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Gender gap in STEM pathways: the role of secondary curricula in a highly differentiated school system—the case of Chile

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Abstract

Background STEM fields are instrumental in increasing the technological and innovative capacity of the economy. As women are underrepresented in the STEM workforce, diverse strategies have been implemented to boost their preparedness and interest in these fields, including early exposure to academic and vocational STEM courses. Using the case of Chile's highly differentiated school system, this paper examines the role of secondary curricula on students' enrollment and persistence in STEM programs offered by vocational postsecondary institutions and universities. In doing so, we seek to identify whether exposure to STEM courses within the academic or vocational tracks translates into fewer gender differences in STEM higher education.

Results Our results reveal that upper-secondary tracks connected to STEM courses are positively associated with enrollment in STEM higher education and, to some degree, persistence. More specifically, exposure to STEM courses in the academic track is the most effective path to boost chances of enrolling in STEM university programs but has no connection to later persistence. In contrast, applied STEM courses within the vocational tracks perform better in the case of STEM programs in postsecondary vocational institutions both in enrollment and persistence. However, this STEM pipeline significantly amplifies gender gaps as males benefit more than women from early exposure to applied STEM courses. We also found that other indirect routes, such as enrolling in STEM university programs from the vocational track with applied STEM courses, boost female participation in these programs, helping reduce gender gaps.

Conclusions While secondary STEM courses attract more female students to STEM higher education, they alone are insufficient to achieve gender equality in STEM fields as gender gaps widen in the more effective routes. In highly differentiated school systems, policymakers and high school leaders should offer increased support to women interested in STEM studies and careers across all secondary tracks to boost female participation in STEM fields. At the same time, all high school students should be able to select both academic and applied STEM courses as a part of their non-mandatory curriculum.

Keywords Vocational education, Higher education, STEM pipeline, Gender differences

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Introduction

The global emphasis on promoting STEM-related courses (Science, Technology, Engineering, and Mathematics) has become a key priority in educational public policy. STEM fields are crucial in advancing technological capabilities and fostering innovation while serving as a pathway to enhanced social mobility. Extensive research indicates that pursuing majors in STEM fields leads to favorable early career outcomes, transcending students' social backgrounds (Sullivan et al., 2018; Wolniak & Engberg, 2019). Therefore, ensuring equal opportunities for both men and women to participate in STEM fields becomes imperative to establishing a more gender-equitable, innovative, and prosperous society (UNESCO, 2017). However, despite these efforts, a persistent gender gap and male dominance in STEM prevails globally, cutting across regions, countries, educational levels, and the labor market (OECD, 2018; UNESCO, 2017).

The underrepresentation of women in STEM at various stages, including secondary school, postsecondary education, and careers, is a complex issue influenced by multiple interdependent factors (Avolio et al., 2020). In secondary school, girls often encounter traditional gender role beliefs and stereotypes that discourage their interest and confidence in STEM subjects (Chan, 2022). Postsecondary education experiences also play a role, as a lack of representation and a perceived sense of not belonging contribute to the gender disparity in STEM fields (Blackburn, 2017; Cheryan et al., 2017). In the labor market, biases, workplace culture, and work–life balance issues further influence women's underrepresentation in STEM careers (Wynn, 2020).

Scholars commonly employ the metaphor of a "leaking pipeline" to illustrate the continuous decrease in the proportion of women in STEM fields from elementary school to initial employment and professional career stages (Gottfried & Bozick, 2016; Griffith et al., 2016; Makarova et al., 2016). The premise of the STEM pipeline metaphor is that people build interest in these fields early on, enroll in advanced STEM courses in high school, continue with STEM studies at the postsecondary level, and end with a degree and career in STEM (Maltese & Tai, 2011; Metcalf, 2010). According to this account, secondary school curricula is instrumental in predicting whether students will pursue postsecondary STEM studies and a STEM career (e.g., Chang et al., 2023; Kelly, 2023; McKinney et al., 2021).

Extensive research has explored how secondary school curricula influence postsecondary STEM outcomes and the resulting gender gaps. Studies have examined the effect of selecting both conventional academic STEM courses, such as mathematics and science (Darolia et al., 2020; De Philippis, 2021; Jacob et al., 2020Wan, 2013), and applied STEM courses within vocational curricula in high schools (Gottfried et al., 2016; Gottfried & Plasman, 2018; Xu & Backes, 2023). However, since these studies have examined academic STEM or applied STEM courses separately, there is a research gap in understanding the relative effect of these courses on gender differences in STEM outcomes at the postsecondary level. At the same time, this literature refers exclusively to developed countries, overlooking other contexts characterized by highly differentiated school systems, where subject selection is less prevalent and the secondary curricula remain rigid, with a clear distinction between vocational education (VE) and academic education (AE) tracks.

Chile's highly differentiated school system presents a compelling case to examine the role of secondary school curricula on later STEM outcomes from a pathway perspective. Although there is a clear distinction between AE and VE, both tracks offer viable options for accessing higher education institutions and provide opportunities for students to delve into STEM fields. In AE, advanced science and mathematics courses are available in most high schools, while in VE, multiple programs linked to diverse economic sectors, like electricity, metalworking, information technology, and chemistry, expose students to STEM-related content and practical skills.

Purpose of the study

Our paper focuses on the case of Chile to explore the relationship between curriculum tracking at the upper-secondary level and enrollment and persistence in STEM higher education programs, with a specific focus on gender differences. In doing so, we aim to investigate whether exposure to STEM courses during upper-secondary education, in either VE or AE, diminishes gender differences in STEM programs offered by vocational postsecondary institutions or universities. By contrasting academic and vocational routes, STEM and non-STEM, our study moves beyond the traditional STEM pipeline metaphor and adopts a pathway perspective, highlighting that there are multiple entry points into a STEM career, especially for women and other underrepresented groups.

Our research questions are as follows:

- To what extent does the secondary school curriculum predict enrollment and persistence in STEM higher education programs, both in vocational postsecondary institutions and universities?
- How does exposure to STEM courses during upper-secondary education, in either VE or AE, influence gender differences in STEM program enrollment and persistence at vocational postsecondary institutions or universities?

Background

Secondary school curriculum and gender disparities in postsecondary STEM programs

Worldwide, VE at the upper-secondary level has evolved significantly, emphasizing a viable path to higher education (and not merely a direct route to the labor market).

Thus, over recent decades, scholars have directed considerable attention to the relative value of this type of education in student postsecondary trajectories. Overall, research findings are not promising, as the VE tends to reduce the likelihood of enrollment and success in higher education (Holm et al., 2013; Malamud & Pop-Eleches, 2011; Ollikainen & Karhunen, 2021; Tieben, 2020). However, there is evidence that the relationship between VE and postsecondary outcomes broadly relates to the types of programs students select. In the United States, where Career and Technical Education (CTE) is the primary source of VE, applied STEM-CTE courses are positively associated not only with postsecondary enrollment overall, but also with enrollment in baccalaureate programs. Conversely, concentrating in other fields is inversely related to access to any postsecondary program (Giani, 2019). Moreover, among students entering four-year colleges, those who took STEM-related courses in high school are more likely to select a major in a technology and engineering fields over a non-STEM major (Gottfried & Bozick, 2016; Gottfried & Plasman, 2018), obtain a credential in these fields (Plasman et al., 2019), and having a STEM job during college (Gottfried et al., 2023). However, while this literature has helped establish a positive relationship between high school CTE and a later step in the STEM pipeline, it does not present causal effects as it does not account for student self-selection into these courses.

