Does Coeducation Close the STEM Gap? Evidence from a Single-Sex Schooling Transition in Colombia*

Jaime Polanco-Jiménez† Kristof De Witte‡ Gloria L. Bernal§

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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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†Corresponding author. Leuven Economics of Education Research, KU Leuven, Belgium; Department of Economics at Pontificia Universidad Javeriana, Colombia (email: jaime.polanco@javeriana.edu.co, jaime.polancojimenez@kuleuven.be) Jaime Polanco-Jimenez And Kristof De Witte acknowledges financial support from the Horizon Europe project BRIDGE (grant 211012702). Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the granting authority. Neither the European Union nor the granting authority can be held responsible for them.

‡Full Leuven Economics of Education Research, KU Leuven, Belgium; UNU-Merit, Maastricht University, the Netherlands (email: kristof.dewitte@kuleuven.be)

§Department of Economics at Pontificia Universidad Javeriana, Colombia (email: gbernal@javeriana.edu.co)

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. This gap contributes to gender inequality in the labor market and potentially hinders aggregate innovation. Understanding the factors that influence women's choices in STEM fields is therefore crucial for designing effective policies.

What are the consequences of dismantling a long-standing system of single-sex schooling? For much of the 20th century, single-sex public education was a feature of many school systems worldwide, often justified by pedagogical theories and societal norms (Pahlke et al., 2014; Pedraza, 2011). In recent decades, most systems have transitioned to coeducation, yet large-scale causal evidence on this fundamental policy shift remains scarce. Existing literature largely compares outcomes between single-sex and coeducational schools (Eisenkopf et al., 2015; Jackson, 2021), a design often confounded by student sorting and selection.

This paper provides new causal evidence by analyzing a nationwide policy in Colombia where 459 formerly all-female public secondary schools were converted to coeducational settings. Crucially, the timing of this transition was driven by administrative logistics—specifically, the need to optimize school assignment based on proximity—rather than school-specific academic strategies. This plausibly exogenous variation allows us to identify the causal effect of the transition itself, isolating the impact of introducing male peers into the classroom on female students' post-secondary choices.

We combine rich administrative data from the Integrated School Enrollment System (SIMAT) and the National Higher Education Information System (SNIES) with a staggered difference-in-differences (S-DiD) research design, using the Callaway and Sant'Anna (2021) estimator to account for dynamic treatment effects. We find that the transition to coeducation had complex and often contradictory effects. On the surface, the policy appeared to achieve a key goal of gender equality advocates: it significantly increased the probability that female

graduates enroll in STEM majors by 6.43 percentage points.

However, this aggregate effect masks a crucial trade-off between the *field of study* (horizontal choice) and the *level of degree* (vertical choice). We find that the increase in STEM enrollment was driven entirely by shorter-cycle vocational and technical programs, while enrollment in traditional four-year university bachelor's degrees simultaneously *declined* by 6.26 percentage points. This result suggests that while coeducation lowers the barriers to entering STEM fields, the accompanying change in classroom dynamics—potentially driven by comparative advantage assessments (Loyalka et al., 2017) or increased competitiveness (Niederle and Vesterlund, 2011; Sutter and Rützler, 2010)—discourages female students from pursuing the most rigorous academic tracks.

The policy's impact is further nuanced by the school's initial context. In a key validation exercise, we examine the reverse transition: formerly all-male schools that also became coeducational. In stark contrast to our main result, we find that for the small number of female students who began attending these schools, the probability of pursuing a STEM degree *decreased* following the transition. This striking asymmetry challenges simple mechanism stories centered on peer gender ratios (Böheim et al., 2017) and instead points to the powerful role of pre-existing institutional norms in mediating peer effects (Brenøe and Zölitz, 2020).

This paper makes three primary contributions. First, we provide the first large-scale causal evaluation of a shift from female-school to coeducational schooling, contributing to the literature on single-sex education (Jackson, 2021). Second, we add crucial evidence to the gender peer effects literature (Lavy and Schlosser, 2011) by demonstrating that the introduction of male peers has opposite effects depending on the school's original gender composition. Third, we uncover a previously undocumented "Horizontal-Vertical Trade-off," showing that a policy can simultaneously steer women toward male-dominated fields and away from higher-level university education.

The remainder of the paper is organized as follows. Section 2 details the institutional context and the exogeneity of the policy rollout. Section 3 outlines our theoretical framework. Section 4 describes the data and establishes covariate balance. Section 5 presents the empirical strategy. Section 6 discusses the main results and the vertical trade-off. Section 7 provides mechanism

tests and validation exercises. Section 8 concludes.

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).

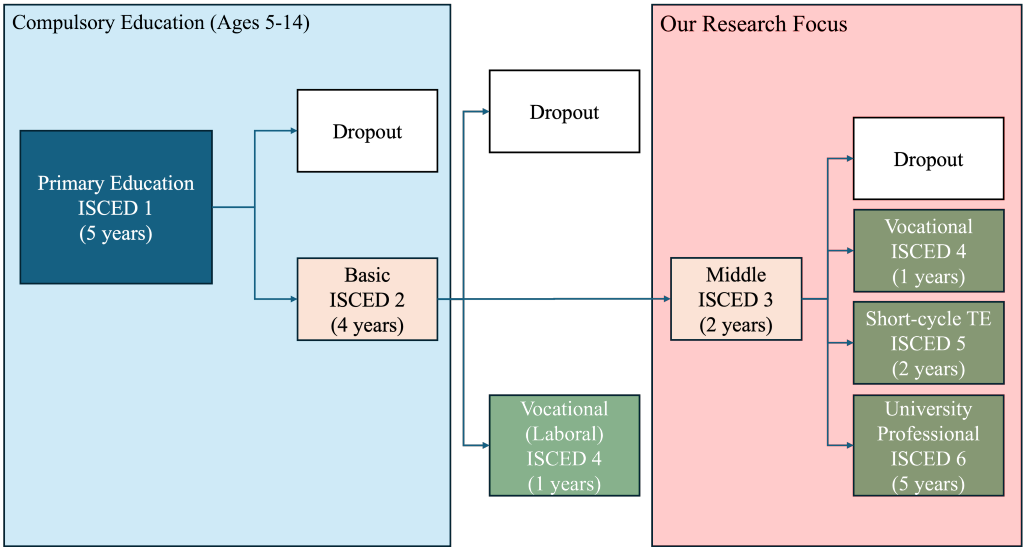


Figure 1: Structure of Colombia's education system, including its alignment with the International Standard Classification of Education (ISCED)

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 Grade 11, the final year of secondary education in Colombia (equivalent

[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 6.

to Middle ISCED 3), at which point students are typically 16-17 years old and make binding decisions about their post-secondary pathways.

