex to coeducational settings across different schools. By comparing trends in female students' post-secondary schooling choices between the classrooms of schools that transitioned to coeducation at different points in time and those that have not yet transitioned, we can robustly identify the causal effect of classroom gender composition on these choices. Specifically, we utilize the Callaway and Sant'Anna (2021) estimator to address potential time and cohort heterogeneity in treatment effects, as discussed in

Section 5.

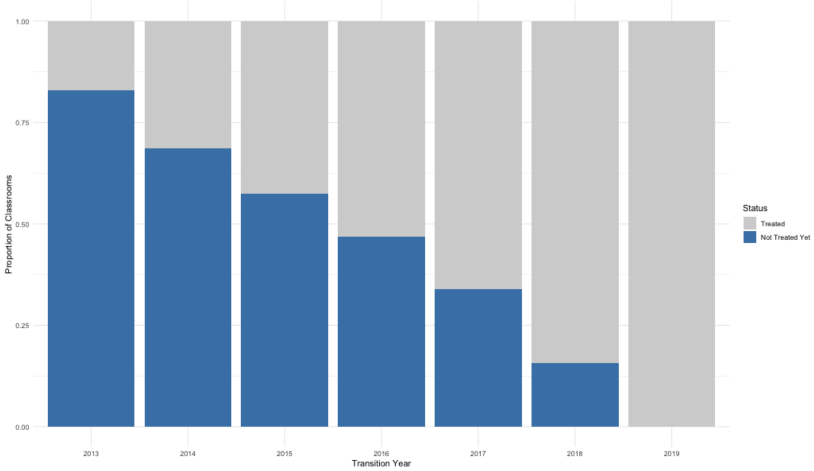

Figure 4: Proportion of Treated and Not-Yet-Treated Classrooms by Transition Year

We present baseline descriptive statistic characteristics for each cohort of treatment schools separately, measured in the year prior to each cohort's transition. The treatment group consists of 459 schools with a unique classroom that transitioned from single-sex (female) to coeducational settings between 2013 and 2019. The comparison group for each cohort in the treatment group consists of classrooms that had not yet transitioned to coeducation by that cohort's transition year.

Tables 1 and 2 present descriptive statistics for classroom attributes, student characteristics, and post-secondary schooling decisions one year before the transition to coeducation. Following the terminology of Callaway and Sant'Anna (2021), we refer to each cohort transitioning in a given year as a "treated group". This breakdown allows for an examination of potential pre-treatment differences across cohorts, which is crucial for assessing the validity of the parallel trends assumption.

Table 1: Descriptive Statistics of Classrooms One Year Prior to Transition (2013-2019)

	Transition Year						
Variable	2013	2014	2015	2016	2017	2018	2019
Transitioned Schools	90	62	46	49	56	83	73
Classroom Attributes							
Total Students (N)	8.9 (14.8)	18.3 (19.2)	13.7 (20.6)	11.3 (13.3)	11.3 (13.7)	15.2 (16.9)	13.6 (14.9)
Average Age (Years)	16.553 (1.385)	16.340 (0.655)	16.611 (1.162)	16.645 (1.115)	16.341 (0.736)	16.526 (1.044)	16.810 (2.084)
Student Characteristics							
Low Socioeconomic Strata	0.794 (0.354)	0.852 (0.272)	0.86 (0.277)	0.822 (0.33)	0.814 (0.29)	0.758 (0.344)	0.720 (0.367)
Middle Socioeconomic Strata	0.087 (0.234)	0.087 (0.204)	0.044 (0.092)	0.094 (0.257)	0.121 (0.242)	0.176 (0.293)	0.174 (0.287)
High Socioeconomic Strata	0.000 (0.000)	0.000 (0.004)	0.001 (0.004)	0.019 (0.139)	0.002 (0.010)	0.02 (0.09)	0.019 (0.070)
Pass Rate for Last Year	0.880 (0.284)	0.951 (0.18)	0.914 (0.251)	0.974 (0.065)	0.973 (0.136)	0.907 (0.231)	0.895 (0.265)
Failure Rate for Last Year	0.013 (0.055)	0.005 (0.019)	0.024 (0.147)	0.014 (0.044)	0.011 (0.052)	0.039 (0.158)	0.053 (0.204)

Note: This table shows mean values (with standard deviations in parentheses) for relevant variables, measured one year prior to the classrooms' transition to coeducation, for each cohort defined by the transition year. Source: SIMAT and SNIES. "Transitioned Schools" indicates the number of unique schools that transitioned in the corresponding year.

Table 1 displays the number of schools and classrooms that transitioned from single-sex to coeducational schools. It also provides descriptive statistics for the average number of students, average age, and socioeconomic information. The presence of overlapping confidence intervals for these means across treated groups suggests preliminary evidence of homogeneity in pre-treatment classroom characteristics.[2] Across all treated groups, the average student age is around 16 years old, in classrooms with an average of 14 students. Approximately 80% of the students were in low socioeconomic strata, with a pass rate exceeding 90% in the last academic year. These observations further suggest similarity in student populations across treated groups before the transition.

Table 2 focuses on the distribution of intended post-secondary schooling choices one year prior to the transition, offering insights into pre-existing academic preferences. The table presents the proportion of female students intending to pursue STEM fields and various other fields of study, broken down by treated group.

Among students who intend to pursue tertiary education, approximately 19% intend to enter STEM fields, while approximately 16% intend to pursue non-STEM fields. However, a substantial proportion (around 65%) do not plan to continue to any tertiary education. The fact

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[2] Confidence intervals for each treated group are estimated at the 95% level using the standard formula. Overlapping 95% confidence intervals imply that we fail to reject the null hypothesis that the true population means are equal for the two groups being compared at the 5% significance level, suggesting that there is not enough evidence to conclude a statistically significant difference between the groups. This homogeneity is crucial because large discrepancies in pre-treatment characteristics could indicate differing pre-existing trends between the groups, potentially biasing our S-DiD estimates.

Table 2: Pre-Transition Major Choice Proportions by Treatment Group

	Transition Year						
Variable	2013	2014	2015	2016	2017	2018	2019
Post-secondary Major Choice Proportion in STEM							
STEM Fields	0.177 (0.242)	0.23 (0.212)	0.177 (0.210)	0.166 (0.198)	0.226 (0.248)	0.185 (0.172)	0.157 (0.180)
Non-STEM Fields	0.187 (0.275)	0.197 (0.205)	0.161 (0.19)	0.1 (0.146)	0.147 (0.224)	0.164 (0.184)	0.203 (0.186)
Not Continuing Education	0.636 (0.317)	0.573 (0.238)	0.662 (0.244)	0.733 (0.237)	0.627 (0.296)	0.651 (0.243)	0.639 (0.230)
Post-secondary Major Choice Proportion by Field of Knowledge							
Health Sciences	0.108 (0.258)	0.112 (0.170)	0.065 (0.178)	0.091 (0.207)	0.105 (0.202)	0.042 (0.075)	0.092 (0.226)
Social Sciences/Humanities	0.108 (0.258)	0.097 (0.147)	0.135 (0.254)	0.057 (0.109)	0.157 (0.274)	0.120 (0.211)	0.213 (0.283)
Law	0.019 (0.112)	0.008 (0.020)	0.020 (0.078)	0.005 (0.016)	0.013 (0.035)	0.018 (0.051)	0.019 (0.049)
Education Sciences	0.027 (0.096)	0.019 (0.038)	0.034 (0.078)	0.006 (0.019)	0.010 (0.024)	0.027 (0.113)	0.024 (0.070)
Economics/Business	0.157 (0.239)	0.155 (0.181)	0.124 (0.160)	0.136 (0.194)	0.086 (0.168)	0.121 (0.148)	0.079 (0.104)
Engineering/Architecture	0.047 (0.110)	0.128 (0.199)	0.064 (0.160)	0.025 (0.049)	0.071 (0.108)	0.078 (0.123)	0.060 (0.108)
Mathematics/Natural Sciences	0.013 (0.057)	0.004 (0.010)	0.016 (0.075)	0.019 (0.055)	0.020 (0.076)	0.007 (0.026)	0.022 (0.119)
Fine Arts	0.002 (0.009)	0.003 (0.013)	0.005 (0.021)	0.003 (0.009)	0.022 (0.134)	0.014 (0.044)	0.016 (0.049)
Agronomy/Veterinary	0.006 (0.031)	0.011 (0.057)	0.003 (0.012)	0.015 (0.048)	0.034 (0.108)	0.014 (0.057)	0.016 (0.067)

Note: This table shows the proportion of female students intending to pursue each field of study one year prior to their classrooms' transition to coeducation. Values are presented as means with standard deviations in parentheses, disaggregated by cohort transition year. Source: SIMAT and SNIES.

that the proportion intending to study STEM is only slightly higher than for non-STEM fields underscores the persistent underrepresentation of women in STEM, even before considering the large share of students not pursuing tertiary education at all. Similar distributions of intended major choices across treated groups lend preliminary support to the parallel trends assumption. However, a more rigorous assessment will be conducted through a formal pre-trend analysis as part of our S-DiD approach (Section 5) following the recommendations of Callaway and Sant'Anna (2021). This will involve visually inspecting event study plots for several periods before the transition and conducting formal hypothesis tests. This rigorous pre-trend analysis strengthens the causal interpretation of our findings.