Considering the present inequalities in the STEM workforce, researchers also have examined how the rise of STEM-CTE courses has affected the participation of students from different backgrounds. There has been particular interest in the impact of these courses in improving the representation of women in advanced STEM coursework. Some studies reveal positive findings for specific STEM pathways, indicating that participation in engineering CTE coursework encourages completion of a degree in the same field, with a clear difference across gender, as women benefited more than men (Gottfried & Plasman, 2018). Conversely, other studies conclude that although applied STEM course completion in high school is associated with an increased probability of enrolling and obtaining a postsecondary credential in STEM fields, these CTE courses tend to reinforce gender imbalances (Dougherty & Harbaugh Macdonald, 2019; Xu & Backes, 2023). Researchers that have focused on the impact of accessing traditional academic STEM courses on postsecondary enrollment, looking at gender differences, have arrived at a similar conclusion. They suggest that female and underrepresented minority students are less responsive to changes in access to STEM courses in high school than White males (De Philippis, 2021; Darolia et al., 2020). Mixed effects have also been found in studies examining the impact of attending STEM-focused public schools in the United States. While several studies suggest that women may benefit from attending these schools (Bicer et al., 2018; Means et al., 2018, 2021), other studies have found no differences in STEM interest (Bottia et al., 2018) or achievement (Saw, 2019) among students enrolled in STEM-focused schools in this country.

In the European continent, the findings regarding the effect of participating in specialized or advanced school STEM courses have also been somewhat mixed. For example, in England, Broecke (2013) found that although a curricular reform improved the learning intensity in sciences in high school, this improvement significantly increased the chances of pursuing a STEM degree in higher education only for men. Conversely, in Germany, there is evidence that making math and science courses compulsory for all secondary students through a curricular reform did not change the share of men completing STEM degrees, but reduced the share of women graduating from STEM programs (Biewen & Schwerter, 2022). Lastly, a cross-country analysis covering Germany, Ireland, and Scotland indicated that more STEM subjects at school predict entering related fields within higher education to the same extent for men and women. Thus, it concluded that educational policies that encourage females to study science subjects within upper-secondary education appear necessary but insufficient to ensure gender equality in the progression to STEM fields (Jacob et al., 2020).

Efforts to expand postsecondary STEM outcomes for females through early exposure to STEM courses assume that the trajectories in these fields are linear and one-way. Scholars make the same assumption when constructing their research around the "leaky pipeline" metaphor, which provides a means to effectively understand why some women are lost to STEM as they advance through the educational system (Makarova et al., 2016). However, during and after upper-secondary school, students not only change from a STEM trajectory to a non-STEM pathway but also vice versa. Indeed, there are multiple pathways that women or other minorities take to exit and re-enter STEM fields (Fealing et al., 2015; Lykkegaard & Ulriksen, 2019; Vitores & Gil-Juárez, 2016). Research has rendered various trajectories visible when studying participation in these fields, suggesting that although there is no single pathway into STEM, self-driven interest is a significant factor in STEM persistence, especially for males.

Conversely, for women, the development of STEM interests largely depends on support from others, such as their teachers and faculty (Maltese & Cooper, 2017; Verdín, 2021). Other factors identified by studies that have adopted a holistic view of inequality in STEM participation include high school mathematics achievement, sense of mathematics self-efficacy, and exposure to mathematics and science courses. However, these factors are notably more relevant for four-year college-bound students than their counterparts heading to two-year colleges (Wang, 2013).

In Chile, school counseling policies are generally underdeveloped, leading to poor career decisions in the upper-secondary levels when students choose between VE or AE, as well as their program of study in higher education (Farías, 2014). In this sense, vocational sub-tracks encompassing technical courses and various advanced academic STEM programs offer an opportunity to build interest in STEM fields early on, thus influencing students' career decision-making. In addition, prior research has identified that although VE has a negative effect in terms of enrolling and persistence in higher education at the aggregate level, graduate students from VE-sub-tracks who continue in postsecondary VE programs directly related to their previous studies perform better than students from AE (Farías & Sevilla, 2015). However, a mixed-methods study has also suggested that in these male-dominated vocational sub-tracks related to STEM fields, micro-practices and discourses that reproduce and amplify gender stereotype beliefs are still critical barriers for women to engage in the STEM pipeline (Sevilla et al., 2019). Along the same line, a recent study found that enrolling in a VE-STEM-focused program in secondary school has limited positive effects on females' career development in postsecondary vocational institutions: It can boost their self-efficacy but may not affect their career expectations in STEM fields (Sevilla & Snodgrass Rangel, 2023).

The Chilean education system

The Chilean School System is highly differentiated, with about 37% of students enrolled in vocational education. At the secondary level, after two years of a common core (grades 9 and 10; (*International Standard Classification of Education*, ISCED 2), the curriculum is split into academic and vocational education (AE and VE) (grades 11 and 12, ISCED 3). VE includes numerous programs of study (around 35) determined nationally and clustered into 15 economic sectors. Conversely, AE encompasses a unique program of study, focusing on general subjects (mathematics, sciences, and language).

The curricula of VE programs are designed around the primary technical and foundational skill needs of a specific industry sector and combine preparation for initial employment and further studies. Predominantly, vocational sub-tracks in sectors related to electricity, metalworking, information technology, and chemistry involve courses (e.g., instrumental analysis techniques, electrical project development, network operating systems) that provide students with STEM-related skills opportunities by incorporating practical vocational experiences and hands-on learning. These VE-STEM sub-tracks concentrate about 40% of the total student population in VE and are male-dominated, with female enrollments constituting only 16.5% of this population. Contrarily, in VE-non-STEM sub-tracks, there is a gender imbalance in the opposite direction, with female enrollments accounting for 66% of the student population.

In the AE track, students have the option to complement their mandatory curriculum with advanced specialized science and mathematics courses, such as algebra, statistics, specific physics, and geometry. The availability and contents of these academic STEM courses vary across high schools and are not accessible to vocational students (even in comprehensive high schools) as VE programs of study only include compulsory courses in the related industry sector. About 30% of AE students take these academic STEM courses, which, unlike the VE-STEM sub-track, exhibit a balanced composition regarding students' gender (49.4% male vs 50.6% females).

At the postsecondary level, the Chilean education system comprises universities and postsecondary vocational institutions that differ in the type of programs they offer students. While universities mainly focus on bachelor's degrees (ISCED 6) and postgraduate degree programs (ISCED 7 and 8), vocational institutions focus on technical/professional programs of diverse lengths between 2 and 4 years (ISCED 5). Graduates from both AE and VE tracks are eligible for these two types of higher education institutions. However, universities require a mandatory entrance examination test based on preceding study in secondary general subjects. In contrast, postsecondary vocational institutions have open-enrollment policies, being the secondary diploma the only access requirement. The academic selective admission policy of the universities results in the disproportionate enrollment of secondary VE graduates in postsecondary vocational institutions in contrast to AE graduates. Reports indicate that in 2017, close to 70% of VE graduates who continued higher education studies enrolled in vocational postsecondary institutions, while only 25% of students from academic backgrounds opted for the same path (Mineduc, 2020). In both higher education institutions, students enroll directly in their selected program of study in a one-step decision: choosing a program and type of institution simultaneously. Notably, in STEM fields, female enrollments constitute 25% of the student population in the university sector, while in the postsecondary vocational sector, this percentage is considerably lower, only 16%. Over recent times, there have been no significant variations in these proportions (Field & Guez, 2018).

