Pathways to Engineering Graduate Studies for Women: Challenges and Opportunities Revealed through Mining Students' Application, Admission, and Enrollment Data

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Unearthing Gender Equity: A Data-Driven Analysis of Application and Admission Patterns in Graduate Engineering Studies

Abstract

Outreach, support, and mentorship for women considering or pursuing careers in engineering are widely employed to increase female representation in the profession. These efforts have mostly focused on women in undergraduate studies or industry. Outreach and retention efforts for women considering or pursuing graduate studies are limited, despite the underrepresentation of women in postgraduate studies in Canada.

At a major research-based Canadian university, we investigated a) the recruitment practices of engineering departments for graduate studies, and b) the factors contributing to undergraduate students' intention to apply to graduate studies and their admission success. This article presents findings from the first phase of a multiphase mixed-method research project exploring the barriers women face in pursuing engineering graduate studies and existing interventions to address these barriers.

Using application, admission, and enrollment data for undergraduate and graduate degrees from 2006 to 2021, we applied statistical analysis and a multilevel logistic regression to examine the application and admission patterns in the engineering graduate departments. In most engineering departments, we found that domestic citizenship status, grade-based academic performance, and an undergraduate degree from the same university were significant positive predictors of admission to an engineering graduate program. Gender was not a significant contributing factor in the admission process in the engineering faculty.

Understanding these patterns in the existing students' data contributes to identifying spaces to strive for gender parity and equity in graduate studies in the engineering faculty. The results suggest a) supporting first-year undergraduate students as they, particularly women, have their lowest grades in the first year, b) diversifying admission requirements to benefit from the large applicant pools in the most populated departments, c) improving international applicants' admission success rate, who are refused admission due to high tuition fees, d) enhancing domestic students application rate, and e) learning from success stories in the faculty.

Keywords: gender equity, gender parity, engineering, graduate studies

Introduction

The small number of women in Science, Technology, Engineering, and Math (STEM), and more specifically, in engineering, has been well documented during the last few decades [1], [2]. Despite ongoing progress towards gender parity in engineering disciplines in higher education and the workplace, the gender gap still exists. The underrepresentation of women (and other minority groups) in engineering in Canada leads to untapped opportunities for innovation, economic growth, and a just society where the design and development of new inventions embed the needs and differences of diverse populations. While many researchers have examined various equity, diversity, and inclusion issues in undergraduate engineering studies, the historical and ongoing EDI issues in graduate degrees have remained intact. The small number of women in engineering graduate degrees raises concerns about an equitable workforce in higher-level engineering positions or research opportunities and innovations [3]. Few researchers have investigated the transition between undergraduate and graduate programs, such as undergraduate students' decision-making factors with respect to pursuing graduate degrees or the graduate admission processes.

In this research, we try to identify existing gender exclusions and inequalities in the transition from undergraduate to graduate degrees in engineering at a major, research-based university in Ontario (Canada). Before examining the challenges women face on their way to graduate degrees and the organizational and cultural practices that overtly or covertly emanate those challenges, we need to better understand the application and admission patterns for graduate degrees in each engineering department. The research questions focus on the intersectional effects of gender and citizenship status on undergraduate students' intention to pursue graduate degrees and their chance of admission to engineering graduate degrees. Here are the research questions this paper tries to address:

- Research question 1: How do the application and admission patterns in the engineering graduate departments change over time, focusing on gender?
- Research question 2: What are the factors impacting these patterns?

We used different institutional data sets from the researched university, including anonymous graduate and undergraduate students' application, admission, and enrollment data. Mining data to answer the research questions for each engineering department may reveal challenges and opportunities facing women on their way to graduate degrees. The uniqueness of this study is its focus on women transitioning from undergraduate to graduate programs in each engineering department and graduate degree, considering the intersection of gender with other factors, such as citizenship status.

The paper begins by reviewing existing literature on women in engineering in higher education and undergraduate students' decision-making factors in pursuing graduate degrees. After overviewing the methods and data used, we present and discuss findings about application and admission patterns in engineering departments and graduate degrees. We also discuss how factors such as citizenship status, gender, baccalaureate origin, and academic performance interact with each other and affect undergraduate students' intention to apply for graduate degrees and their chances of admission. We finish the paper by suggesting potential spaces of

opportunities to enhance gender parity at graduate degrees in engineering, which can disrupt practices that have reinforced and reproduced gender imbalances.