2.1 Institutional Context and Policy Exogeneity

The transition from single-sex to coeducational schooling in Colombia was driven by a convergence of international norms and local administrative pressures. While the National Education Plan (1996–2005) and international advocacy from organizations like UNICEF promoted coeducation as a tool for gender equality, the practical implementation at the municipal level was largely dictated by logistical constraints.

In the Colombian public system, municipalities are responsible for assigning students to schools. Historically, single-sex restrictions created inefficiencies in this allocation process. A student living near a female-only school might be forced to travel to a distant male-only school, and vice versa. As enrollment demand grew, these gender-based restrictions became increasingly untenable. The transition to coeducation allowed municipalities to optimize resource utilization and assign slots based solely on proximity rather than gender. Consequently, the decision to convert a specific school was typically a function of local capacity constraints and administrative planning rather than school-specific academic strategies.

This logistical mechanism supports the exogeneity of the transition timing with respect to our outcome of interest. It is unlikely that a municipality's decision to solve an enrollment bottleneck was driven by the specific STEM aspirations of the female students in that school. This assumption is corroborated by the empirical evidence presented in Section 4. As shown in Table 2, the pre-treatment proportion of female students intending to pursue STEM fields is statistically uncorrelated with the year of transition. The stability of these baseline characteristics across cohorts confirms that the staggered rollout was not endogenous to pre-existing trends in female STEM participation.

3 How Institutional Context Mediates the Effects of Coeducation

The transition from single-sex to coeducational schooling introduces a complex set of incentives that may reshape female students' educational trajectories. While existing literature has largely focused on the binary decision to enter STEM fields, we hypothesize that coeducation induces a more nuanced trade-off between the *field of study* (horizontal choice) and the *level of degree* (vertical choice).

3.1 The Horizontal-Vertical Trade-off

The introduction of male peers into formerly all-female schools creates a theoretical tension. On one hand, exposure to male peers with strong STEM interests may normalize these fields as viable pathways, lowering the psychological or social barriers to entry (Lavy and Schlosser, 2011). This "horizontal" effect encourages female students to cross the gender divide into STEM disciplines.

However, this shift may come at a "vertical" cost. The presence of male students introduces a new competitive dynamic into the classroom. Research indicates that males, on average, exhibit higher levels of competitiveness (Gindi et al., 2019; Sutter and Rützler, 2010), particularly in tasks involving mathematical or spatial skills. For female students, this heightened competition may trigger a "flight to vocational tracks." Loyalka et al. (2017) suggest that female students often base educational decisions on *comparative advantage* (their relative strength in STEM vs. non-STEM subjects) rather than absolute advantage. In a coeducational setting, even high-performing girls may perceive a lower comparative advantage in professional STEM tracks when directly compared to a larger pool of male peers, leading them to opt for shorter-cycle technical or technological programs where the competitive pressure is perceived to be lower, yet the content remains STEM-oriented.

Thus, the transition to coeducation may not simply "close the gap," but rather redistribute female participation across the educational hierarchy. A key contribution of this paper is to em-

pirically test this hypothesis: that coeducation increases female STEM participation (horizontal margin) while simultaneously shifting enrollment from long-cycle university degrees to shorter vocational qualifications (vertical margin).

3.2 Mechanisms: Competition, Peers, and Stereotype Threat

Beyond the horizontal-vertical trade-off, three specific mechanisms mediate the effects of coeducation:

1. Competitive Environment: Historically, female education in Colombia emphasized cooperative learning environments (Pedraza, 2011). The transition disrupts these norms. As Urbano Bernal (2023) observed in Colombian private schools, the introduction of male students often intensifies competition for grades and recognition. For some girls, this acts as a motivator (Niederle and Vesterlund, 2011), but for others, particularly those sensitive to stereotype threat, it may discourage the pursuit of the most competitive university tracks (Böheim et al., 2017).

2. Peer Networks and Role Models: Coeducation alters the supply of role models. While male peers can serve as positive examples of STEM engagement (Schunk and Hanson, 1989), they can also reinforce traditional gender stereotypes that deter female participation (Liu et al., 2023). The net effect depends on whether the exposure to male peers demystifies STEM or amplifies the perception that these fields are "male domains."

3. Asymmetric Effects: Crucially, we hypothesize that these effects are path-dependent. The introduction of males into a female environment (our primary treatment) brings STEM-oriented peers into a setting with established female-centric norms. Conversely, the introduction of females into a formerly all-male school places them as a minority in a male-dominated culture, potentially amplifying stereotype threat (Steele and Aronson, 1995). This framework predicts an asymmetric policy effect, which we test as a validation exercise in Section 7.

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 2 presents the distribution of female students across secondary schools in Colombia for each year of our sample period. Figure 2 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. Within our transition sample of 459 schools, the average class size is 13.18 students, comprising a total of $N = 6,050$ student observations. Over the years, the gender composition in classrooms has remained stable with no significant changes observed.