5 Empirical Strategy

To isolate the causal effect of transitioning from single-sex to coeducational settings on female students' post-secondary schooling choices, we leverage the staggered adoption of this policy across Colombian schools. This staggered implementation allows us to employ a staggered difference-in-differences (S-DiD) design, comparing trends in schools that transitioned to coeducation (treatment group) with schools that had not yet transitioned (comparison group). Our primary outcome variable, $Y_{c,t}$, is the proportion of female students in classroom c at time t (final year of secondary school) who enroll in a STEM-related major the following year (time $t+1$):

$$Y_{c,t} = \frac{\text{Number of female students from classroom } c \text{ enrolled in STEM at } t+1}{\text{Total number of female students in classroom } c \text{ at time } t} \tag{1}$$

To estimate the causal effect, we utilize the Callaway and Sant'Anna (2021) estimator, a non-parametric approach specifically designed for staggered adoption designs. This estimator is robust to treatment effect heterogeneity across groups and over time, a crucial advantage over traditional Two-Way Fixed Effects (TWFE) models, which can produce biased estimates in staggered settings (see, e.g., de Chaisemartin Clément and D'Haultfœuille Xavier, 2020; Goodman-Bacon, 2021). TWFE can be biased when treatment effects are not constant, as it implicitly compares already-treated units to later-treated units (see Appendix E.1 for a more detailed discussion of TWFE and its limitations). The Callaway and Sant'Anna (2021) estimator avoids this by comparing each treated group only to units that have not yet been treated.

Our identification relies on the key assumption of parallel trends: absent the transition to coeducation, the trends in STEM major choices for treated and comparison groups would have been similar. We assess the plausibility of this assumption through visual inspection of pre-treatment trends (see Figure 8) and a formal Wald pre-test (results presented in Section 6). We also address potential violations of the Stable Unit Treatment Value Assumption (SUTVA) through robustness checks (details in Appendix D). Further discussion and sensitivity analysis of the parallel trends assumption are provided in Appendix E.3.

Our primary estimation strategy uses the Callaway and Sant'Anna (2021) estimator (see Appendix E.2 for further details) to obtain event-study coefficients, $\hat{\beta}_r$. These coefficients represent the average treatment effect r periods before and after the transition to coeducation, allowing us to examine the dynamic impact of the policy change. A fuller description of potential selection concerns and the measures we take to address them, including robustness checks, is available in Appendix E.4.

6 Results

Using the staggered difference-in-differences (S-DiD) approach, we find that the transition to coeducational settings significantly increases female students' likelihood of choosing STEM majors. On average, the proportion of female students selecting a STEM major rises by 6.43 percentage points after their schools transition, compared to female students in classrooms that have not yet transitioned. To appreciate the magnitude of this effect, consider that the pre-treatment average proportion of female students choosing STEM was 16% (see Table 2). This 6.43 percentage point increase represents a substantial 40% rise relative to the pre-treatment level, suggesting that for every 100 female high school graduates, the number choosing STEM majors increases from 16 to 22. Figure 5 displays the dynamic effects of this transition, showing the estimated Average Treatment Effect on the Treated (ATT) for each year before and after coeducation is implemented, along with their 95% confidence intervals.

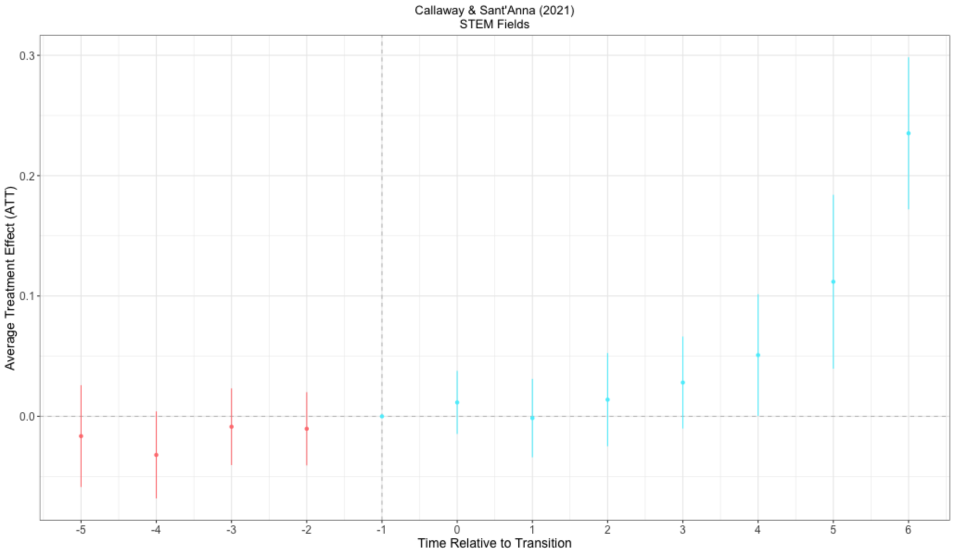


Figure 5: Dynamic Effects of Transition to Coeducation on Female Students' STEM Choices

Figure 5 reveals no evidence of pre-existing trends in STEM major choices in the years leading up to the transition (event times -5 to -1). The estimated effects during these pre-treatment periods are not statistically different from zero, as indicated by the confidence intervals overlapping with the horizontal zero line. To formally assess the parallel trends assumption, we conduct a Wald pre-test on the pre-treatment coefficients, as suggested by Callaway and Sant'Anna (2021).

The resulting Wald statistic (p-value = 0.71059) is not statistically significant, providing strong evidence in support of the parallel trends assumption. This finding suggests that, in the absence of the transition to coeducation, the proportion of female students choosing STEM majors would have followed similar trends in both treatment and comparison groups.

Following the transition to coeducation (event times 0 to 6), the estimated ATTs exhibit a clear positive trend, suggesting a gradual increase in the likelihood of female students choosing STEM majors. While the effect is not statistically significant immediately after the transition, it becomes significant in the third year (event time 3) and continues to grow in magnitude. This positive effect of coeducation on female students' STEM choices is consistent with multiple potential mechanisms. The estimated ATT peaks in the sixth year, reaching 24.1 percentage points (See Figure 5). This finding implies that prolonged exposure to a coeducational environment strengthens the positive impact on female students' STEM choices. In practical terms, this translates to an increase from 16 to 40 female students per 100 choosing STEM careers six years after the transition to coeducation (based on the baseline proportion presented in Table 2).

To ensure the robustness of our findings, we conducted a series of sensitivity analyses, as detailed in Appendix G. These analyses strengthened the support for our findings by addressing potential concerns related to the selection of comparison groups, estimator choice, and pre-existing trends. First, employing a never-treated comparison group yielded similar results (ATT = 0.0516, $p < 0.05$), confirming that our findings are not influenced by the specific choice of comparison group. Second, the use of the Sun and Abraham estimator produced a more conservative estimate of 0.040 points, providing additional support for the main model. Finally, placebo tests with randomly assigned treatment years demonstrated no significant pre-trends and aligned with our identification. Our validation test examining findings from schools transitioning from single-sex male settings reinforced our main effects (See more in appendix G.1, G.2, G.3, G.4).

These robustness checks, fully detailed in Appendix G, provide strong evidence that our primary findings are reliable and not driven by specific methodological choices or confounding factors. The findings also support the policy's causal effect, which enhances female students' participation in STEM studies.

7 Heterogeneous Effects of Coeducation

Our analysis reveals that the impact of transitioning to coeducation is not uniform. The effects vary significantly across STEM fields, educational pathways, and the speed of the transition. This section explores these heterogeneous effects, providing a more nuanced understanding of how coeducation influences female students' post-secondary choices.

7.1 Heterogeneity Across STEM Fields

Table 3 shows the average treatment effects (ATTs) for specific STEM fields. While the overall impact of coeducation on STEM enrollment is positive (as shown in previous results), this effect is primarily driven by a substantial increase in female students choosing Mathematics (ATT = 0.65 percentage points, $p < 0.05$). We also observe a statistically significant, though smaller, increase in Technology majors (ATT = 4.66 percentage points, $p < 0.01$). However, there is a marginally significant effect in Engineering (ATT = 1.47 percentage points, $p < 0.1$), and no statistically significant effect on female enrollment in Science-related fields. The Wald test p-values indicate no evidence of violation of the parallel trend assumption.

Table 3: Effect on STEM Fields Separately

STEM Field	Overall ATT	Wald Test p-value
Science	0.0071 (0.0063)	0.700
Technology	0.0466 (0.0162) **	0.992
Engineering	0.0147 (0.0079) .	0.199
Mathematics	0.0065 (0.0031) *	0.733

Note: This table shows the effect in percentage points on female students choosing STEM careers. Values are presented as ATT (estimated using the Callaway and Sant'Anna (2021) estimator) with standard errors in parentheses. The Wald Test p-value refers to the pre-trend test for each STEM field. A p-value greater than 0.05 indicates no evidence of a violation of the parallel trends assumption. ATT significance codes: 0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1 ’ ’ 1

7.2 Heterogeneity in Educational Pathways

The transition to coeducation also significantly influences the type of post-secondary education pursued by female students. Table 4 shows that coeducation increases enrollment in Vocational/technical education (ATT = 2.05 percentage points, $p < 0.01$) and Short-cycle tertiary education (ATT = 4.66 percentage points, $p < 0.01$), while decreasing enrollment in University bachelor's degree programs (ATT = -6.26 percentage points, $p < 0.01$). There is no significant effect on the proportion of students not continuing their education. These results suggest a shift towards shorter, more vocationally oriented programs after the transition.