Review of the literature

Despite ongoing progress towards gender parity in engineering disciplines in higher education and to a lower degree in the workplace, the gender gap still exists [1]. The underrepresentation of women in engineering, particularly those from other equity-deserving groups (Indigenous, Black, women of color, non-binary sexual orientations, women from lower socioeconomic backgrounds), leads to untapped opportunities for innovation, economic growth, and a just society. Closing this gap calls for further reforms in K-12 and higher education [2].

Such reform can be facilitated by having more female role models and mentors as faculty members in engineering disciplines and as managers in the engineering workforce. Increasing diversity at the graduate level can be inspiring for undergraduate students from underrepresented groups to pursue graduate degrees [3]. Having faculty members and mentors as role models can foster the development of motivation and self-efficacy in undergraduate students, which increases the likelihood of their decisions to pursue and thrive in graduate degrees [4]. In addition, a postgraduate degree is usually accompanied by higher lifetime earnings, enhanced occupational and social status, better working conditions, and a lower probability of unemployment [5]. Therefore, gender parity in graduate degrees in engineering is essential for closing the gender gap and advancing equity in undergraduate studies and professions in engineering. However, while many researchers have examined various Equity, Diversity, and Inclusion (EDI) issues in undergraduate engineering enrollment, far fewer studies have explored historical and ongoing EDI issues in application, admission, and enrollment processes at the graduate level.

Most current efforts target K-12 schools to encourage elementary and high-school female students to consider undergraduate studies in engineering. Equally, recruitment and retention efforts are highly weighted towards keeping women in engineering programs to finish their undergraduate degrees, increasing the number of licensed female professionals, and recruiting them for engineering positions [1].

Concerning gender disparity in engineering, many scholars and practitioners have described the engineering continuum as a ‘leaky pipeline’ [1], [6] or ‘gender filter’ [7], trying to show the stages where women and girls leak from the pipeline, either by not entering the field at all or leaving the field. For instance, Wells and his colleagues argue that high school years and after post-secondary graduation are the leakiest parts of the engineering pipeline for Ontarian (Canada) women in engineering. They showed that only 8.5% of all grade 10 female science students pass the prerequisite to apply for engineering degrees in their post-secondary education, compared with 16.5% for their male counterparts. They also found that women only formed 11% of licensed engineers in Ontario in 2018 [6]. While this continuum provides valuable information

to identify where women leave engineering, it does not include the transition from undergraduate to graduate degrees in engineering.

Even though there has been a slight growth in research about EDI challenges and perspectives in engineering graduate degrees in recent years [4], the body of research in this area is still small. Some of these studies have explored undergraduate students' perceptions and decision-making factors regarding graduate degrees in engineering [8], [9]. For instance, Crede and Borrego (2011) argue that the presence of role models, students' perception of their success, and students' awareness of graduate school contribute to their decision to consider graduate school [9]. Borrego and her colleagues also found that self-efficacy strongly affects graduate school intention [8]. Eagan and his colleagues (2013) found that participation in research programs at the undergraduate level significantly improves students' intention to enroll in a graduate program [10]. These findings are consistent with what Ro and her colleagues showed in their research. They discuss that participating in undergraduate research, math proficiency, and self-assessed leadership skills increase the chance of considering graduate school [11].

Even fewer studies have looked at women in graduate programs in engineering. Cuny and Aspray (2002) have consolidated experts' opinions regarding the recruitment and retention of female graduate students in computer science and engineering. They listed several recommendations to increase the number of women's enrollment and retention in engineering departments, such as: more flexibility in admission criteria, encouraging reentry students, providing undergraduate students with information about graduate school and the opportunities that come with it, exposing undergraduate students to research opportunities, improving students' relations with faculty members and other students, providing women role models, and promoting equal participation of women [12].