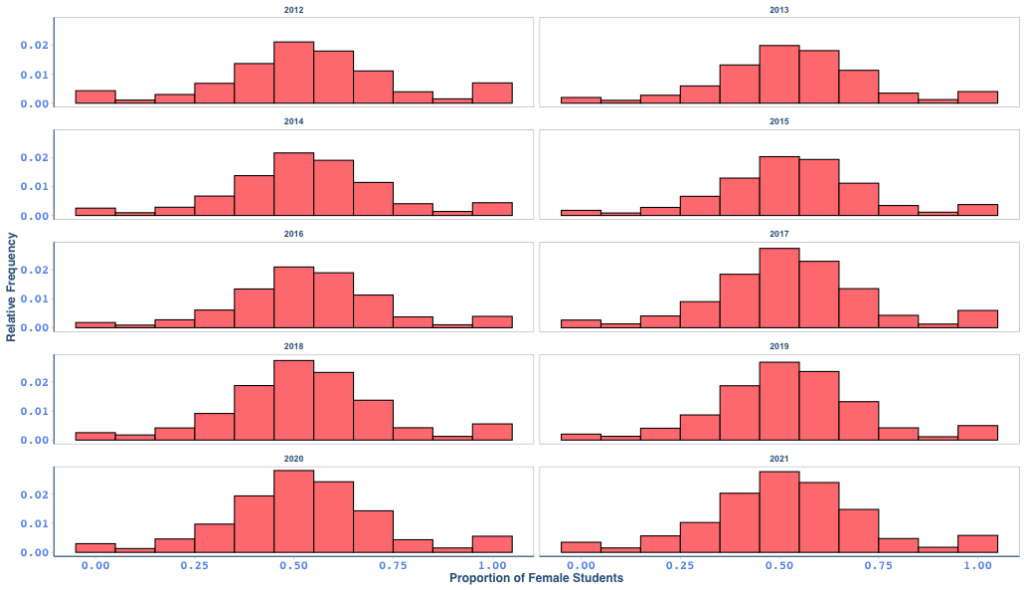


Figure 2: Distribution of Female Student Proportion by Year with Summary Statistics

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 3 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.

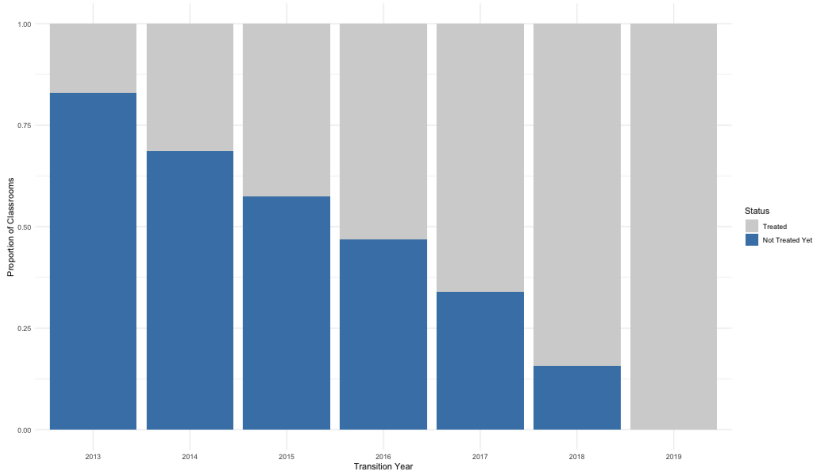


Figure 3: Proportion of Treated and Not-Yet-Treated Classrooms by Transition Year

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. This results in a total sample of 6,050 student observations ($N = 6,050$), with an average class size of 13.18 students per classroom. 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: Covariate Balance: Classroom Characteristics One Year Prior to Transition

	Transition Cohort (Year)						
Variable	2013	2014	2015	2016	2017	2018	2019
School Count	90	62	46	49	56	83	73
Classroom Attributes							
Class Size (N)	8.9	18.3	13.7	11.3	11.3	15.2	13.6
	(14.8)	(19.2)	(20.6)	(13.3)	(13.7)	(16.9)	(14.9)
Average Age	16.55	16.34	16.61	16.65	16.34	16.53	16.81
	(1.39)	(0.66)	(1.16)	(1.12)	(0.74)	(1.04)	(2.08)
Student Demographics (Proportion)							
Low SES Strata	0.79	0.85	0.86	0.82	0.81	0.76	0.72
	(0.35)	(0.27)	(0.28)	(0.33)	(0.29)	(0.34)	(0.37)
Middle SES Strata	0.09	0.09	0.04	0.09	0.12	0.18	0.17
	(0.23)	(0.20)	(0.09)	(0.26)	(0.24)	(0.29)	(0.29)
High SES Strata	0.00	0.00	0.00	0.02	0.00	0.02	0.02
	(0.00)	(0.00)	(0.00)	(0.14)	(0.01)	(0.09)	(0.07)
Academic History							
Pass Rate (Last Year)	0.88	0.95	0.91	0.97	0.97	0.91	0.90
	(0.28)	(0.18)	(0.25)	(0.07)	(0.14)	(0.23)	(0.27)

Notes: Means are reported with standard deviations in parentheses. Variables are measured in the year immediately preceding the transition to coeducation ($t-1$). 'Low SES' corresponds to Strata 1-2, 'Middle' to Strata 3-4, and 'High' to Strata 5-6. Source: SIMAT.

Covariate Balance and Pre-Treatment Outcomes

Table 1 reports baseline characteristics for each cohort in the year prior to their transition. To interpret our difference-in-differences estimates as causal, the timing of the transition must be unrelated to potential outcomes. The data strongly support this assumption. Schools transitioning in different years exhibit remarkable similarity in observable characteristics. Across all cohorts, the average student age remains constant at approximately 16.5 years, and class sizes hover around 14 students. Socioeconomic composition is also stable, with roughly 80% of students belonging to the lowest socioeconomic strata across all transition years. We formally test for joint equality of means across cohorts and fail to reject the null hypothesis, suggesting that early and late adopters of the coeducation policy were drawn from the same underlying population.

Table 2 examines the pre-treatment levels of our primary outcome variables. A key threat to identification would arise if schools with historically higher female STEM enrollment transitioned earlier. The data alleviate this concern. The proportion of female students intending to pursue STEM fields is stable across cohorts, fluctuating without a systematic trend between 15% and

23%. Similarly, the share of students not continuing to tertiary education remains consistent, averaging approximately 65% across groups. This stability in baseline outcomes, combined with the balance in demographic covariates, suggests that the timing of the transition was not driven by pre-existing differences in student composition or academic preferences. While we rely on the formal event-study plots in Section 6 to test for parallel trends, this baseline balance lends credibility to our identification strategy.

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.

5 Empirical Strategy

To isolate the causal effect of transitioning to coeducation, we exploit the staggered adoption of the policy across schools between 2013 and 2019. Our identification strategy relies on comparing the evolution of post-secondary choices in schools that transitioned to coeducation (treated) against those that had not yet transitioned (control).

5.1 Identification Challenges in Staggered Designs

Standard Two-Way Fixed Effects (TWFE) models are well-documented to produce biased estimates in settings with staggered adoption and heterogeneous treatment effects (de Chaisemartin

Clément and D'Haultfœuille Xavier, 2020; Goodman-Bacon, 2021). In our context, heterogeneity is expected: the impact of coeducation likely evolves over time as the cumulative exposure to male peers increases. A static TWFE model would improperly average these dynamic effects, potentially weighting early-transition schools negatively against late-transition schools.