Table 4: Effect on Educational Pathways

Post-Secondary Path	ISCED Code	Overall ATT	Wald Test p-value
Vocational/technical education	ISCED 4	0.0205 (0.0069) **	0.601
Short-cycle tertiary education	ISCED 5	0.0466 (0.0161) **	0.992
University bachelor's degree	ISCED 6	-0.0626 (0.0192) **	0.992
Not continuing education		0.0047 (0.0147)	0.849

Note: This table shows the effect in percentage points on female students choosing each post-secondary path. Values are presented as ATT (estimated using the Callaway and Sant'Anna (2021) estimator) with standard errors in parentheses. The "Wald Test p-value" column refers to the pre-trend test for each pathway. A p-value greater than 0.05 indicates no evidence of a violation of the parallel trends assumption. ATT significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

One possible explanation for the observed heterogeneity in STEM field choices can be grounded in the human capital investment model (Becker, 1993). As shows in the equation 2, this framework posits that individuals weigh the present discounted value (PDV) of expected benefits against the PDV of costs when making educational decisions.

$$E\left[\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}\right] > E\left[\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}\right] \tag{2}$$

where B_t represents the expected benefits in year t, C_t represents the costs in year t, r is the individual's discount rate, and T is the time horizon.

In our context, this implies that the decision to pursue a Bachelor's degree (B_a), a Vocational program (V), or a Short-cycle tertiary education program (S_c) is based on a comparison of expected benefits and costs.

Theoretically, the perceived benefits and costs associated with each option will vary across individuals and fields. Drawing on the Ministry of National Education of Colombia (2023), we may assume that the employment rate can be used as an approximation for the benefits perceived from each education level. However, as we can see in Figure 6, this benefit is apparently similar for students graduating with a short-cycle tertiary degree and a bachelor's degree. If there is no clear advantage to pursuing a bachelor's degree compared to a short-cycle degree, students will decide to invest in education based on the lowest cost. This paradox can be explained as follows (see equation 7.2).

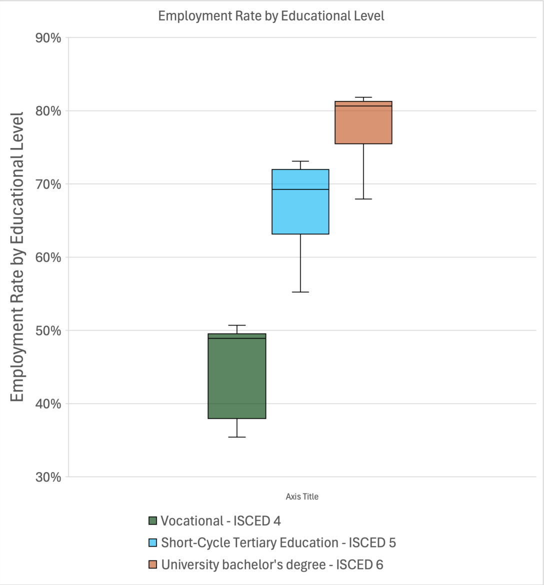


Figure 6: Employment Rate by Educational Level

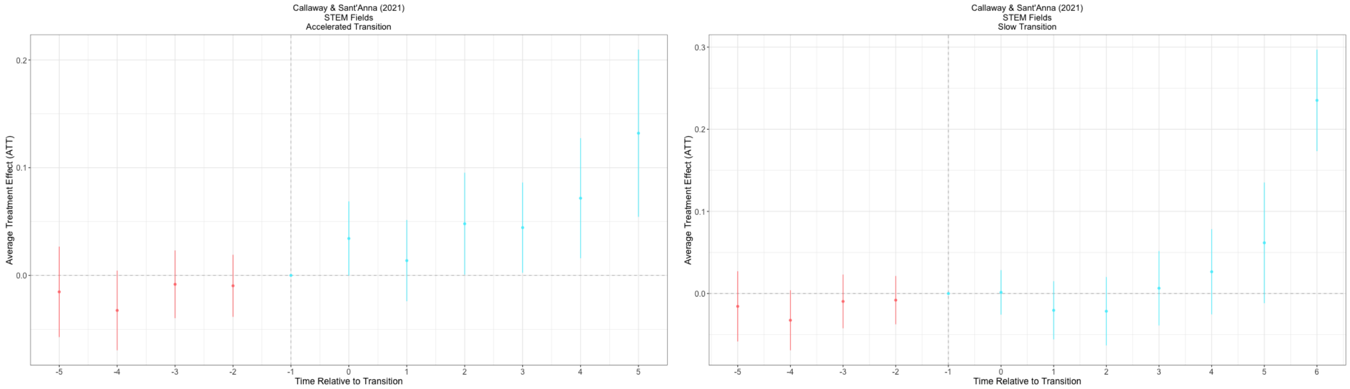
$$E\left[\sum_{t=0}^{T}\frac{B_t}{(1+r)^t}\right]^{S_c} \approx E\left[\sum_{t=0}^{T}\frac{B_t}{(1+r)^t}\right]^{B_a} \wedge E\left[\sum_{t=0}^{T}\frac{C_t}{(1+r)^t}\right]^{S_c} < E\left[\sum_{t=0}^{T}\frac{C_t}{(1+r)^t}\right]^{B_a}$$

The shift towards vocational training might thus be rationalized as a strategy to minimize costs and mitigate risk. The shorter duration of vocational programs reduces monetary and non-monetary cost, appealing to female students who are not ready to commit to a five-year degree. It's important to acknowledge that a vocational program is not necessarily a dead end; for these female students, they may be seeing it as a stepping stone to a short-cycle tertiary degree, with the intention of obtaining more resources for a full bachelor's degree later. While a vocational program represents fewer immediate benefits, the opportunity to complete a S_c may open opportunities to decrease the cost of a future B_a due to resources obtained after finishing V.

The results in our study can be driven because a rational student makes the decision based on the costs between choosing a S_c and a B_a. The shift towards vocational training might thus be rationalized as a strategy to minimize costs and mitigate risk. The shorter duration of vocational programs reduces monetary and non-monetary cost, appealing to female students not choosing a five-year degree. It's important to acknowledge that a Vocational program is not necessarily a dead end; for those female, they may be seeing it as a stepping stone degree to a short cycle teritiary degree for obtaining more resources for a full bachelor degree. While a Vocational program represents fewer immediate benefits, the opportunity to complete a S_c may open opportunities to decrease the cost of a future B_a due resources obtained when finishing V.

7.3 Heterogeneity Impact by Transition Speed

Finally, we examine the impact of the speed at which schools transitioned to coeducation. We classify schools as "Accelerated Transition" if the average proportion of male students over the study period is at or above the median (12.6%) and "Slow Transition" otherwise. Figure 7 presents the dynamic treatment effects for these two groups.



(a) Accelerated Transition

(b) Slow Transition

Figure 7: Dynamic Effects of Transition to Coeducation on Female Students' STEM Choices, by Speed of Transition

The results show that the positive impact of coeducation on STEM enrollment emerges more quickly in schools with an accelerated transition (Overall ATT = 5.73 percentage points, $p<0.01$) compared to those with a slow transition (Overall ATT = 4.13 percentage points, $p<0.01$). This suggests a potential dose-response relationship: a faster and more substantial change in classroom gender composition leads to a faster and potentially larger effect on female students' STEM choices. However, we acknowledge the possibility of selection bias, as discussed in Appendix E.4, and interpret this finding with caution.

7.4 Heterogeneity Impact on Other Fields of Study

Table 5 shows the effects on major choices outside of STEM. We find a statistically significant decrease in female enrollment on: Fine Arts (ATT = -1.47 percentage points, $p < 0.001$), Medicine (ATT = -1.71 percentage points, $p < 0.001$), Social Sciences/Humanities (ATT = -9.47 percentage points, $p < 0.001$), and Education Sciences (ATT=-1.32 percentage points, $p < 0.01$).

Table 5: Effect on Other Fields of study

Post-Secondary Fields	Overall ATT	Wald Test p-value
Mathematics/Natural Sciences	0.0058 (0.0032) .	0.98014
Engineering/Architecture	-0.0256 (0.0121) *	0.26745
Social Sciences/Humanities	-0.0947 (0.017) ***	0.35565
Law	0.0069 (0.0053)	0.48625
Economics/Business	0.0174 (0.014)	0.92544
Education Sciences	-0.0132 (0.0043) **	0.96238
Fine Arts	-0.0147 (0.0038) ***	0.01298
Agronomy/Veterinary	0.0038 (0.0024)	0.48625
Health Sciences	-0.0123 (0.0117)	0.84443
Medicine	-0.0171 (0.004) ***	0.02072

Note: This table shows the effect in percentage points on female students choosing each post-secondary field of study. Values are presented as ATT (estimated using the Callaway and Sant'Anna (2021) estimator) with standard errors in parentheses. The "Wald Test p-value" column refers to the pre-trend test for each pathway. A p-value greater than 0.05 indicates no evidence of a violation of the parallel trends assumption. ATT significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

We observe a negative effect on Social Sciences and Humanities (Appendix Figure 17), which could reflect a similar dynamic as in Fine Arts (Appendix Figure 21) and Medicine (Appendix Figure 25), although the effect is less pronounced. The negative effect on Education Sciences

(Appendix Figure 20), while also not statistically significant, might suggest that coeducation influences female students' career aspirations within the education sector itself. The remaining fields—Mathematics/Natural Sciences (Appendix Figure 14), Engineering/Architecture (Appendix Figure 15), Law (Appendix Figure 16), Economics/Business (Appendix Figure 19), Agronomy/Veterinary (Appendix Figure 22), and Health Sciences (Appendix Figure 24) show no substantial impact from the transition to education.