Method

Data

To investigate the relationship between upper-secondary tracks and students' enrollment and persistence after the first year in STEM higher education programs, we utilized extensive panel data by merging various administrative records obtained from the Chilean Ministry of Education. We tracked the cohort of students who entered 11th grade in 2014, whether in AE or VE and successfully completed high school by 2015, followed them 2 years afterward to capture enrollment and first-year persistence. We linked this panel data with academic and socioeconomic student information from the Chilean Education Quality Assessment System (SIMCE), which assesses curricular content across different subjects and grades. Specifically, we utilized SIMCE data from 2013 when students were in 10th grade, prior to the allocation of upper-secondary tracks between VE and AE, which takes place in grades 11th and 12th.

The panel data provided information on the specific program of study for students in both high school and higher education. Within each main upper-secondary track (VE and AE), we distinguished students enrolled in STEM-related programs from those in other programs. In VE, STEM-related programs referred to those aiming to qualify students for occupations requiring STEM skills, as defined by UNESCO (2020). We labeled VE secondary students selecting a STEM-related program as VE-STEM, while those in non-STEM programs were labeled as VE-non-STEM. Similarly, we distinguished students in AE, categorizing them as either AE-STEM (taking advanced academic courses in STEM) or AE-non-STEM (not taking advanced academic courses in STEM). At the postsecondary level, we defined STEM programs offered in university or postsecondary vocational institutions as those grouped under three of the 11 broad groups of ISCED (UNESCO-UIS 2012): natural sciences and mathematics, information and communication technology, engineering, manufacturing, and construction. Based on this definition, we classified programs of study in each type of higher education institution (i.e., universities and vocational institutions) into STEM and non-STEM.

Analytic samples

Our initial analytic sample comprises 170,497 students of the 2014 cohort from 11th grade enrolled in public or private-subsidized high schools. We did not include students from private-non-subsidized schools where VE is almost nonexistent. In addition, we removed cases without academic and socioeconomic student information from SIMCE (24,881 students). These missing cases belong to students who did not take the SIMCE test in 2013 in 10th grade, mainly those from small rural schools or students who repeated a grade. Thus, the results of this analysis should not be extrapolated to these specific groups of students.

We use propensity score matching (PSM) to approximate a causal relationship between upper-secondary tracks and enrollment and persistence in postsecondary STEM programs of study (we discuss this strategy in detail in the next section). Using PSM as a pre-processing strategy also diminishes our analytic sample size. To maximize comparability between AE and VE students regarding PSM, we excluded 19,988 cases (not present in the region of common support) from our analysis. Thus, our final analytic sample consists of 125,628 observations that were then used to estimate the effects of upper-secondary tracks on students' enrollment in STEM higher education programs. From this sample, to estimate persistence in STEM programs, we select cases of first-year students in STEM programs in postsecondary vocational (17,688 students) and university institutions (12,689 students).

To estimate the PSM model, we used the following student-level covariates: sex (female = 1, otherwise = 0), socioeconomic status (SES), the logarithm of per capita family income (Ln Income per capita), father's education, mother's education, attendance in 10th grade, GPA in 10th grade, SIMCE language test score in 10th grade (SIMCE Language), SIMCE math test score in 10th grade (SIMCE Math). These variables (except for sex) were standardized to have a mean of 0 and a standard deviation of 1. Additionally, we included school-level covariates such as school socioeconomic status (school SES) and rural school indicator (rural = 1, otherwise = 0) in the models.

Table 1 displays the basic descriptive statistics for the final analytic sample and differentiating by track. Students from the AE, representing 51% of the sample, exhibit higher socioeconomic and academic outcomes and greater enrollment rates in higher education (86%). Around 40% were exposed to advanced science and mathematics courses (the AE-STEM sub-track). Conversely, the VE main track includes less affluent students with lower academic performance, and only 60% enroll in higher education. In this case, 37% attended STEM-related study programs (the VE-STEM sub-track). Of the total student sample, less than 15% and 10% enrolled in STEM programs in postsecondary vocational and university institutions, respectively. Although among students from the VE-STEM sub-track enrollment in postsecondary vocational STEM programs rose to 37%, in university STEM programs, it rose to 25% among those from the AE-STEM upper-secondary sub-track.

Table 1 Descriptive statistics by upper-secondary track

Variables	Entire sample (Mean)	Sub-sample AE			Sub-sample VE		
		Total (Mean)	STEM (Mean)	Non-STEM (Mean)	Total (Mean)	STEM (Mean)	Non-STEM (Mean)
Students characteristics							
Women = 1; else = 0	0.52	0.55	0.51	0.59	0.49	0.17	0.69
Socioeconomic status (St)	− 0.38	0.01	0.14	− 0.08	− 0.78	− 0.70	− 0.82
Ln income per capita (St)	10.99	11.17	11.23	11.13	10.80	10.84	10.77
Father's education (St)	− 0.20	0.07	0.16	0.01	− 0.47	− 0.41	− 0.50
Mother's education (St)	− 0.19	0.08	0.16	0.01	− 0.46	− 0.41	− 0.50
Attendance 10th grade (St)	0.10	0.16	0.25	0.10	0.03	0.10	− 0.01
GPA 10th grade (St)	0.00	0.21	0.44	0.03	− 0.20	− 0.25	− 0.17
SIMCE language (St)	− 0.08	0.18	0.29	0.10	− 0.34	− 0.35	− 0.34
SIMCE math (St)	− 0.12	0.16	0.45	− 0.03	− 0.42	− 0.28	− 0.48
Expected higher education = 1; else = 0	0.91	0.96	0.98	0.95	0.85	0.84	0.86
Enrollment in Higher Education = 1; else = 1	0.73	0.86	0.90	0.83	0.60	0.59	0.60
Enrollment in VE-STEM = 1; else = 0	0.14	0.10	0.11	0.10	0.18	0.36	0.07
Enrollment in university-STEM = 1; else = 0	0.10	0.16	0.25	0.09	0.04	0.07	0.03
School characteristics							
School SES (St)	− 0.32	0.00	0.10	− 0.07	− 0.65	− 0.60	− 0.69
Rural school = 1; else = 0	0.03	0.02	0.02	0.02	0.05	0.05	0.05
Public school = 1; else = 0	0.38	0.35	0.25	0.42	0.40	0.39	0.41
Subsidized private school = 1; else = 0	0.62	0.65	0.75	0.58	0.60	0.61	0.59
Number of observations	125,628	63,561	25,956	37,605	62,067	22,892	39,175

High school graduates sample

VE = vocational education; AE = academic education; ln income per capita = logarithm of the family income per capita; St indicates that the variable was standardized to a mean of 0 and a standard deviation of 1

Analytical strategy

Our main goal is to understand the effect of upper-secondary tracks on students' enrollment and persistence in postsecondary STEM programs. However, the educational choice between main tracks in high school (AE and VE) is not random but likely associated with other observable and unobservable variables such as socioeconomic status, perceived abilities, and cultural family values, among others. At the same time, these variables may also be associated with enrollment and persistence in STEM higher education, making it difficult to isolate the effect of the upper-secondary track from other possible factors affecting the outcome of interest. Thus, our analytical approach relies on applying PSM as a pre-processing strategy before estimating our central models of enrollment and persistence to reduce selection bias to the best our data allow. Accordingly, we proceed in three steps. First, we apply PSM and compute PSM weights to each observation to maximize comparability between students attending VE and those attending AE. Second, after ensuring comparability, we conduct multinomial logistic models to estimate the effect of upper-secondary tracks on students' enrollment and persistence in STEM programs. Lastly, we assess the matching models' susceptibility to confounding factors omission.