5.2 Estimation Strategy

To address these challenges, we employ the estimator proposed by Callaway and Sant'Anna (2021). This approach avoids "forbidden comparisons" by using only not-yet-treated units as the control group for each cohort. The core estimand is the Group-Time Average Treatment Effect ($ATT(g,t)$), which measures the treatment effect at time t for the cohort of schools that transitioned in year g:

$$ATT(g,t) = \mathbb{E}[Y_t - Y_{g-1}|G_g = 1] - \mathbb{E}[Y_t - Y_{g-1}|C = 1] \tag{1}$$

where Y_t is the outcome of interest (e.g., the proportion of female students enrolling in STEM), G_g denotes the group of schools treated in year g, and C denotes the valid comparison group (not-yet-treated schools).

To capture the dynamic evolution of the policy effect, we aggregate these group-time parameters into event-study coefficients (θ_e), where e represents the time relative to the transition year ($e = t - g$). The dynamic aggregation is given by:

$$\theta_e = \sum_g w_g ATT(g, g+e) \tag{2}$$

where w_g represents the sample weight of each cohort. This specification allows us to trace the causal path of coeducation from the year of adoption ($e = 0$) through subsequent years ($e > 0$), providing a direct test of the "dose-response" mechanism discussed in Section 3.

5.3 Identifying Assumptions

The validity of this design rests on the parallel trends assumption: that in the absence of the transition, the trends in STEM enrollment for treated schools would have evolved similarly to those of the not-yet-treated schools. The covariate balance established in Section 4 provides strong support for this assumption, as treated and control units are drawn from the same observable population. We formally test this assumption in Section 6 using the pre-treatment event-study coefficients (θ_e for $e < 0$).

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 4 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 4 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 4). 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 H. 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 H.1, H.2, H.3, H.4).

These robustness checks, fully detailed in Appendix H, 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.

6 Results

We present our findings in three parts. First, we estimate the aggregate impact of the transition to coeducation on female STEM participation. Second, we decompose this effect by the level

of the degree, revealing a crucial trade-off between the field of study and educational depth. Third, we explore heterogeneity across specific STEM disciplines.

6.1 The Horizontal Shift: Impact on STEM Enrollment

Table 4 (Column 1) presents the overall average treatment effect on the treated (ATT) for female enrollment in STEM fields. We find that the transition to a coeducational setting significantly increases the probability of choosing a STEM major by 6.43 percentage points ($p < 0.01$). Given the pre-treatment baseline of 16% (see Table 2), this corresponds to a substantial 40% increase in relative terms. This result confirms the "horizontal" hypothesis: the introduction of male peers effectively lowers the barriers to entry for women in traditionally male-dominated fields.

Figure 4 displays the event-study coefficients, tracing the dynamic evolution of this effect. Two key patterns emerge. First, the pre-treatment coefficients (periods $t-5$ to $t-1$) are statistically indistinguishable from zero. We formally test the parallel trends assumption using the Wald test proposed by Callaway and Sant'Anna (2021) and fail to reject the null hypothesis ($p = 0.71$), confirming the validity of our identification strategy.

Second, the treatment effect is dynamic. The impact is small and statistically insignificant in the year immediately following the transition ($t = 0$), but grows monotonically over time, becoming statistically significant by year three ($t = 3$) and peaking at 24.1 percentage points by year six. This gradual accumulation is consistent with a dosage mechanism: as the cohort of male peers grows and the coeducational culture stabilizes, the normative influence on female students' choices intensifies.

6.2 The Vertical Shift: The Quality-Quantity Trade-off

While the aggregate increase in STEM enrollment appears to be a policy success, decomposing the effect by degree type reveals a significant unintended consequence. As shown in Table 3, the transition to coeducation induces a substitution away from long-cycle professional degrees toward shorter-cycle technical options.

We observe a sharp decline in enrollment in four-year university bachelor's degrees ($\beta =$

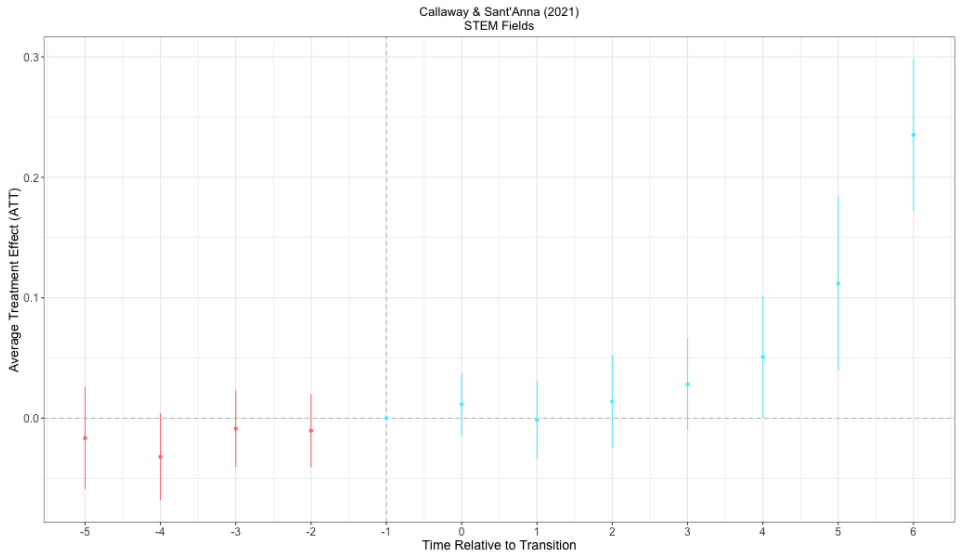


Figure 4: Dynamic Effects of Transition to Coeducation on Female Students' STEM Choices

-6.26 percentage points, $p < 0.01$). This decline is almost perfectly offset by a simultaneous increase in enrollment in short-cycle technological ($\beta = +4.66$ pp) and vocational/technical programs ($\beta = +2.05$ pp).