This finding aligns with the literature on stereotype threat, which posits that individuals might underperform or avoid domains in which they fear confirming negative stereotypes about their group (Steele and Aronson, 1995). In the context of our study, the introduction of male students into formerly all-female schools might create a sense of stereotype threat for some female students interested in Fine Arts and Medicine, leading them to question their abilities or feel less welcome in these fields. Additionally, the increased competition in a coeducational setting, especially in fields where female students might perceive themselves as having a comparative advantage, could contribute to this negative effect. As discussed in Section 3, the transition to coeducation can disrupt established school dynamics, potentially creating a less supportive or more competitive environment that discourages some female students from pursuing traditionally female-dominated fields. Further investigation into these nuanced effects is warranted to understand the complex interplay of factors shaping female students' choices across various academic disciplines.

8 Conclusions

This study investigated the causal impact of transitioning from single-sex (female) to coeducational settings on female students' post-secondary schooling choices in Colombia. Using a staggered difference-in-differences (S-DiD) approach with the Callaway and Sant'Anna (2021) estimator, we found that this transition significantly increased the proportion of female students pursuing STEM majors. This effect emerged gradually, becoming more pronounced three years after the transition, suggesting that longer exposure to a coeducational environment might amplify the positive influence on female students' STEM preferences.

Our analysis revealed that this positive effect on STEM enrollment was not uniform across all fields. We observed substantial increases in female students choosing Technology and, to a lesser extent, Mathematics. However, the transition had limited impact on Science and a more ambiguous effect on Engineering. Factors such as peer influence, role models, shifts in classroom dynamics, and potentially altered teacher expectations might play different roles in different fields.

Furthermore, our findings revealed that the transition to coeducation impacted female students' broader educational pathways. We found a significant increase in the proportion of female students pursuing shorter-cycle tertiary options, such as Vocational/technical and Technological programs, alongside a decrease in enrollment in traditional university bachelor's degrees. This pattern suggests that coeducation might influence female students' perceptions of different post-secondary options and their self-efficacy in navigating a more competitive environment.

Our study contributes to the growing literature on the impact of single-sex versus coeducational schooling by providing robust causal evidence from a natural experiment in the Colombian context. The staggered adoption of coeducation across schools allowed us to employ a rigorous S-DiD approach, minimizing potential biases from selection and other confounding factors. Our findings have important implications for policymakers and educators seeking to promote gender equality in STEM fields. While coeducation appears to be a promising strategy for encouraging female students to pursue STEM, our results highlight the importance of considering potential unintended consequences in other fields and for overall educational pathways.

While our results demonstrate a positive effect of transitioning to coeducation in the Colombian context, we acknowledge that countries with long-established coeducational systems continue to experience underrepresentation of women in STEM fields. This suggests that coeducation, while potentially beneficial, is not a singular solution. As demonstrated in Appendix G.4, when formerly all-male schools transition to coeducation, we observe a decrease in female STEM participation. This highlights that the direction of the change in gender composition, and the pre-existing gender dynamics of the school, are critical factors. Therefore, other mechanisms, such as addressing stereotype threat, promoting female role models in STEM, fostering inclusive classroom environments, and tackling societal biases, are likely crucial complement to structural changes like coeducation to achieve sustained progress in gender equity in STEM."

Future research should explore the long-term career outcomes associated with different educational choices made by female students who experienced the transition to coeducation. Understanding the lasting consequences of these early decisions is crucial for determining whether coeducation ultimately leads to greater gender equity in STEM and related fields. Additionally, further investigation into the specific mechanisms driving the observed effects, particularly within different STEM fields, is necessary to develop targeted interventions that can maximize the benefits of coeducation while mitigating potential drawbacks.

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A Description

Table 6: Descriptive Statistics of Colombian Secondary Schools by Classroom Gender Composition (2012-2021): Classroom Attributes and Student Characteristics

	Female Proportion by Quartile				
	100 - 63.64	63.64 - 53.22	53.22 - 42.42	42.42 - 0.00	Full Sample
	Classroom Attributes				
Male Students (N)	6.83 (5.56)	13.40 (7.45)	16.31 (8.93)	18.56 (10.88)	13.82 (9.50)
Female Students (N)	22.96 (14.02)	18.53 (10.20)	15.01 (8.34)	8.54 (5.86)	16.24 (11.31)
Total Students (N)	29.79 (16.58)	31.93 (17.51)	31.33 (17.14)	27.11 (15.25)	30.06 (16.75)
Stu. Failed Last Year (%)	1.82 (5.03)	2.09 (5.37)	2.17 (5.49)	2.22 (5.95)	2.08 (5.47)
Stu. Passed Last Year (%)	96.51 (8.82)	96.08 (9.10)	95.86 (9.40)	95.51 (10.36)	95.99 (9.45)
Stu. Retired Last Year (%)	1.06 (3.37)	1.20 (3.54)	1.31 (3.87)	1.50 (4.57)	1.27 (3.87)
Female Stu. Proportion (%)	76.43 (11.72)	58.06 (3.14)	47.83 (2.97)	31.03 (10.23)	53.22 (18.19)
	Student Characteristics				
Age (Years)	16.48 (0.66)	16.53 (0.60)	16.57 (0.62)	16.66 (0.80)	16.56 (0.68)
Stu. from Rural Area (%)	30.19 (37.73)	30.37 (37.14)	29.67 (37.17)	30.15 (38.41)	30.10 (37.61)
Stu. from Urban Area (%)	69.81 (37.73)	69.63 (37.14)	70.33 (37.17)	69.85 (38.41)	69.90 (37.61)
Stu. in Stratum 6 (%)	0.45 (4.76)	0.27 (3.61)	0.40 (4.52)	0.59 (5.06)	0.43 (4.51)
Stu. in Stratum 5 (%)	0.88 (5.99)	0.68 (5.51)	0.87 (6.03)	1.47 (7.80)	0.97 (6.39)
Stu. in Stratum 4 (%)	2.36 (8.81)	1.65 (7.34)	2.15 (8.53)	3.36 (10.68)	2.37 (8.93)
Stu. in Stratum 3 (%)	13.25 (20.31)	11.53 (19.08)	12.95 (20.39)	15.08 (21.52)	13.19 (20.37)
Stu. in Stratum 2 (%)	31.78 (26.03)	32.09 (26.62)	31.44 (26.70)	29.24 (25.99)	31.14 (26.37)
Stu. in Stratum 1 (%)	46.97 (34.43)	49.22 (34.26)	47.49 (34.89)	45.12 (35.67)	47.22 (34.85)
Number of students	1071055	1224640	1160485	1002615	4488846

Note: Values represent the mean, with standard deviations in parentheses. "Proportion of Male Students in Classroom" groups are based on quartiles. "(N)" indicates the average number of students per classroom. "(%)" indicates the average classroom-level proportion of students choosing a specific field. Data sources: SIMAT for classroom attributes and STEM proportions; SNIES for post-secondary major choices. The "Stu. in Stratum" refers to the socioeconomic stratum of students, where 1 is the lowest and 6 is the highest in Colombia.

B ISCED Classification in Colombia Education System

Table 7: Mapping of the Colombian Education System to the ISCED Classification

Colombian Level	**Description**	**ISCED Level**	**ISCED Name**
Educación Preescolar	Early childhood education for children aged 3–5 years.	ISCED Level 0	Early Childhood Education (Pre-primary)
Educación Básica Primaria	Primary education, typically covering grades 1–5 (ages 6–10).	ISCED Level 1	Primary Education
Educación Básica Secundaria	Lower secondary education, typically grades 6–9 (ages 11–14).	ISCED Level 2	Lower Secondary Education
Educación Media	Upper secondary education, typically grades 10–11 (ages 15–17). Focus on general and technical tracks.	ISCED Level 3	Upper Secondary Education
Educación Técnica (Nivel Medio)	Vocational training during upper secondary education, often preparing for specific trades.	ISCED Level 3	Upper Secondary Education (with a vocational specialization)
Educación Técnica (Nivel Superior)	Vocational training after secondary education, typically lasting 1–2 years (e.g., SENA programs).	ISCED Level 4	Post-secondary Non-tertiary Education (Vocational)
Educación Tecnológica	Programs lasting 2–3 years that combine practical and theoretical training (e.g., technical institutes).	ISCED Level 5	Short-cycle Tertiary Education (Associate Degree)
Educación Profesional	University-level undergraduate programs lasting 4–5 years (e.g., bachelor's degrees).	ISCED Level 6	Bachelor's Degree or First Degree at the Tertiary Level
Especialización Técnica/Profesional	Postgraduate specialization programs lasting 1 year, focused on advanced professional skills.	ISCED Level 7	Postgraduate Certificate or Diploma (aligned with Master's short-cycle programs)
Maestría	Master's degree programs lasting 1–2 years, focused on advanced academic or professional skills.	ISCED Level 7	Master's Degree
Doctorado	Doctoral degree programs lasting 3–5 years, focused on original research (e.g., PhD programs).	ISCED Level 8	Doctoral or Equivalent Level
Postdoctorado	Postdoctoral research programs, typically non-degree and highly specialized.	Beyond ISCED 8	Postdoctoral Research (not formally categorized under ISCED levels)