Step 1: propensity score matching

We used PSM, as developed by Rosenbaum and Rubin (Rosenbaum & Rubin, 1983; Rubin, 1974, 1980), to reduce selection bias and obtain plausible estimates of causal effects. PSM is defined as the conditional probability of selection into treatment given a set of observed pre-treatment characteristics. By using PSM, we can establish a comparison group to simulate and estimate the counterfactual outcomes of the treatment group (Rubin, 1974). Given pre-treatment characteristics, this strategy assumes that potential treatment outcomes are independent of treatment assignment.

To estimate the propensity scores for selecting VE—the dichotomous treatment variable in this study—we conducted a standard logistic regression that uses student data produced only before the choice between AE and VE. Therefore, the PSM is not affected by the treatment. The model used is the following:

$$ln\left(\frac{\mathrm{VE_i}}{1-\mathrm{VE_i}}\right) = \beta_0 + \beta_1 S_i + \beta_2 H_i + \beta_3 D_i + \varepsilon_i, \quad (1)$$

where $\mathrm{VE_i}$ is the estimated propensity score for student i, β_0 through β_3 are estimated coefficients, S, H, and D are vectors of observed students' high school and district characteristics, and ε_i denotes a random error term that is logistically distributed. After estimating each student's propensity score, we equated the treatment and control group by combining the Kernel and the nearest-neighbor matching techniques. This strategy allows us to build a virtual control group using more information, as we rely on an averaged combination of individuals rather than just one individual as a control. We set a propensity score distance (caliper) of 0.0001 and a maximum of 10 cases within this distance, providing more weight to individuals with a propensity score closer to the matched case (bi-weight kernel algorithm). As observations in the control group could have different weights, we re-weighted observations by the sum of all weights in all cases. Moreover, to minimize the possibility of poor matches, we constrain the cases to those in the region of common support where distributions of the propensity score for treatment and control groups overlap (Caliendo & Kopeinig, 2008). Therefore, of the valid cases of the 2014 cohort of students, we removed 19,988 cases not present in the common support region, as already mentioned.

After the matching process, we used two approaches to assess the balance between the control and treatment groups. The first is plotting the propensity score distribution of both groups before and after the matching process (Dehejia, 2005). As observed in Fig. 1, there was an almost perfect match between the control and treatment groups, indicating an effective matching process. The second approach compared the bias percentage before and after the matching procedure. If treatment and control groups are balanced, bias will be considerably reduced after the matching. Table 2 shows that the bias percentage was largely reduced for all key variables and remains below 10% for each variable. Finally, following Reardon (2010), we included the student-level covariates used in the matching process as control variables in the multinomial logistic models to account for any remaining differences. These covariates included sex, socioeconomic status (SES), family income per capita, father's and mother's education, attendance in 10th grade, GPA in 10th grade, and SIMCE test scores in math and language.

Step 2: multinomial logistic regression models

We conducted a series of multinomial logistic models (Wooldridge, 2002) to estimate the effect of the upper-secondary tracks on students' enrollment and persistence in STEM programs. This modeling choice is justified by the distinctive characteristic of the Chilean higher education system, where students make a single decision to choose both the institution and program they wish to pursue. In this straightforward process, students directly enroll in their selected program of study, which involves deciding on both the specific program and the higher education institution, whether it is a postsecondary vocational school or a university. Models were weighted by PSM to deal with selection bias due to self-selection into

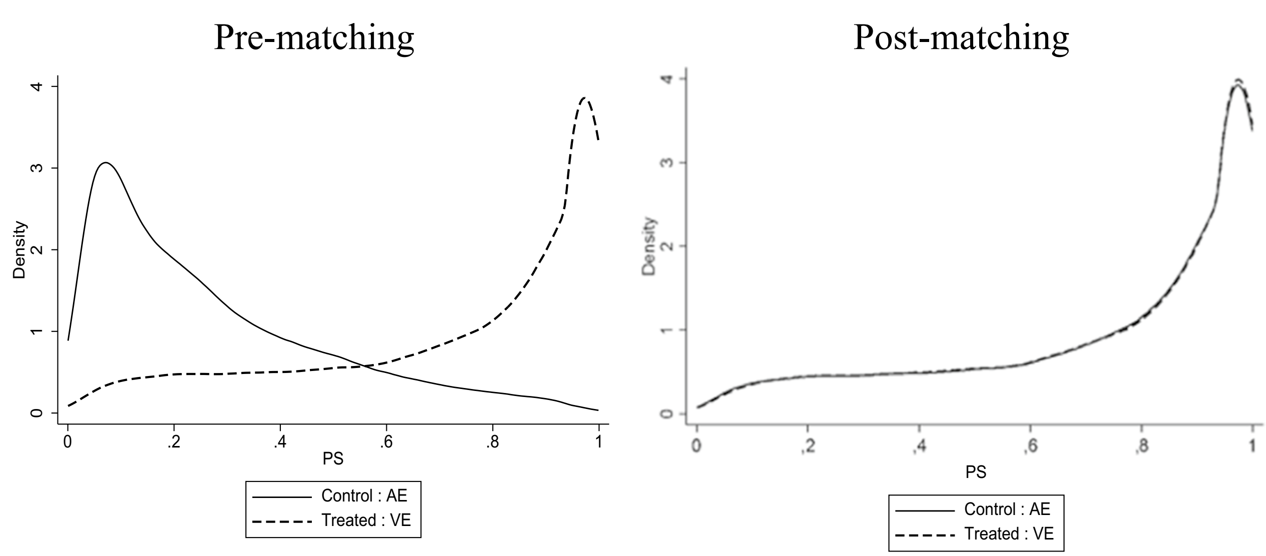

Fig. 1 Assessing balance. Propensity score distribution between treatment and control groups, pre-matching and post-matching situation