These findings provide strong empirical support for the "comparative advantage" framework outlined in Section 3. While female students are more likely to enter STEM fields in a co-educational setting, the heightened competitive pressure or altered peer dynamics appears to discourage them from the most academic rigorous university tracks. Instead, they divert into vocational STEM pathways, effectively trading "vertical" educational depth for "horizontal" field alignment.

Table 3: Effect on Educational Pathways (Vertical Shift)

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.

6.3 Heterogeneity by Field

Finally, we examine which specific disciplines drive the aggregate STEM increase. Table 4 reveals that the effect is not uniform. The growth is driven primarily by "Technology" majors ($\beta = +4.66$ pp, $p < 0.01$), which aligns with the increase in short-cycle degrees observed above. We also find a smaller but significant increase in Mathematics ($\beta = +0.65$ pp). However, we find no significant impact on "Hard Science" enrollment ($p > 0.10$). This heterogeneity further reinforces the vocational nature of the shift: the policy successfully encourages practical technical training but fails to close the gap in theoretical scientific research fields.

Table 4: 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: ATT estimated using the Callaway and Sant'Anna (2021) estimator. Standard errors in parentheses. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

7 Mechanisms and Validation

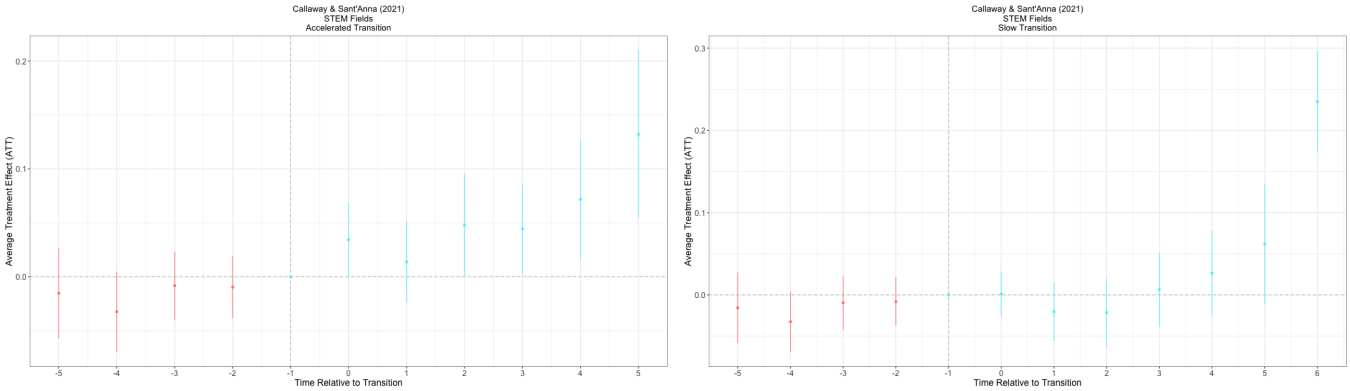
Our results establish that coeducation increases female STEM enrollment but shifts it toward vocational tracks. In this section, we test the mechanisms driving these results by exploiting variation in the intensity of the treatment and examining the reverse policy experiment.

7.1 Dose-Response: Speed of Transition

If the effect is driven by the normalization of mixed-gender environments, we should expect larger effects in schools that transitioned more rapidly. We classify schools as "Accelerated Transition" if the proportion of male students increased faster than the median rate.

Figure 5 presents the dynamic treatment effects for these two groups. The results indicate a clear dose-response relationship. In schools with an accelerated transition, the positive impact on STEM enrollment emerges quickly and reaches a higher magnitude (ATT = 5.73 pp, $p < 0.01$).

In contrast, schools with a slow transition show a delayed and smaller effect (ATT = 4.13 pp). This supports the hypothesis that the *intensity* of exposure to male peers is a key driver of the behavioral change.



(a) Accelerated Transition (b) Slow Transition

Figure 5: Dynamic Effects by Speed of Transition

7.2 Validation: The Asymmetric Effect in Male Schools

A central prediction of our theoretical framework (Section 3) is that the effect of coeducation depends on the incumbent gender norms. While introducing males into female schools normalizes STEM (positive horizontal effect), introducing females into formerly all-male schools may amplify stereotype threat (negative effect).

To test this, we estimate our model on the subset of schools that transitioned from single-sex *male* to coeducational settings. As shown in Figure 6, the results are strikingly different. For the small number of female students entering these historically male environments, the probability of choosing a STEM major *decreases* significantly after the transition (ATT = -15.8 pp, $p < 0.05$).

This asymmetry is critical. It suggests that "coeducation" is not a uniform treatment. When women enter a male-dominated culture, the competitive pressure and lack of critical mass deter STEM participation. When men enter a female-dominated culture, they disrupt the norms enough to encourage STEM entry (horizontal) but discourage high-stakes university competition (vertical).

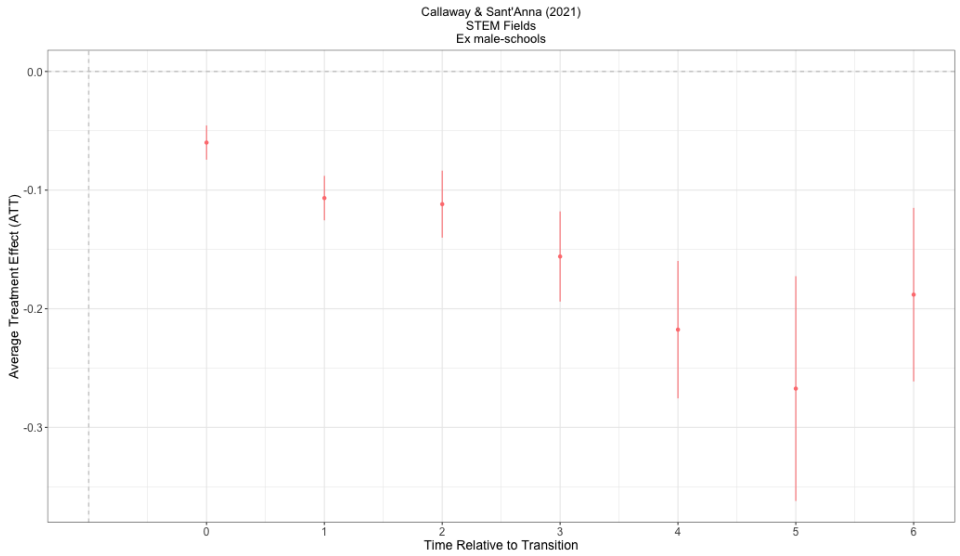


Figure 6: Validation: Effect of Transitioning *Male* Schools to Coeducation

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 5: 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 6: 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 7: 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:

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

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). $\hat{ATT}(g, g+r)$ 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 Callaway and Sant'Anna (2021) estimator, 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

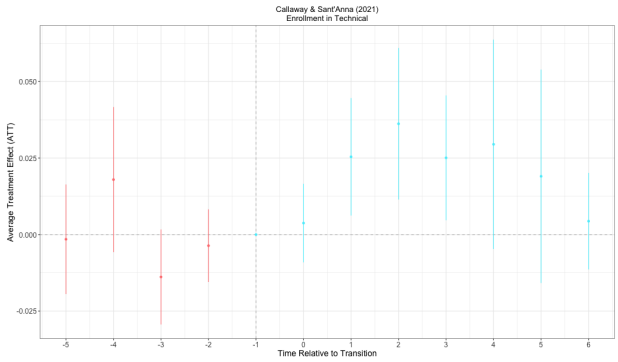

Figure 8: Technical Education

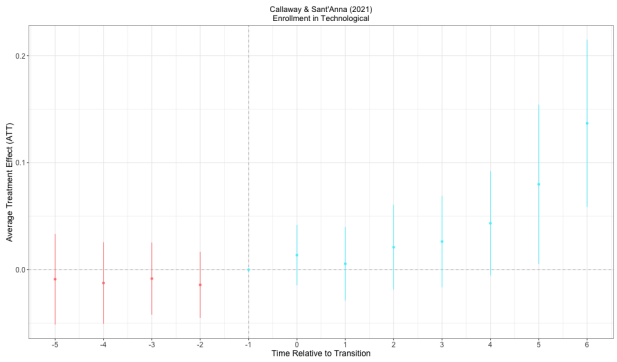

Figure 9: Technological Tertiary Education

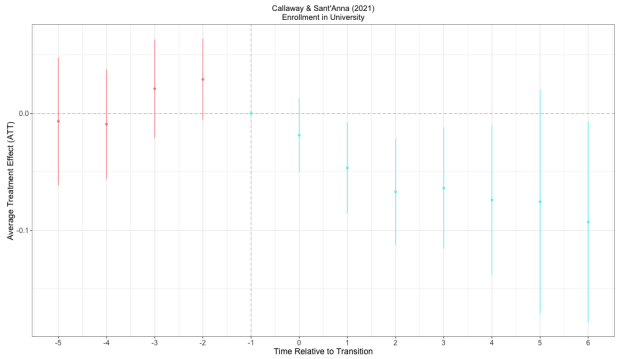

Figure 10: University Bachelor's Degree

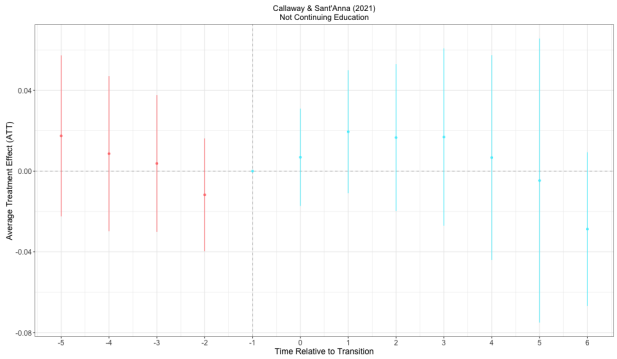

Figure 11: Not Continuing Education

Figure 12: Dynamic Effects of Transition to Coeducation (Summary)

F.2 Impact on Other Fields of Study

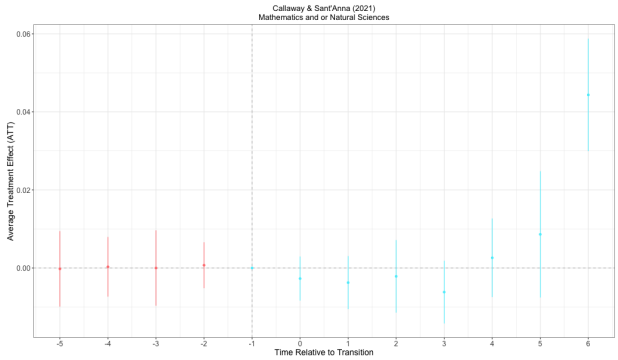

Figure 13: Math & Sciences

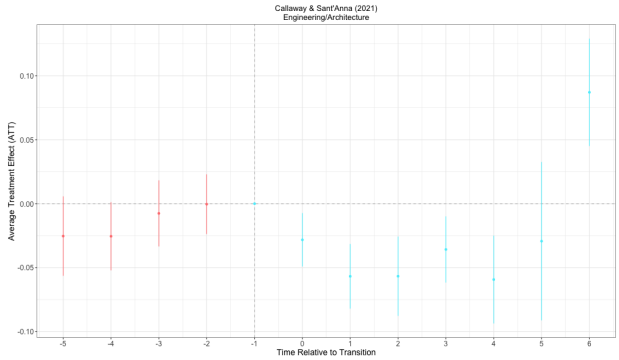

Figure 14: Eng. & Arch.

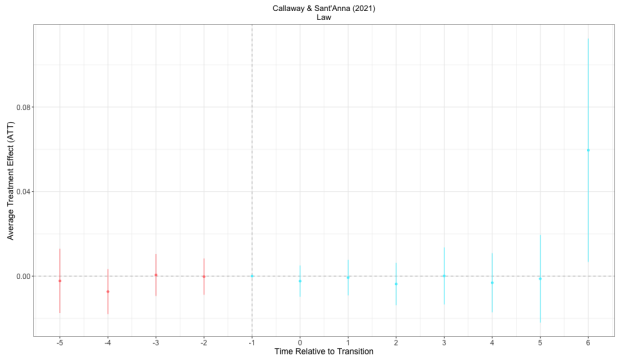

Figure 15: Law

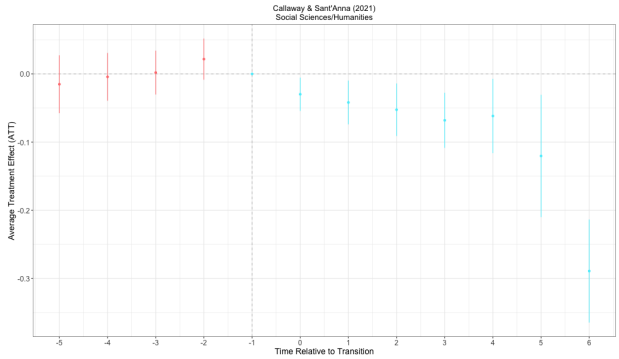

Figure 16: Soc. Sci. & Hum.