C Description of University Major Choices by Knowledge Areas

This section provides an overview of university major choices categorized into distinct knowledge areas. The aggregated classification is structured as follows:

- 1. Economics, Business & related Careers (e.g., Economics, Business Administration, Finance, Accounting, Marketing, Management, Entrepreneurship, International Business, Human Resources)
- 2. Engineering, Architecture and related Careers (e.g., Civil Engineering, Mechanical Engineering, Electrical Engineering, Architecture, Computer Science, Information Technology, Software Engineering, Industrial Design, Environmental Engineering, Biomedical Engineering)
- 3. Fine Arts (Visual Arts, Performing Arts (e.g., Theater, Dance, Music), Graphic Design, Interior Design, Animation)
- 4. Mathematics and Natural Sciences (e.g., Mathematics, Physics, Chemistry, Biology, Environmental Science, Geology, Astronomy, Statistics)
- 5. Social Sciences and Humanities (e.g., Sociology, Anthropology, History, Political Science, Geography, Literature, Philosophy, Religious Studies, Linguistics, Communication Studies)
- 6. Agronomy, Veterinary and related Careers (e.g., Agronomy, Animal Science, Veterinary Medicine, Zoology, Horticulture, Fisheries and Aquaculture)
- 7. Education Sciences (e.g., Early Childhood Education, Special Education, Educational Psychology, Education in Mathematics, Education in Sciences)
- 8. Health Sciences (e.g., Nursing, Dentistry, Pharmacy, Physical Therapy, Occupational Therapy, Public Health, Nutrition, Biomedical Sciences, Health Administration,)
- 9. No Studies (The student does not continue with professional studies)

D Stable Unit Treatment Value Assumption (SUTVA)

The Stable Unit Treatment Value Assumption (SUTVA) is a crucial assumption in causal inference, particularly in studies involving treatment effects. SUTVA has two main components:

1. No Interference: The treatment status of one unit (in our case, a classroom) does not affect the outcome of other units. In other words, there are no spillover effects between classrooms. A classroom's transition to coeducation should only affect the outcomes of students within that classroom, not students in other classrooms.
2. No Hidden Variations of Treatment: The treatment is consistently defined and implemented across all treated units. There are no different "versions" of the treatment that might lead to different effects. In our context, this means that the transition to coeducation should be relatively uniform across all transitioning classrooms.

Potential Violations in Our Context:

The most likely potential violation of SUTVA in our study arises from spillover effects within schools. While our primary analysis focuses on the classroom level, the staggered nature of the school-level transition to coeducation could lead to interactions between students in different classrooms, even if some classrooms remain single-sex. For example:

- Social Interactions: Students from coeducational classrooms might interact with students from single-sex classrooms during breaks, extracurricular activities, or through social networks. This interaction could influence the attitudes and behaviors of students in single-sex classrooms, potentially affecting their major choices. To mitigate this possible violation, we use only secondary schools with no more than one classroom.
- School-Wide Policies: Even if some classrooms remain single-sex, the overall school environment may change after transitioning to coeducation. School-wide policies, teacher training, and resource allocation might shift in ways that impact all students, regardless of their classroom's gender composition. To mitigate this violation, we only use public schools that, due to resource constraints, can not change their allocations in the short term.

E Identification and Empirical Strategy

Figure 8: Average Female Enrollment in STEM by Year for Different Transition Periods

E.1 Two-Way Fixed Effects (TWFE) Details

For illustrative purposes, consider a standard Two-Way Fixed Effects (TWFE) model. Let Y_{cst} represent the outcome of interest (e.g., proportion of female students choosing STEM) for classroom c in school s at time t. $Intensity_{cst}$ represents the proportion of male students in the classroom. A basic TWFE model could be written as:

$$Y_{cst} = \beta \cdot Intensity_{cst} + \gamma_s + \lambda_t + \epsilon_{cst} \tag{3}$$

where:

γ_s represents school fixed effects, controlling for all time-invariant differences between schools (e.g., school quality, resources, location). λ_t represents year fixed effects, controlling for aggregate time trends that affect all classrooms equally (e.g., changes in national education policy, economic conditions). ϵ_{cst} is the error term, typically clustered at the school level to account for correlation in outcomes within the same school over time. β is the coefficient of interest, estimating the average effect of classroom gender composition on the outcome.

Limitations of TWFE in Staggered Adoption Settings:

While TWFE is a common approach for panel data analysis, it has significant limitations when treatment adoption is staggered (i.e., different units receive treatment at different times). These limitations include:

1. Negative Weighting: In staggered adoption settings, TWFE can assign negative weights to certain treatment effect estimates. This happens because TWFE implicitly compares already-treated units to units that will be treated later. If treatment effects change over time (dynamic treatment effects), these comparisons can be misleading and lead to biased estimates (de Chaisemartin Clément and D'Haultfœuille Xavier, 2020; Goodman-Bacon, 2021).
2. Heterogeneous Treatment Effects: TWFE assumes a constant treatment effect across all units and time periods. This assumption is often unrealistic, especially in social science settings. If treatment effects vary across groups or over time (as is likely in our study), TWFE can produce a weighted average of these heterogeneous effects that is difficult to

interpret and may not represent any meaningful causal quantity.

3. Violation of Parallel Trends: If pre-treatment trends differ across groups with different treatment timing, the standard parallel trends assumption required for TWFE can be violated. TWFE relies on a single, common pre-treatment trend for all units.

These limitations motivate our use of the Callaway and Sant'Anna estimator, which is specifically designed to address these issues in staggered adoption settings.

E.2 Callaway and Sant'Anna Estimator Details

The Callaway and Sant'Anna (2021) estimator provides a robust approach for estimating causal effects in settings with staggered treatment adoption. It addresses the limitations of TWFE by:

- Using "Not-Yet-Treated" Units as Controls: For each group of units treated at a given time period (a "cohort"), the estimator uses only units that have not yet been treated as controls. This avoids the problematic comparisons between already-treated and later-treated units that can bias TWFE estimates.
- Allowing for Heterogeneous Treatment Effects: The estimator allows treatment effects to vary across cohorts (groups treated at different times) and over time. It does not impose a constant treatment effect assumption.
- Estimating Group-Time Average Treatment Effects: The estimator first calculates Average Treatment Effects on the Treated (ATT) for each group (cohort) and time period, denoted as ATT(g, t). These ATTs represent the average effect of the treatment for units in group g at time t.
- Aggregating ATTs: The estimator then aggregates these ATTs to produce various summary measures of the treatment effect, such as the overall average treatment effect or event-study coefficients.

The event-study coefficients, which are our primary focus, are calculated as:

$$\hat{\beta}_r = \sum_g \omega_g A\hat{T}T(g, g+r) \tag{4}$$

Where $\hat{\beta}_r$ is the estimated event-study coefficient for relative time r (i.e., r periods before or after the treatment). g indexes the treatment group (cohort). $A\hat{T}T(g, g+r)$ is the estimated ATT for group g at time g+r (i.e., r periods after group g was first treated). ω_g are weights that sum to one. These weights can be chosen based on policy relevance (e.g., proportional to group size). The 'did' package in R, which we use for estimation, provides various weighting options.

These event-study coefficients allow us to examine the dynamic impact of the transition to coeducation, tracing the effect over time both before and after the treatment.

E.3 Additional Parallel Trends Checks

This section include additional analysis related to the parallel trends assumption. Examples include:

- Placebo Tests: Estimating the model with "fake" treatment years before the actual transition.
- Alternative Comparison Groups: Exploring different ways of defining the comparison group (e.g., using schools that never transitioned).
- Controlling for Pre-Treatment Trends: Adding control variables to the model that capture pre-treatment trends in STEM enrollment.

E.4 Selection Concerns

While our staggered difference-in-differences (S-DiD) design, combined with the **?**stimator, provides a robust approach for estimating causal effects, it is important to acknowledge potential selection concerns. The Callaway and Sant'Anna (CS) estimator, while robust to many common issues, relies on the parallel trends assumption.

Limitations of the S-DiD Approach:

The core assumption of our S-DiD design, combined with the CS estimator, is the parallel trends assumption. While the CS estimator is robust to heterogeneous treatment effects (meaning the magnitude of the effect can differ between groups and over time), it still requires that the trends in the outcome variable would have been parallel between treated and control groups in the absence of treatment. The main limitation is the potential for unobserved time-varying confounders that violate this assumption.

Specific Selection Concerns:

- Selective Attrition: If students (or families) with specific characteristics related to STEM interest are more likely to leave schools that transition to coeducation (or to enroll in those schools in the first place), this could bias our estimates. For example, if families who are less supportive of girls in STEM are more likely to move their daughters out of schools that become coeducational, this could lead to an overestimate of the positive effect of coeducation.

- Non-Compliance: While all schools in our sample eventually transitioned to coeducation, the degree of implementation might vary. Some schools might have transitioned more quickly or thoroughly than others. If the degree of implementation is correlated with unobserved factors related to STEM interest, this could also bias our results. (Our "treatment intensity" variable partially addresses this, but it might not capture all aspects of implementation.)