Table 2 Percentage bias before and after matching procedure

Variable	Status	Treated	Control	% Bias	% Reduced bias
Women	Unmatched	0.484	0.547	− 12.7	88.5
	Matched	0.485	0.478	1.5	
Socioeconomic status (St)	Unmatched	0.750	0.714	3.3	− 10.7
	Matched	0.745	0.784	− 3.7	
Ln income per capita (St)	Unmatched	10.794	11.273	− 69.4	97.2
	Matched	10.797	10.783	1.9	
Father's education (St)	Unmatched	− 0.480	0.175	− 74.2	96.5
	Matched	− 0.476	− 0.499	2.6	
Mother's education (St)	Unmatched	− 0.479	0.180	− 74.3	95.2
	Matched	− 0.475	− 0.507	3.5	
Attendance 10th grade (St)	Unmatched	− 0.041	0.125	− 17.8	83.0
	Matched	− 0.041	− 0.013	− 3.0	
GPA 10th grade (St)	Unmatched	− 0.292	0.184	− 50.8	98.3
	Matched	− 0.288	− 0.280	− 0.9	
SIMCE language (St)	Unmatched	− 0.393	0.224	− 66.7	97.8
	Matched	− 0.389	− 0.376	− 1.5	
SIMCE math (St)	Unmatched	− 0.465	0.227	− 77.6	99.4
	Matched	− 0.462	− 0.466	0.5	
School SES (St)	Unmatched	− 0.665	0.155	− 151.6	92.3
	Matched	− 0.660	− 0.723	9.6	
Rural school	Unmatched	0.052	0.017	19.1	74.7
	Matched	0.052	0.060	− 4.8	

Ln income per capita = Logarithm of the family income per capita; St indicates that the variable was standardized to a mean of 0 and a standard deviation of 1

the treatment (secondary VE as the main track). As we were particularly interested in understanding how this effect differs for female and male students, we added to the baseline models an interaction term between the track chosen in high school and gender.

For enrolling in STEM programs—our first outcome—we differentiated between programs (STEM and non-STEM) delivered in postsecondary VE and universities, given the different admission mechanisms used in these institutions (open vs. more selective enrollment). Also, enrolling in higher education and selecting among STEM and non-STEM programs was modeled as a one-time decision, as students enter directly into their chosen programs in the Chilean higher education system. Thus, we used a categorical variable with five categories indicating enrollment in: VE-STEM, VE-non-STEM, University-STEM, University-non-STEM, and not enrolled in higher education as the omitted reference category. The specification used is the following:

$$ln\left(\frac{Pr\left(Y_i=j\right)}{Pr(Y_i=4)}\right)=\beta_0+\beta_1\text{VE}+\beta_2(\text{VE}\times\text{Women})+X\prime\gamma_x+\varepsilon_i, \quad (2)$$

where VE is the treatment, (VE × women) is an interaction term that captures the effect of VE on the enrollment gender gap in the path to postsecondary programs. If enrolling in VE in secondary education reduces this gap, then the coefficient of this interaction should be positive and statically significant when the likelihood of enrolling in different programs for higher education is predicted. Finally, a vector of individual student characteristics was included to control for differences in the treatment estimations in (1). To identify whether the exposure to either academic or vocational STEM courses translates into less gender difference in postsecondary STEM programs, we also conducted (2) breaking down the treatment and control groups into STEM and non-STEM. Therefore, we differentiated between VE-STEM and VE-non-STEM and between AE-STEM and AE-non-STEM. This distinction allowed us to identify pipeline STEM vocational or academic routes from high school to higher education.

For persistence in postsecondary STEM programs in the second year, we used a similar specification to (2) for three possible pathways: persisting in the initially chosen STEM program, switching to another non-STEM program, and leaving higher education. A separate multinomial logistic model for students in postsecondary VE-STEM and University-STEM was undertaken to demonstrate the different potential effects of vocational education at the secondary level in persistence depending on the type of program. All estimations accounted for the inverse probability of enrolling in the respective STEM program.

Step 3: sensitivity analysis

The assumption known as conditional independence (CIA) must be tested to ensure that the matching model is supported by potential unobserved covariates that might significantly influence the selection into treatment and treatment outcomes. We conducted the Mantel–Haenszel test model (Mantel & Haenszel, 1959) to ensure this assumption and check the robustness of our results estimates. Similar approaches have been used in econometric literature (Becker & Caliendo, 2007) and educational research to increase the confidence that empirical estimations represent a causal effect (Alcott, 2017; Alvarado & Muniz, 2018).

The Mantel–Haenszel test indicates how strong an unobserved dichotomous variable's influence would need to be to undermine the results of a given model (Mantel & Haenszel, 1959). Specifically, we ran the Mantel–Haenszel test using the mhbounds test in Stata, using aggregate outcomes for enrollment and persistence in higher education as dichotomous variables. In addition, to further check our estimations, we performed individual tests for each possible outcome in enrolling in higher education (VE-STEM, University-STEM) and for persistence in the two types of STEM programs (VE-STEM and University-STEM).

Results and discussion

Enrollment in STEM higher education programs

Table 3 summarizes the results of the baseline multinomial logistic models weighted by PSM estimated to examine the upper-secondary tracks' effect on different enrollment pathways (models are shown in additional files). We present the results in terms of average marginal effects (AMEs), which can be interpreted as differences across upper-secondary tracks in the probability of pursuing each pathway to higher education enrollment. The upper part of the table shows the AMEs of enrolling in VE instead of AE. The bottom part presents the AMEs of these tracks breaking down into STEM and non-STEM. Finally, we use AE-non-STEM as the base of comparison, the sub-track most taken by students at the upper-secondary level.

Our results show that the secondary school curriculum is instrumental in predicting pathways to enrollment in higher education, including those leading to STEM programs. First, compared to their matched peers in AE, on average, VE students increase their probabilities of enrolling in both STEM and non-STEM postsecondary vocational programs. However, at the same time, VE students experienced significant decreases in their likelihood of attending university programs, mainly in non-STEM fields. Furthermore, as recent studies have suggested (Ollikainen & Karhunen, 2021; Tieben, 2020; Xu & Backes, 2023), this main track significantly boosts the chances of not enrolling in higher education.

When we examine the effects of AE and VE, considering the type of programs students select, we find that exposure to STEM-related content and skills in both tracks is related to a higher probability of enrolling in higher education STEM programs. However, the extent to which the two paths are related to students' enrollment options differs across higher education institutions. For STEM programs delivered by universities, the more robust predictor of enrolling is the AE-STEM sub-track with a marginal effect of 9 percentage points. In contrast, VE-STEM performs better in the case of STEM programs

Table 3 Marginal effects of enrollment in different higher education pathways

	Not-enrolled HE		Vocational postsecondary institutions				University			
			STEM		Non-STEM		STEM		Non-STEM	
VE	0.080	**	0.063	**	0.031	**	− 0.033	**	− 0.141	**
	(0.002)		(0.002)		(0.002)		(0.002)		(0.002)	
AE-STEM	− 0.017	**	0.026	**	− 0.028	**	0.086	**	− 0.067	**
	(0.003)		(0.003)		(0.003)		(0.003)		(0.004)	
VE-STEM	0.094	**	0.190	**	− 0.085	**	0.046	**	− 0.246	**
	(0.004)		(0.003)		(0.003)		(0.003)		(0.004)	
VE-non-STEM	0.086	**	− 0.022	**	0.075	**	− 0.007	**	− 0.131	**
	(0.003)		(0.002)		(0.003)		(0.002)		(0.003)	
Number of observations									125,628	

Effects of the VE track and upper-secondary tracks split by STEM and non-STEM

Marginal effects are evaluated at the means; HE = higher education; AE = academic education; VE = vocational education; AE-non-STEM as based

+ $p < 0.05$ *$p < 0.01$ **$p < 0.001$; standard error in parenthesis provided by postsecondary vocational institutions. There is an increase of 19 percentage points in the probability of enrolling in these programs, creating a clear STEM route between secondary and postsecondary VE levels. This is in line with a large body of research suggesting that applied STEM CTE strengthens the college and career pipeline (Gottfried & Bozick, 2016; Gottfried & Plasman, 2018; Gottfried et al., 2023; Plasman et al., 2019). Conversely, this differs from those studies that, leveraging on variation within high schools over time in course offerings, conclude that high school STEM-related courses do not impact postsecondary STEM enrollment or degree attainment (e.g., Darolia et al., 2020).