Figure 17: Dynamic Effects of Transition to Coeducation on Enrollment by Fields of Study

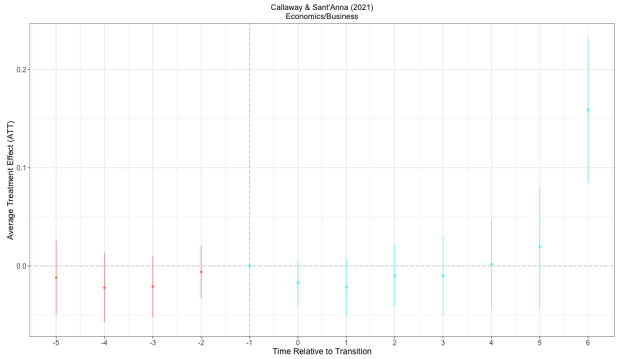

Figure 18: Econ. & Business

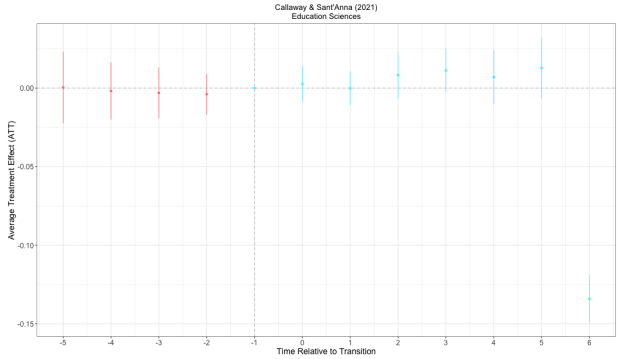

Figure 19: Education

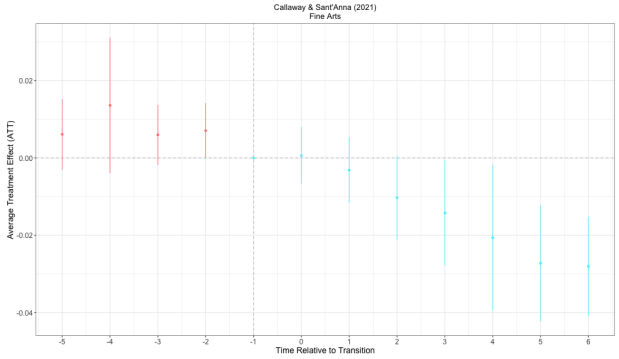

Figure 20: Fine Arts

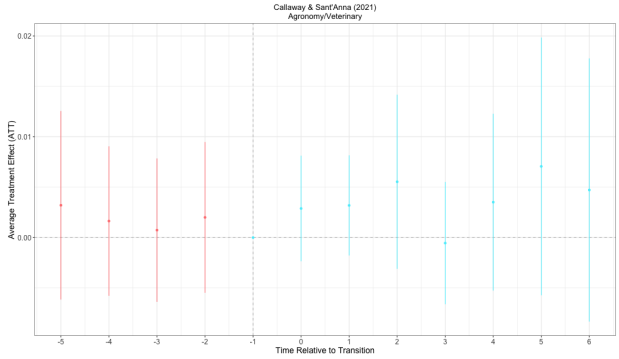

Figure 21: Agronomy & Vet.

Figure 22: Dynamic Effects of Transition to Coeducation on Enrollment by Fields of Study

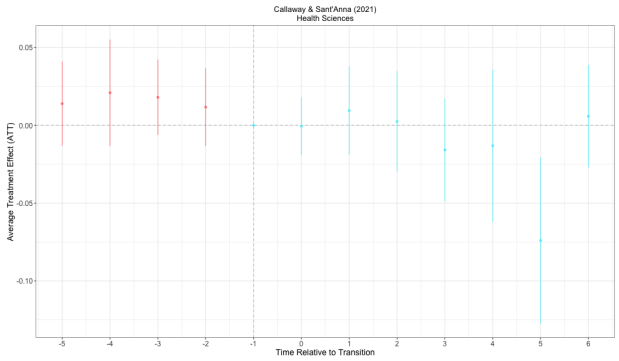

Figure 23: Health Sciences

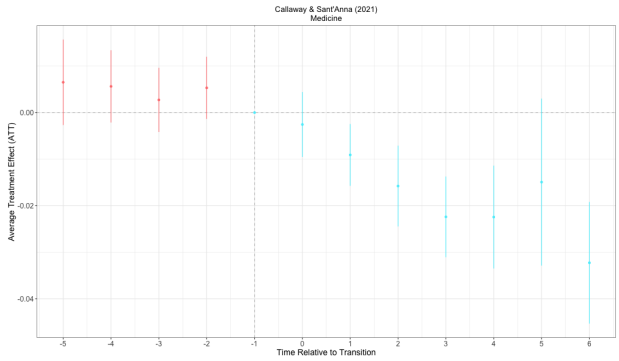

Figure 24: Medicine

Figure 25: Dynamic Effects of Transition to Coeducation on Enrollment by Fields of Study

G Heterogeneity Effect

G.1 Heterogeneity Impact on Other Fields of Study

Table 7 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 7: 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 16), which could reflect a similar dynamic as in Fine Arts (Appendix Figure 20) and Medicine (Appendix Figure 24), although the effect is less pronounced. The negative effect on Education Sciences (Appendix Figure 19), 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 13), Engineering/Architecture (Appendix Figure 14), Law (Appendix Figure 15), Economics/Business (Appendix Figure 18), Agronomy/Veterinary (Appendix Figure 21), and Health Sciences (Appendix Figure 23) 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.

H 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.

H.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 26 displays the dynamic effects of transitioning to coeducation on female students' STEM choices, using this never-treated group as the comparison.