- Time-Varying Confounders: Even with our S-DiD design, there might be unobserved time-varying factors that are correlated with both the timing of the transition to coeducation and female students' STEM choices. For example, changes in local labor market conditions, government initiatives promoting STEM education, or shifts in societal attitudes towards gender roles could all influence both the transition to coeducation and students' major choices.

Mitigating Selection Bias:

Several aspects of our research design and analysis help to mitigate these selection concerns:

- Staggered, Policy-Driven Transition: The staggered nature of the transition to coeducation in Colombia is crucial. The timing of the transition was largely driven by administrative and logistical factors, as discussed in Section 2, rather than by school-level choices or student characteristics. This policy-driven variation makes it less likely that the transition timing is correlated with unobserved factors related to STEM interest, providing a quasi-experimental setting.
- Classroom-Level Analysis: By focusing on the classroom level, we can control for many school-level confounders. Even if schools that transitioned earlier are systematically different, we can compare classrooms within those schools before and after the transition. This helps to isolate the effect of changing gender composition from other school-level factors.
- The CS estimator addresses Non-Compliance: The Callaway and Sant'Anna (CS) estimator allows for treatment effect heterogeneity. This is important because non-compliance, by its nature, often leads to variations in the intensity or effectiveness of the treatment received by different units. If there are variations in how schools implement coeducation (i.e., non-compliance), the CS estimator can still provide valid estimates, and by construction, the CS estimatior compares each group only to units that have not yet been treated, which further mitigates the issues with comparing heterogeneous effects.
- Robustness Checks: Our robustness check, comparing effects in classrooms that transitioned quickly to classrooms that transitioned more slowly.

Robustness Check: Fast vs. Slow Transition Classrooms:

To further address selection concerns, and to investigate potential heterogeneity in treatment effects, we conduct a robustness check comparing classrooms that transitioned to coeducation relatively quickly (i.e., a rapid increase in the proportion of male students) with those that transitioned more slowly.

- Rationale: If our results are driven by selection bias, we might expect to see larger effects in the faster-transitioning classrooms. For example, if schools that transition quickly are also those that are actively promoting STEM education, or if families who are more supportive of girls in STEM are more likely to keep their daughters in schools that transition rapidly, this could lead to a spurious positive correlation between coeducation and STEM choices.
- Implementation: Define a measure of ”transition speed” (e.g., the change in the proportion of male students in the first few years after the transition). Divide classrooms into ”fast” and ”slow” transition groups based on this measure. Re-estimate our main S-DiD model separately for these two groups.
- Expected Results: If the estimated effects are significantly larger in the fast-transition group, this could be evidence of selection bias. However, it could also be consistent with our core hypothesis: a larger and more sudden change in gender composition might have a stronger impact on female students' choices. Therefore, this robustness check should be interpreted cautiously, in conjunction with our other findings and robustness checks.
- Limitations: We acknowledge the exogenous nature of the transition and how the use of classroom-level data, and the estimator's ability to account for treatment heterogeneity minimize this concern.

By thoroughly addressing these selection concerns and conducting appropriate robustness checks, we aim to strengthen the causal interpretation of our findings.

F Dynamic Effects of Transition to Coeducation

F.1 Impact on Educational Pathways

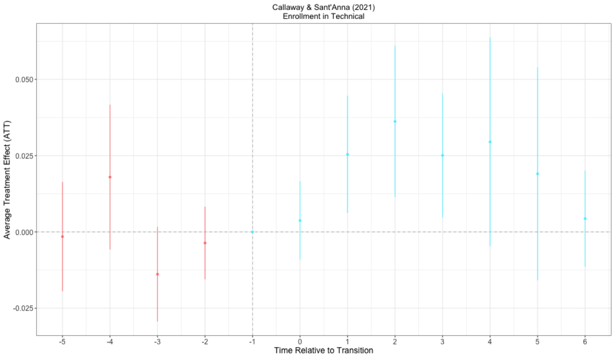

Figure 9: Technical Education

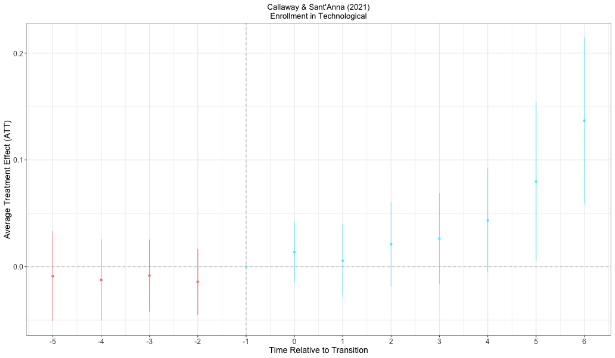

Figure 10: Technological Tertiary Education

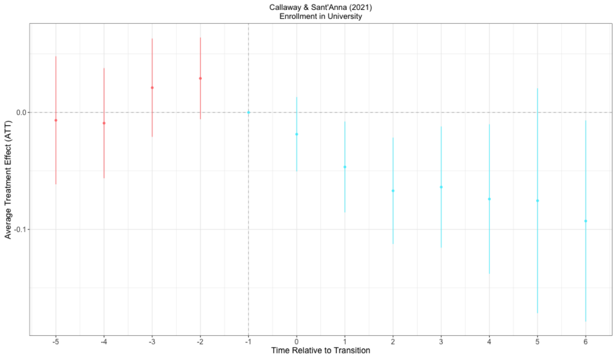

Figure 11: University Bachelor's Degree

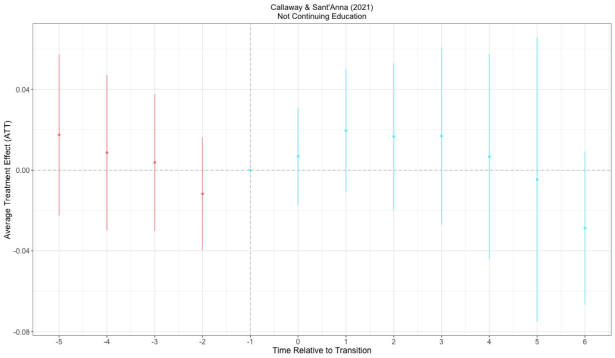

Figure 12: Not Continuing Education

Figure 13: Dynamic Effects of Transition to Coeducation (Summary)

F.2 Impact on Other Fields of Study

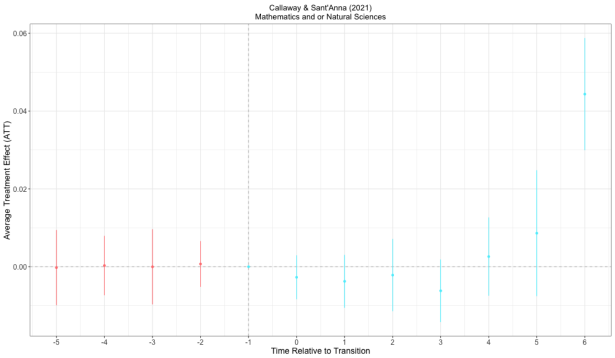

Figure 14: Math & Sciences

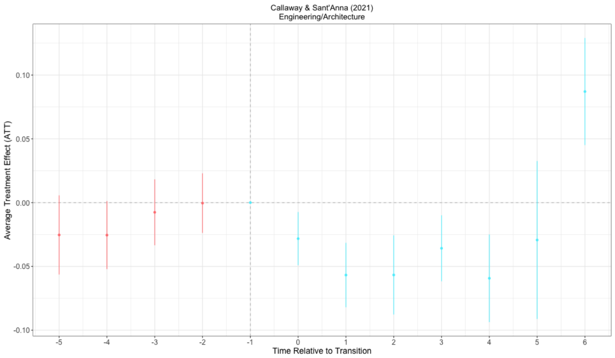

Figure 15: Eng. & Arch.

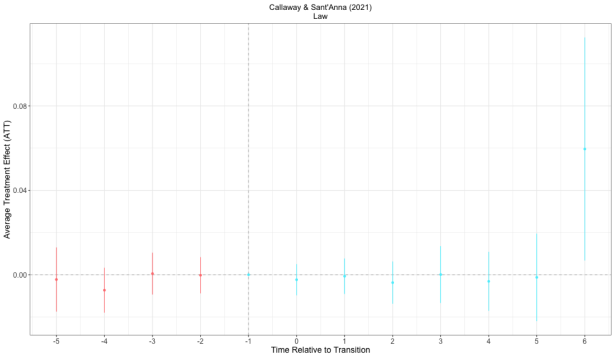

Figure 16: Law

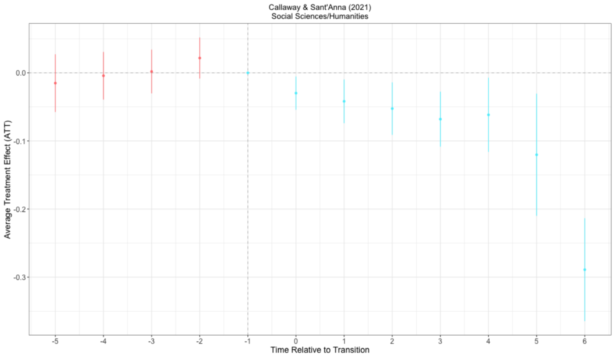

Figure 17: Soc. Sci. & Hum.