The results of models that include multiplicative terms between the upper-secondary track and gender (models are shown in additional files) are recapped in Tables 4 and 5. We found that VE affects men's and women's paths to higher education in different magnitudes. As shown in Table 4, the influence of VE on enrollment in STEM programs offered by both vocational institutions and universities is considerably larger for men than for women (11.3 vs. 1.4 and − 5.7 vs. − 0.8 percentage points, respectively). Gender differences are also observable when the upper-secondary tracks are divided into STEM and non-STEM (see Table 5). Advanced and specialized math and science courses provided in the AE-STEM sub-track slightly benefit men more than women in STEM programs enrollment across higher education institutions. However, more significant differences to the detriment of women are observed in the VE pipeline between secondary and postsecondary levels, as the VE-STEM sub-track boosts male chances of enrolling in STEM programs in vocational institutions by 14 percentage points more than for women. These findings support prior research showing that enrollment in high school academic or applied STEM courses widen gender gaps in STEM higher education, with males benefiting more than females (Jacob et al., 2020; Xu & Backes, 2023).

Remarkably, the gendered inequality pattern observed in the STEM pipeline between secondary and postsecondary VE does not repeat in enrollment in university STEM programs as female students in the VE-STEM sub-track increase their options to a greater extent than men (8.2 vs. 2.1 percent points). Likewise, we identify that women's chances of enrolling in STEM programs across postsecondary institutions slightly increase in the VE-non-STEM route while for men decreases. These results support the "pathways" approach, indicating that women can pursue various routes to enroll, persist, and ultimately succeed in STEM fields rather than relying on a single path (Fealing et al., 2015).

Persistence in postsecondary STEM programs

Table 6 recaps the results of the multinomial logistic models estimated to predict the likelihood of persisting, leaving, or switching out of STEM programs conditional on having enrolled in postsecondary vocational or university institutions (models are shown in the Additional file 1: Online Appendix). As in the case of enrollment, we display the AMEs of the VE track instead of enrolling in AE, and the AMEs of these tracks are broken down between STEM and non-STEM. We find that VE as a main track is not significant in predicting later persistence in postsecondary STEM programs. Likewise, considering the type of courses that students select within each track, we identify that having been exposed to STEM content in the academic track, although relevant for university STEM programs enrollment, is not related to later persistence. On the contrary, we identify that for STEM programs in postsecondary vocational institutions only, the VE-STEM sub-track increases the chances of persistence,

Table 4 Marginal effects by gender of enrollment in different higher education pathways

	Not-enrolled HE		Vocational postsecondary institutions				University			
			STEM		Non-STEM		STEM		Non-STEM	
Men VE	0.063	**	0.113	**	0.015	**	− 0.057	**	− 0.133	**
	(0.003)		(0.003)		(0.003)		(0.003)		(0.003)	
Women VE	0.097	**	0.014	**	0.047	**	− 0.008	**	− 0149	**
	(0.003)		(0.002)		(0.003)		(0.002)		(0.004)	
Men vs. women	− 0.033	**	0.098	**	− 0.032	**	− 0.049	**	0.016	**
	(0.004)		(0.004)		(0.004)		(0.004)		(0.005)	
Number of observations									125,628	

Effects of the VE track

Marginal effects are evaluated at the means; HE = higher education; AE = academic education; VE = vocational education; AE-non-STEM as based

+ $p < 0.05$ * $p < 0.01$ ** $p < 0.001$; standard error in parenthesis

Table 5 Marginal effects by gender of enrollment in different higher education pathways

		Not-enrolled HE		Vocational postsecondary institutions				University			
				STEM		Non-STEM		STEM		Non-STEM	
Men	AE-STEM	– 0.031	**	0.040	**	– 0.028	**	0111	**	– 0.091	**
		(0.004)		(0.005)		(0.004)		(0.005)		(0.005)	
	VE-STEM	0.048	**	0,260	**	– 0.090	**	0.021	**	– 0.239	**
		(0.004)		(0.005)		(0.003)		(0.004)		(0.004)	
	VE-non-STEM	0.057	**	– 0.055	**	0.128	**	– 0.030	**	– 0.100	**
		(0.004)		(0.004)		(0.005)		(0.004)		(0.005)	
Women	AE-STEM	– 0.004		0.010	**	– 0.024	**	0.061	**	– 0.043	**
		(0.004)		(0.002)		(0.005)		(0.003)		(0.005)	
	VE-STEM	0.066	**	0.120	**	-0.016	**	0.082	**	– 0.251	**
		(0.007)		(0.006)		(0.008)		(0.006)		(0.008)	
	VE-non-STEM	0.098	**	0.002	*	0.049	**	0.009	**	– 0.158	**
		(0.003)		(0.002)		(0.004)		(0.002)		(0.004)	
Men vs. women	AE-STEM	– 0.028	**	0.031	**	-0.005		0.050	**	– 0.048	**
		(0.006)		(0.005)		(0.006)		(0.006)		(0.007)	
	VE-STEM	– 0.018	*	0.140	**	– 0.073	**	– 0.062	**	0.013	
		(0.008)		(0.008)		(0.009)		(0.008)		(0.009)	
	VE-non-STEM	– 0.042	**	– 0.057	**	0.080	**	– 0.038	**	0.057	**
		(0.005)		(0.004)		(0.006)		(0.005)		(0.006)	
Number of observations										125,628	

Effects of upper-secondary tracks split by STEM and non-STEM

Marginal effects are evaluated at the means; HE = higher education; AE = academic education; VE = vocational education; AE-non-STEM as based

Significant differences between groups: + $p < 0.05$ *$p < 0.01$ **$p < 0.001$; standard error in parenthesis

Table 6 Marginal effects in the persistence in postsecondary STEM programs

	Vocational postsecondary institutions						University		
	Persist		Leave	Switch			Persist	Leave	Switch
VE	0.009		– 0.007	– 0.002			– 0.019	– 0.005	0.024
	(0.015)		(0.012)	(0.013)			(0.021)	(0.012)	(0.019)
AE-STEM	0.015		0.001	– 0.017			0.027	– 0.009	– 0.018
	(0.018)		(0.013)	(0.012)			(0.017)	(0.012)	(0.013)
VE-STEM	0.049	*	– 0.019	– 0.030	*		0.018	– 0.014	– 0.004
	(0.017)		(0.013)	(0.012)			(0.026)	(0.014)	(0.023)
VE-non-STEM	– 0.006		0.000	0.006			– 0.025	– 0.004	0.029
	(0.021)		(0.017)	(0.02)			(0.031)	(0.018)	(0.027)
Number of observations				17,688					12,689

Effects of the VE track and upper-secondary tracks split by STEM and non-STEM

Marginal effects are evaluated at the means; AE = academic education; VE = vocational education; AE-non-STEM as based

Significant differences between groups: + $p < 0.10$ *$p < 0.05$ **$p < 0.01$; standard error in parenthesis

narrowing at the same time those of switching out of these programs. This result is consistent with previous findings that highlighted the importance of applied STEM courses for persistence in postsecondary vocational programs (Farías & Sevilla, 2015) and for acquiring credentials in STEM fields (Plasman et al., 2019).