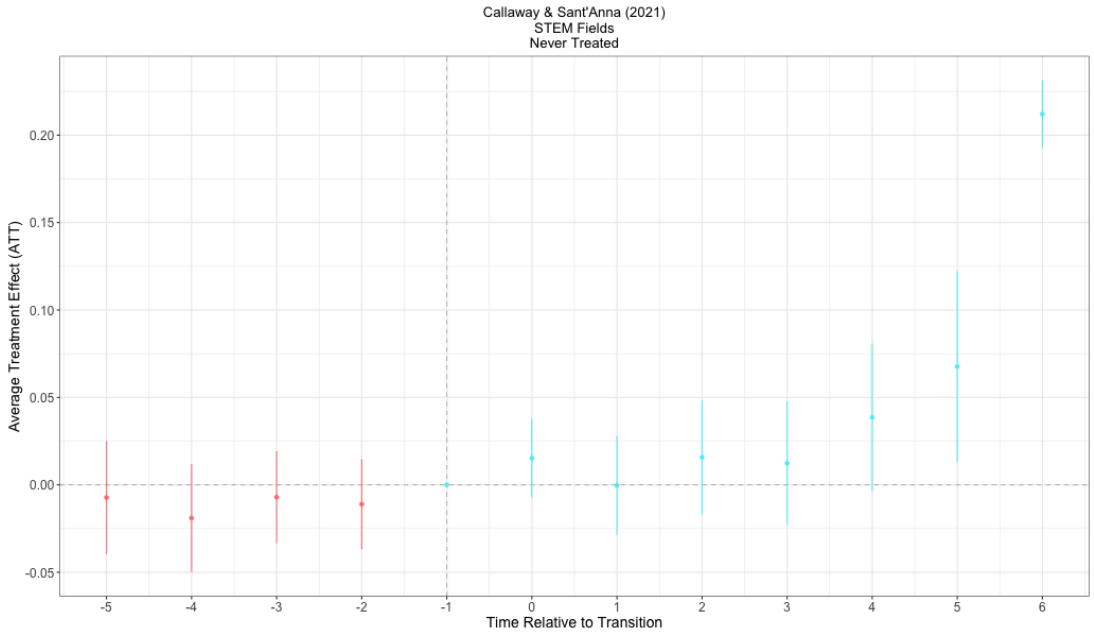

Figure 26: Dynamic Effects of Transition to Coeducation on Female Students' STEM Choices, Using Never-Treated Comparison Group

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 4). The dynamic patterns observed in Figure 26 are also comparable to those in Figure 4, 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.

H.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.

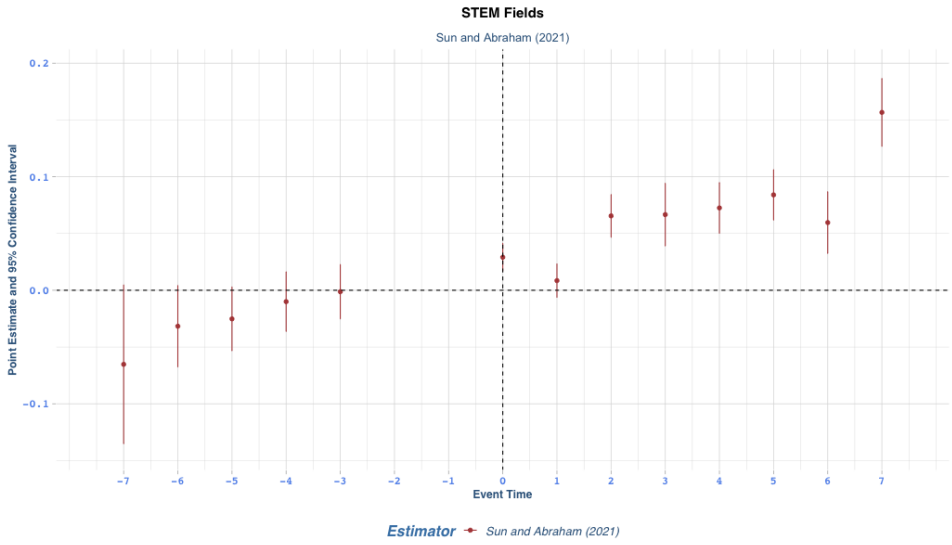

Figure 27: Dynamic Effects of Transition to Coeducation on Female Students' STEM Choices: Sun and Abraham (2021) Estimator

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 4), demonstrating the robustness of the effect size to different estimation approaches. Examining

the dynamic effects in Figure 27, 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.

H.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 28 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.

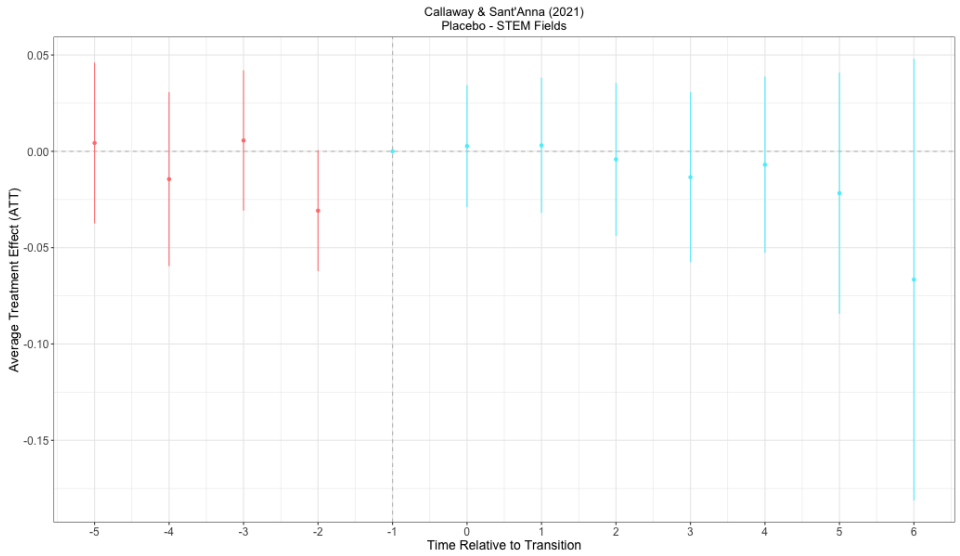

Figure 28: Dynamic Effects of Placebo Treatment on Female Students' STEM Choices

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.

H.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 6 presents the estimated dynamic effects of this transition.

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 4) 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.