Figure 18: Dynamic Effects of Transition to Coeducation on Enrollment by Fields of Study

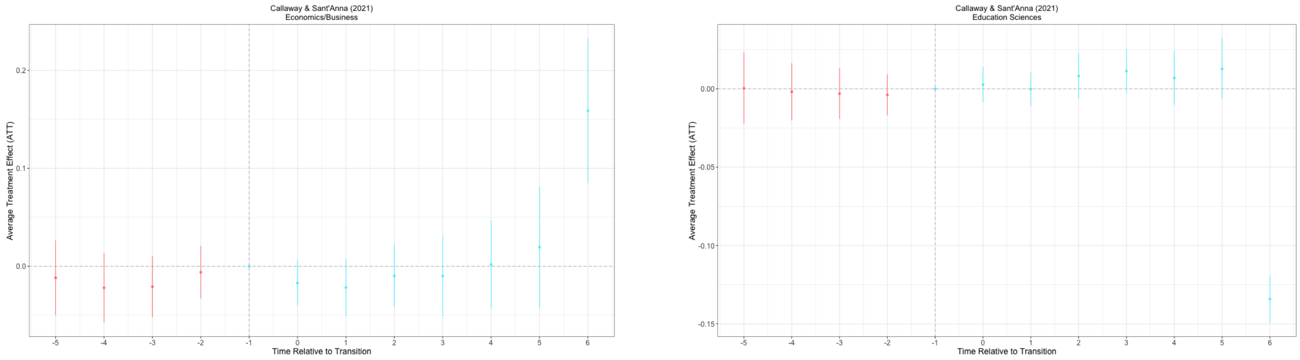

Figure 19: Econ. & Business

Figure 20: Education

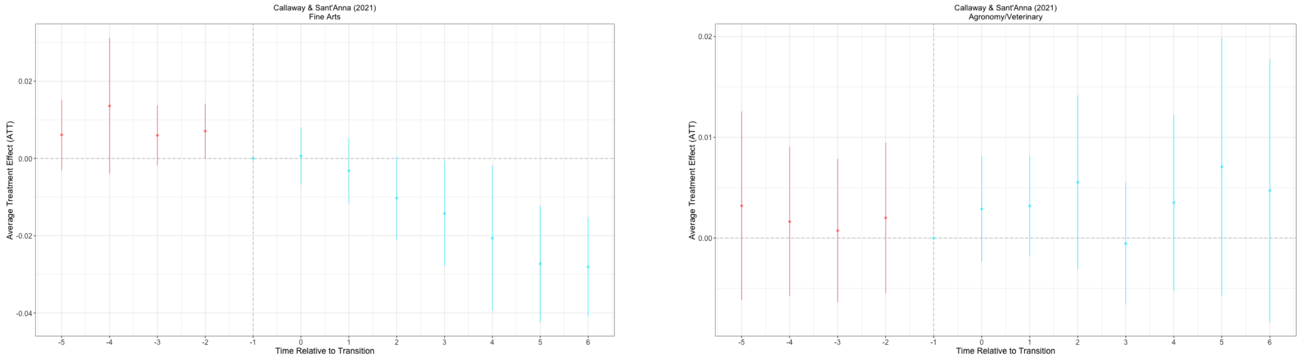

Figure 21: Fine Arts

Figure 22: Agronomy & Vet.

Figure 23: Dynamic Effects of Transition to Coeducation on Enrollment by Fields of Study

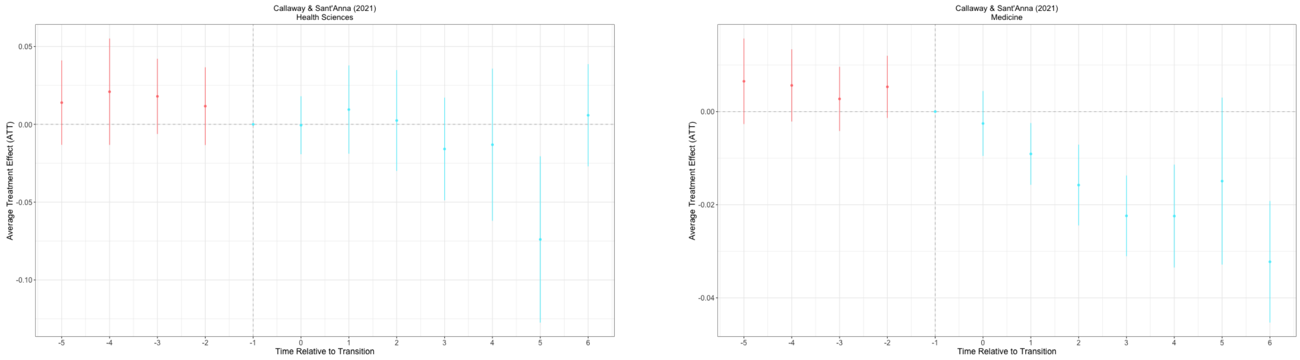

Figure 24: Health Sciences

Figure 25: Medicine

Figure 26: Dynamic Effects of Transition to Coeducation on Enrollment by Fields of Study

G Robustness Checks

To assess the robustness of our findings, we conducted sensitivity analyses and robustness checks, focusing on the validity of the parallel trends assumption and the sensitivity of our results to different estimation strategies.

G.1 Sensitivity to Comparison Groups

To assess the robustness of our findings to the choice of comparison group, we conduct a sensitivity analysis using the never-treated group as our control. This group comprises schools that remained single-sex (female) throughout our study period (2012-2019). Figure 27 displays the dynamic effects of transitioning to coeducation on female students' STEM choices, using this never-treated group as the comparison.

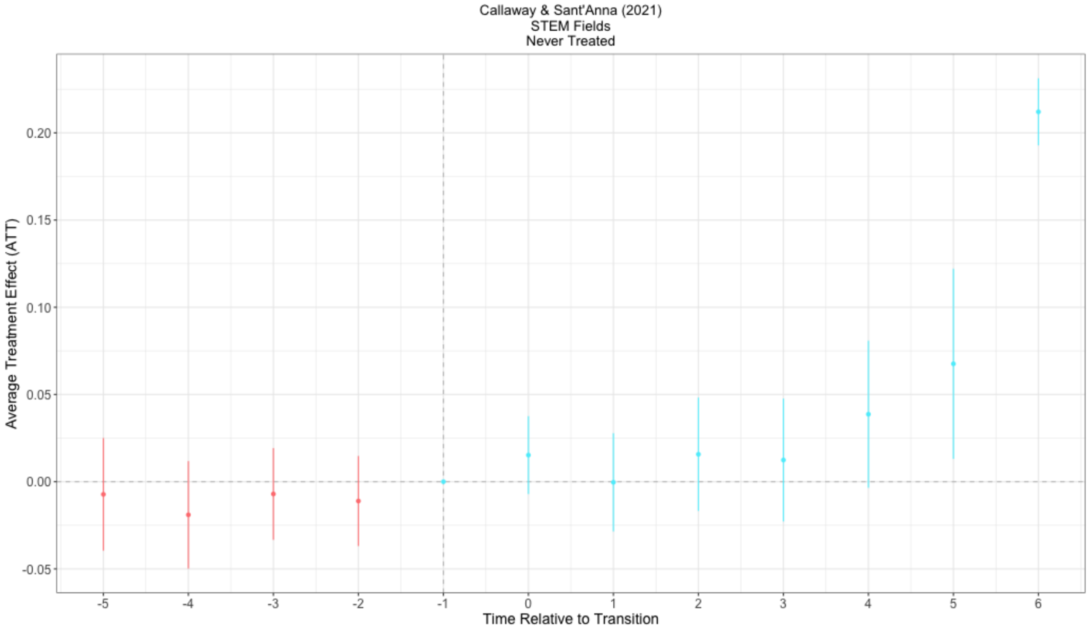

Figure 27: Dynamic Effects of Transition to Coeducation on Female Students' STEM Choices, Using Never-Treated Comparison Group

Using the never-treated comparison group, we find an Overall ATT of 0.0516 (standard error = 0.0118) for STEM enrollment. This estimate is similar to the overall ATT of 0.0643 obtained using the not-yet-treated comparison group in our main analysis (see Figure 5). The dynamic patterns observed in Figure 27 are also comparable to those in Figure 5, with the positive effect on STEM enrollment emerging after the transition and gradually increasing over time. The Wald test for pre-testing the parallel trends assumption yields a p-value of 0.84368, providing strong evidence that this crucial assumption holds when using the never-treated comparison group.

The consistency of our findings across both comparison groups strengthens our confidence in the robustness and validity of our results. It suggests that the positive effect of coeducation on female students' STEM choices is not driven by idiosyncrasies in the choice of comparison group or by time-varying factors affecting only schools that eventually transitioned to coeducation. This consistency across different analytical approaches enhances the internal validity of our study, supporting the causal interpretation of our findings.

Furthermore, the use of the never-treated comparison group provides insights into the external validity of our results. The never-treated schools represent a subset of schools that, for various reasons, did not adopt coeducation during our study period. These schools might differ from those that transitioned in terms of their characteristics, contexts, or underlying trends. The fact that our findings remain consistent even when using this distinct comparison group suggests that the positive effect of coeducation on female STEM choices might generalize to a broader population of schools beyond those that actually transitioned. This strengthens the external validity of our study and increases the potential policy relevance of our findings.