We also contrast the effects of the upper-secondary tracks on the persistence in postsecondary STEM programs between women and men. Beginning with the main tracks, Table 7 shows that VE is relevant in predicting persistence in STEM programs offered by vocational postsecondary institutions and universities,

Table 7 Marginal effects in the persistence in postsecondary STEM programs

	Vocational postsecondary institutions			University		
	Persist	Leave	Switch	Persist	Leave	Switch
Men VE	0.005	− 0.022 *	0.016	− 0.050 *	− 0.007	0.057 *
	(0.024)	(0.011)	(0.024)	(0.025)	(0.015)	(0.025)
Women VE	0.013	0.007	− 0.020	0.017	− 0.002	− 0.015
	(0.027)	(0.022)	(0.017)	(0.031)	(0.021)	(0.026)
Men vs. women	− 0.008	− 0.029	0.037	− 0.067 +	− 0.005	0.072 *
	(0.043)	(0.025)	(0.033)	(0.038)	(0.027)	(0.035)
Number of observations			17,688			12,689

Effects of the VE track

Marginal effects are evaluated at the means; AE = academic education; VE = vocational education; AE-non-STEM as based

Significant differences between groups: + $p < 0.10$ *$p < 0.05$ **$p < 0.01$; standard error in parenthesis

but only for men. However, only in the case of STEM university programs, VE affects gender gaps as men, unlike women, increase their probabilities of switching to other non-STEM programs, having at the same time lower persistence options. When the main tracks are broken down into STEM and non-STEM, as Table 8 shows, there is no evidence that the positive effect of the VE-STEM sub-track in later persistence in vocational postsecondary STEM programs differs between men and women. Moreover, we found that both VE-STEM and non-STEM sub-tracks drive the impact of VE in reducing gender gaps in university STEM programs.

Table 8 Marginal effects in the persistence in postsecondary STEM programs. Effects of the upper-secondary sub-tracks split by STEM and non-STEM

		Vocational postsecondary institutions			University		
		Persist	Leave	Switch	Persist	Leave	Switch
Men	AE-STEM	0.041 **	− 0.015	− 0.026 *	0.020	− 0.014	− 0.006
		(0.015)	(0.01)	(0.012)	(0.02)	(0.017)	(0.014)
	VE-STEM	0.057 **	− 0.034 **	− 0.022	− 0.016	− 0.014	0.030
		(0.017)	(0.011)	(0.015)	(0.028)	(0.018)	(0.024)
	VE-non-STEM	− 0.031	− 0.018	0.049	− 0.074 +	− 0.009	0.083 +
		(0.049)	(0.022)	(0.049)	(0.043)	(0.026)	(0.043)
Women	AE-STEM	− 0.014	0.018	− 0.004	0.027	− 0.003	− 0.024
		(0.031)	(0.025)	(0.02)	(0.025)	(0.016)	(0.02)
	VE-STEM	0.024	0.009	− 0.033	0.088 *	− 0.021	− 0.068 +
		(0.035)	(0.03)	(0.021)	(0.043)	(0.023)	(0.038)
	VE-non-STEM	0.004	0.013	− 0.018	0.013	0.000	− 0.013
		(0.031)	(0.025)	(0.02)	(0.038)	(0.025)	(0.032)
Men vs. women	AE-STEM	0.055 +	− 0.034	− 0.022	− 0.007	− 0.011	0.018
		(0.032)	(0.026)	(0.02)	(0.029)	(0.023)	(0.022)
	VE-STEM	0.033	− 0.044	0.011	− 0.104 *	0.006	0.098 *
		(0.037)	(0.031)	(0.024)	(0.047)	(0.027)	(0.044)
	VE-non-STEM	− 0.035	− 0.031	0.066	− 0.087 +	− 0.009	0.096 +
		(0.067)	(0.035)	(0.057)	(0.053)	(0.038)	(0.052)
Number of observations				17,688			12,689

Marginal effects are evaluated at the means; AE = academic education; VE = vocational education; AE-non-STEM as based

Significant differences between groups: + $p < 0.10$ *$p < 0.05$ **$p < 0.01$; standard error in parenthesis

Robustness check of results

Sensibility analysis

We conduct the Mantel–Haenszel test to assess the susceptibility of the matching model to the omission of confounding factors. As previously explained, this test allows us to examine how strongly any unmeasured variable could affect the selection process to compromise the results of the matching analysis.

Table 9 displays the results of the Mantel–Haenszel test statistic calculated for our dichotomous outcomes of enrollment and persistence in postsecondary STEM programs. The sensitivity column presents the critical value at which the test statistic's significance level exceeds 0.05. For example, in the first model (enrollment in higher education), the critical test statistic is 3.95, suggesting that, for the 95% confidence interval of the model's effect to include zero, an unobserved dichotomous variable would need to cause the odds ratio of treatment assignment to differ between the treatment and comparison groups by a factor of 3.95 (Alcott, 2017; Becker & Caliendo, 2007). The Mantel–Haenszel test provides a critical estimation value ranging from 1.35 to 3.95 for the other outcomes analyzed. To provide a reference point, in the logistic regression model used to generate the propensity scores, we transformed the coefficients to odds ratio to make it comparable with the Mantel–Haenszel test outcomes. The greatest odds ratio for any dichotomous variable at the individual level was 1.59 for the variable educational expectation of students' parents. Only persistence in University-STEM presents a critical value below 1.59. Therefore, we advise precaution when interpreting the results of this particular outcome since they may be sensitive to possible deviations from the identifying confoundedness assumption of the matching process.

Multi-probit regression model

Finally, to ensure the reliability of our findings, we conducted a replication analysis of enrollment and persistence using multi-probit regression models weighted by PSM. These models provide an alternative estimation approach that assumes a standard normal error distribution. The results obtained from this alternative model specification were consistent with our main findings, indicating that our conclusions are not sensitive to the choice of the underlying distributional assumption. This robustness check further strengthens the validity of our study (see Additional file 1: Online Appendix).