G.2 Alternative Estimators

To assess the sensitivity of our results to the choice of estimator, we re-estimated our S-DiD model for STEM majors using the Sun and Abraham (2021) estimator. This estimator, like the Callaway and Sant'Anna estimator, accounts for cohort and time heterogeneity in treatment effects but employs a different identification strategy and weighting scheme.

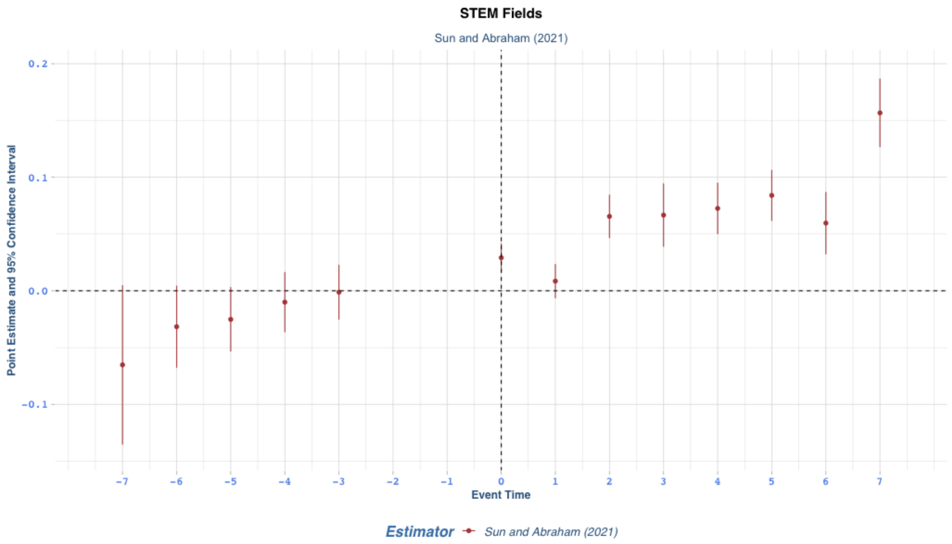

Figure 28: Dynamic Effects of Transition to Coeducation on Female Students' STEM Choices: Sun and Abraham (2021) Estimator

The Sun and Abraham estimator yielded an Overall ATT of 0.048582 (standard error = 0.006444) for STEM majors, a statistically significant result. This estimate is very similar to the overall ATT of 0.0643 obtained using the Callaway and Sant'Anna estimator (Figure 5), demonstrating the robustness of the effect size to different estimation approaches. Examining the dynamic effects in Figure 28, we find that both estimators suggest a positive effect that emerges after the transition to coeducation.

Despite some variations in the precise timing and magnitude of the dynamic effects, the Sun and Abraham estimator confirms our main finding: transitioning to coeducation positively affects female students' STEM choices. The similarity in the overall ATTs across both estimators strengthens our confidence in the robustness of this result to different methodological approaches. This consistency reinforces the validity of our conclusions and suggests that our findings are not driven by the specific choice of estimator.

G.3 Placebo Tests

To further assess the validity of our S-DiD approach, we conduct a placebo test using randomly assigned treatment years. We create a placebo treatment variable by randomly assigning each classroom a transition year between 2012 and 2020, regardless of their actual transition status.

If our model is correctly identifying the causal effect of coeducation, we should not observe significant effects in this placebo analysis.

Figure 29 displays the dynamic effects of this placebo treatment on female students' STEM choices. As expected, the estimated ATTs are generally small and not statistically different from zero. The overall ATT is -0.0153 (standard error = 0.0227), confirming the lack of a significant effect. Furthermore, the Wald statistic (p-value = 0.59538) for pre-testing the common trends assumption is not statistically significant, providing additional support for the validity of our S-DiD design.

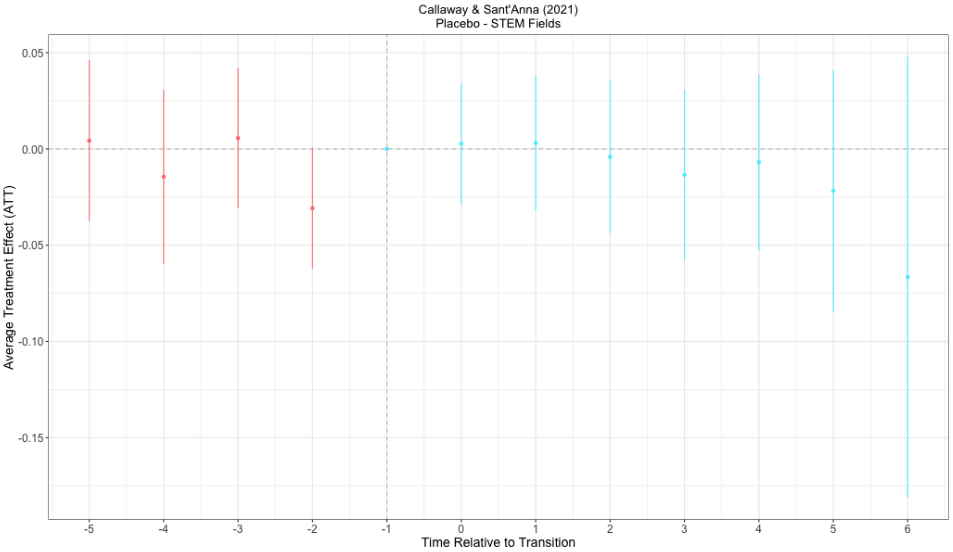

Figure 29: Dynamic Effects of Placebo Treatment on Female Students' STEM Choices

This placebo test result strengthens our confidence that the positive and significant effect of coeducation observed in our main analysis is not due to pre-existing trends, spurious correlations, or other factors unrelated to the transition itself. It provides further evidence that our S-DiD approach is effectively capturing the causal impact of coeducation on female students' STEM choices.

G.4 Validation of the Hypothesis by Contrast: Transitional Male Schools and Female STEM Participation

In our primary analysis, we focused on schools transitioning from single-sex female to coeducational settings, demonstrating a positive effect on female students' likelihood of choosing STEM majors. To further validate our hypothesis, we explore the reverse scenario: schools that were originally single-sex male and transitioned to coeducation. This exploration does not seek to replicate the positive effect, but rather to examine whether the dynamics are different, and even, if a contrasting pattern is observed that can enrich our understanding of the phenomenon.

To assess this, we first identify all schools that transitioned from single-sex male to coeducational during the study period. Unlike the main analysis, here we do not expect an immediate positive effect. Instead, using a Staggered Difference-in-Differences approach, we analyze the temporal evolution of the female STEM enrollment rate in these transitioning male schools. Our model includes year-fixed effects to control for general time trends. Figure 30 presents the estimated dynamic effects of this transition.

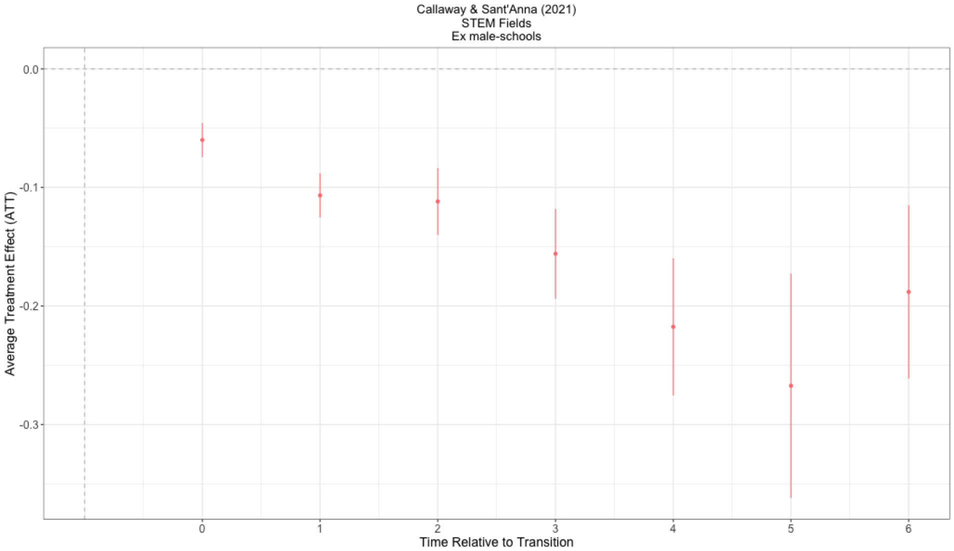

Figure 30: Dynamic Effects of Transition of Male-Schools to Coeducation on Female Students' STEM Choices

The results of the Staggered Difference-in-Differences show a negative and significant overall ATT of -0.1582 ($p<0.05$). Furthermore, the dynamic event study analysis (Figure 5) reveals a decreasing trend in the female STEM enrollment rate following the transition to coeducation in schools that were previously male. Specifically, we observe that the event-time coefficients are negative and increase in magnitude in the periods after the transition, the overall trend suggests a different pattern from that observed in transitioning female schools.

These results suggest an added layer of complexity: the effect of coeducation on female STEM participation may depend on the initial gender context of the school and the nature of the transition. This section, therefore, does not invalidate the positive effect found in female schools, but enriches our analysis by revealing a potentially different and more nuanced dynamic in schools transitioning from a male environment.