Table 9 Sensitivity analysis based on the Mantel–Haenszel test

Outcome	Subsample	Sensitivity
Enrollment higher education	All	3.95
Enrollment VE-STEM	All	2.00
Enrollment university-STEM	All	3.95
Persistence higher education	All	1.95
Persistence STEM in vocational postsecondary institutions	Vocational postsecondary STEM	1.80
Persistence STEM in universities	University STEM	1.35

Values at the "Sensitivity" column are the critical value at which the Mantel–Haenszel (1959) test statistic's significance level exceeds 0.05

Limitations

Despite conducting robustness checks, our study has certain limitations that limit the extent to which we can draw causal interpretations from our findings. First, even after matching on observed covariates, the estimation of treatment effects in PSM methodology can still be subject to bias from unobserved confounders, including omitted variables or unmeasured variables. Besides, while our sensitivity analysis yielded favorable outcomes, as demonstrated early, there were instances where the coefficients did not exhibit sufficient magnitude to offset the potential influence of an omitted or unobserved confounder.

Second, we specifically addressed the distinction between STEM and non-STEM upper-secondary courses using multinomial logistic regression models for analyses considering the type of courses within each track. This was due to sample restrictions that prevented us from performing PSM for multiple treatments directly within the treatment itself. This approach allowed us to overcome those restrictions and effectively examine the relationship between multiple upper-secondary pathways, both STEM and non-STEM and enrollment and persistence in STEM higher education. Nevertheless, results obtained from these model specifications cannot be interpreted causally due to our inability to mitigate selection bias within AE or VE tracks. Another impediment to interpreting these findings causally is the potential influence of the nesting effect of schools' STEM offerings on students. Course offerings at the secondary level may be associated with student sorting to specific schools, as well as access to other resources, which can also impact postsecondary outcomes. Addressing this concern would require using longitudinal panel data that span multiple cohorts of students over an extended period.

Conclusion

This study examines the relationship between secondary school curricula and students' enrollment and persistence in STEM higher education. In doing so, we explore whether exposure to STEM courses within the academic or vocational tracks at the upper-secondary level translates into fewer gender differences in STEM studies in higher education.

Our results shed light on the relevance of exposure to STEM-related courses across upper-secondary tracks in boosting enrollment in STEM higher education programs and, to some degree, persistence. However, at the same time, they indicate that gender gaps increase in the more effective routes between secondary and postsecondary levels. The positive association between AE-STEM sub-track and enrolling in university STEM programs is stronger for male than female students. Likewise, male students in the VE-STEM sub-track are substantially more prone than female students to remain in the STEM pipeline by attending similar programs at the postsecondary level. Furthermore, we discovered that alternative pathways, such as VE-STEM, are stronger associated with higher female enrollment in university STEM programs than AE-non-STEM. Lastly, we found that the effect of VE-STEM on later persistence in STEM postsecondary vocational programs is similar for both male and female students.

Understanding the role of institutional levers, such as secondary school curricula, is essential to inform policy discussions to reduce the gender gap in STEM education and careers. The reduction of this gender gap involves two distinct challenges. One is increasing the retention of women who are already pursuing STEM fields. The second is increasing the recruitment of women into STEM routes. Based on our results, we offer some policy and practice recommendations for both challenges in the intensive and extensive margins.

We begin with the finding that the gender gap substantially increases in the STEM vocational education path between secondary and postsecondary levels. In Chile, secondary school curricula focusing on academic or applied STEM content are untargeted courses that have not been specifically adapted to expand women's participation in STEM fields. Mainly, secondary VE-STEM have been traditionally male-dominated and characterized by a gender-stereotypical culture hindering women's persistence in these fields during the transition to higher education (Sevilla et al., 2019). Thus, in the intensive margin to promote female persistence from secondary VE-STEM to STEM higher education, educators should focus on making this vocational sub-track more inclusive and welcoming to female students so they fully benefit from early exposure to applied STEM courses. This requires addressing the gender barriers that persist in school settings, such as discourses and micro-practices that perpetuate and amplify gender stereotypes (Blair et al., 2017; Sevilla & Carvajal, 2020).

Second, while the "leaky pipeline" metaphor helps explain the attrition of women in STEM as they progress in their careers, our results support the relevance of broadening the focus throughout the pathways perspective. Different routes, and not only a specific one, women can take to gain access to STEM higher education programs. Hence, policymakers and high school leaders should enhance their support for women interested in STEM studies and careers in all secondary tracks, including the non-STEM academic and vocational track. Future research should further investigate the impact of enrolling in different secondary tracks on postsecondary and career choices, aiming to identify the factors contributing to these outcomes.

We continue with our result concerning the "crossed" path from secondary VE-STEM to university-STEM associated with gender gaps reduction in enrollment and persistence. Although the sensitivity analysis asks for some precaution in the case of persistence, it is still worth challenging the inequalities related to the structure of the Chilean educational system in light of this result. The Chilean education system is markedly segmented into academic and vocational tracks. Due to this, academic STEM courses are not available to vocational students. Moreover, these students frequently need more preparation in fundamental subjects like math and sciences (Farías, 2014). Therefore, we advocate for future curriculum reforms that reinforce the academic preparedness of vocational students and remove the false dilemma imposed on students at the secondary level: the choice between academic or applied STEM courses. All high school students attending academic and vocational tracks should have the opportunity to select both options as a part of their non-mandatory curriculum.

We also refer to the equal effect of VE-STEM in later persistence for male and female students. This finding is significant as it provides evidence of the equal gender contribution that applied STEM courses can make once students enroll in STEM postsecondary vocational programs. Thus, efforts should focus on supporting and maintaining female students in their STEM paths, allowing them to leverage their early exposure to applied STEM courses when they enroll in advanced STEM programs. Increasing exposure to female teachers in STEM fields, who act as counter-stereotypical role models, is a promising approach. Research shows that such exposure is highly effective in supporting the seamless progress of female students through the STEM pipeline by enhancing their identification with STEM fields (Solanki & Xu, 2018).

To conclude, considering this study's limitations previously noted, we encourage using alternative analytical strategies to address the methodological gaps. Leveraging plausibly exogenous variation in STEM course offerings within high schools over time has demonstrated promise in estimating the impact of access to these courses on later STEM outcomes in a manner that closely resembles causal relationships (e.g., Darolia et al., 2020). This is because it allows us to mitigate potential endogeneity at the school level regarding the availability of STEM courses within academic or vocational tracks. As this approach requires longitudinal panel data spanning multiple cohorts of students over an extended period, we encourage using such data to better understand the opportunities and limitations of secondary school curricula in shaping female participation in STEM higher education.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40594-023-00450-7.

Additional file 1: Table A1. Multilogit estimation of the effects of the upper-secondary main track on enrollment in different higher education pathways. **Table A2.** Multilogit estimation of the effects of the upper-secondary sub-track on enrollment in different higher education pathways. **Table A3.** Multilogit estimation of the effects of the upper-secondary main track on persistence in higher education. **Table A4.** Multilogit estimation of the effects of the upper-secondary sub-track on persistence in higher education. **Table A5.** Multiprobit estimation of the effects of the upper-secondary main track on enrollment and persistence.

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Author contributions
MPS: conceptualization, investigation, methodology, writing—original draft preparation, writing—reviewing and editing, project administration, funding acquisition. DLA: methodology, writing—original draft preparation, writing-reviewing and editing. MF: investigation, writing—original draft preparation. All authors read and approved the final manuscript.

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Availability of data and materials
The panel datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

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The authors declare that they have no competing interests.

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