The existing body of research is not homogenous concerning the influence of sex on undergraduate students' intentions to pursue graduate degrees. Some studies show that sex has not significantly affected undergraduate decisions to pursue graduate degrees in engineering [10]. However, in Walpole's research, 'self-identifying as a woman' was a significant predictor of attending graduate school within five years in all disciplines (not particularly engineering) [13]. Perna (2004) also argues that sex, along with race, perceived cost-benefits, financial resources, and social and cultural capital, are predictors of deciding to enroll in graduate programs [5]. She explains that women in undergraduate programs with the highest starting salaries, such as engineering, are less likely to enroll in a master's level program, compared with their male counterparts or their female counterparts in the lowest quartile of starting salaries [5].

The intersection of multiple identity factors (e.g., gender, race, class, age, disability, sexual orientation) has been rarely addressed in the existing literature about women in graduate degrees in engineering. The origin of intersectionality returns to black feminism and critical feminism [14], [15]. Intersectionality can be used as a theoretical framework to understand how multiple identity factors shape unique social and cultural experiences and systems of oppression and discrimination [16]. Intersectionality analysis seeks to move beyond simplistic or one-

dimensional analyses to engage and account for the complexity of circumstances that shape people's diverse lived experiences [17]. Therefore, intersectional analytical approaches can provide nuanced understandings of equity and justice by identifying and challenging interconnected statuses that condition a group of people's unique access to opportunities and resources [18], [19].

Few studies have distinguished between graduate degrees (research-based master's (MSc), course-based master's of engineering (MEng), or doctoral (Ph.D.) degrees) when examining students' pursuit of graduate degrees. One of the only studies distinguishing motivational factors to embark on a doctorate degree (not particularly in engineering) is the work of Guerin and her colleagues [20]. Borrego and her team also examined motivational factors to consider master's and Ph.D. degrees separately. For instance, they found that "for every one-unit increase in students' self-efficacy, they were over eight times more likely to plan to enroll in a master's program and 13 times more likely to plan to enroll in a Ph.D. program relative to not attending graduate school" [8, p. 154].

Therefore, the body of literature on women in graduate degrees in engineering remains extremely limited, especially disaggregated on each graduate degree (MSc, MEng, or Ph.D.) or engineering subfields. In order to address systematic challenges that threaten EDI, specifically in engineering graduate programs, it is crucial to understand how inequalities persist in each department and how intersecting identity factors affect those inequalities.

We believe that each engineering department and degree has a unique character with respect to recruiting and retaining women and other equity-deserving groups. Engineering has many subfields and should not be viewed as a homogenous field. Focusing on selected subfields and degrees can improve the effectiveness of targeted practices and policies to enhance EDI in engineering [18].

This paper presents a data-mining research project at a major, public, research–based university in Ontario (Canada). We discuss findings from analyzing the unique graduate student recruitment approaches of engineering departments. Findings will support decision-making to enhance gender equity in each engineering department by predicting opportunities for improvement. In addition, understanding each department's unique application and admission patterns informs the subsequent phases of this research project, which aims to recognize and disrupt the ways that systematic barriers legitimize and reinforce gender disparity in engineering departments.

Data and methodology

This study examines the application and admission patterns in graduate engineering degrees in a large, public, research-based university in Ontario (Canada). It studies the interconnected effects of gender, citizenship status, baccalaureate origin, and grade-based undergraduate academic performance on the application and admission approaches in each engineering department and

graduate degree. We used institutional data available at the engineering faculty in the researched university. After the approval of the ethics board and the Vice-Provost Student of the university, we accessed and worked with different sets of students' records. Here are the datasets we used in our analysis in this study:

Undergraduate students' registration and academic performance (2006-2021): The research sample included data from 26,842 undergraduate students with at least one university record from 2006 to 2021. In total, there were 275,233 records from these undergraduate students, including every session they have registered at the university. Twenty-four parameters described this research sample, but we kept and worked with ten parameters, including: students' unique anonymized ID, gender, citizenship status, department of study, sessional percentage average (an indicator for academic performance), year of study (1-4), registration status, type of program, the session in which each student is registered, and the session in which each student initially applied to begin. The purpose of data analysis was to understand and predict the patterns of applications and admissions to graduate degrees in engineering, with particular attention to potential gender disparities. We organized students' databases in a new data mart during the data processing phase. In each dataset, we cleaned data (e.g., looking for missing values and mistakes) and merged datasets in various ways based on the anonymized unique students' IDs. We also tested for the intersectional effects of gender (female or male) and citizenship status (domestic and international) in the applications and admission success rates, as long as data size allowed us. Our gender records also included 'another' and 'unspecified' as other categories in some years. However, because the sample sizes for these two categories were not large enough for statistical analysis, we only kept female and male records. We also analyzed how our dependent variables (application and admission patterns) changed over time.
Table 1 shows the definition of some of these variables.

Graduate students' application, admission, and registration data (2011-2021): The research sample included data from 44,719 candidates who applied, received admissions, and registered for an engineering graduate degree from 2011 to 2021. In total, there were 109,099 records from these students. Eighteen parameters described this research sample, but we kept and worked with seven parameters: student's unique anonymized ID, gender, citizenship status, degree, engineering department, the session in which each student is registered, the session in which each student initially applied to begin.

Degrees awarded to graduate and undergraduate students (2011-2021): The research sample included data from 18,140 students who received an undergraduate or graduate degree from an engineering department from 2011 to 2021. In total, there were 20,021 records from these students. Fifteen parameters described this research sample, but we kept and worked with seven parameters: student's unique anonymized ID, gender, citizenship status, the department offering degree, the session in which each student originally began their program, the session in which a student graduated, and degree.

The purpose of data analysis was to understand and predict the patterns of applications and admissions to graduate degrees in engineering, with particular attention to potential gender disparities. We organized students' databases in a new data mart during the data processing phase. In each dataset, we cleaned data (e.g., looking for missing values and mistakes) and merged datasets in various ways based on the anonymized unique students' IDs. We also tested for the intersectional effects of gender (female or male) and citizenship status (domestic and international) in the applications and admission success rates, as long as data size allowed us. Our gender records also included 'another' and 'unspecified' as other categories in some years. However, because the sample sizes for these two categories were not large enough for statistical analysis, we only kept female and male records. We also analyzed how our dependent variables (application and admission patterns) changed over time.

Table 1: Definition of variables

Variables	Definition
Gender	Female, Male, Another, Unspecified
Citizenship status	Domestic (citizen, permanent resident), International (student visa, refugee and other)
Department	Aerospace Engineering department (AER)
	Biomedical Engineering department (BME)
	Chemical Engineering department (CHE)
	Civil Engineering department (CIVIL)
	Electrical & Computer Engineering department (ECE)
	Engineering Science department (ESC)
	Mechanical and Industrial Engineering department (MIE)
	Materials Science & Engineering department (MSE)
Degree	Undergraduate, Research-based Master's degree (MSc), Course-based Master's degree (MEng), Doctorate (Ph.D.)
registration status	invited, registered, canceled, financially canceled
type of program	standard undergraduate engineering degree, special statuses such as exchange students, pre-university

We were also interested in understanding factors suspected of impacting undergraduate students' intention to apply (or not) for engineering graduate degrees and their admission success rate based on available data. At any point in time, each individual in our datasets holds multiple interacting statuses. For example, the lived experience of a female domestic undergraduate student is different from a female international undergraduate student. Therefore, factors impacting their respective decisions to apply for a graduate degree will be different, as well as their chance of admission. We tested the intersectional effects of gender, citizenship status, academic performance, and baccalaureate origin on the application and admission process. Additional identity factors such as race, socioeconomic background, sexual orientation, age, and disability are also suspected to be impactful, however we did not have sufficient data to analyze these. We used data from undergraduate students who have been registered at the researched university as regular students and have been at the same university for all their years of study (we refer to this selected dataset as panel data). This eliminated exchange students, students

whose registrations have been canceled, or those who have not started and completed their undergraduate degrees in 2006-2021 from the study. This selection enabled us to work with a panel data of undergraduate students to, more accurately, track the changes in variables, such as grade-based academic performance, across all four years of study and to examine the correlation of these variables with students' decision to apply for graduate degrees or with their admission success rate.

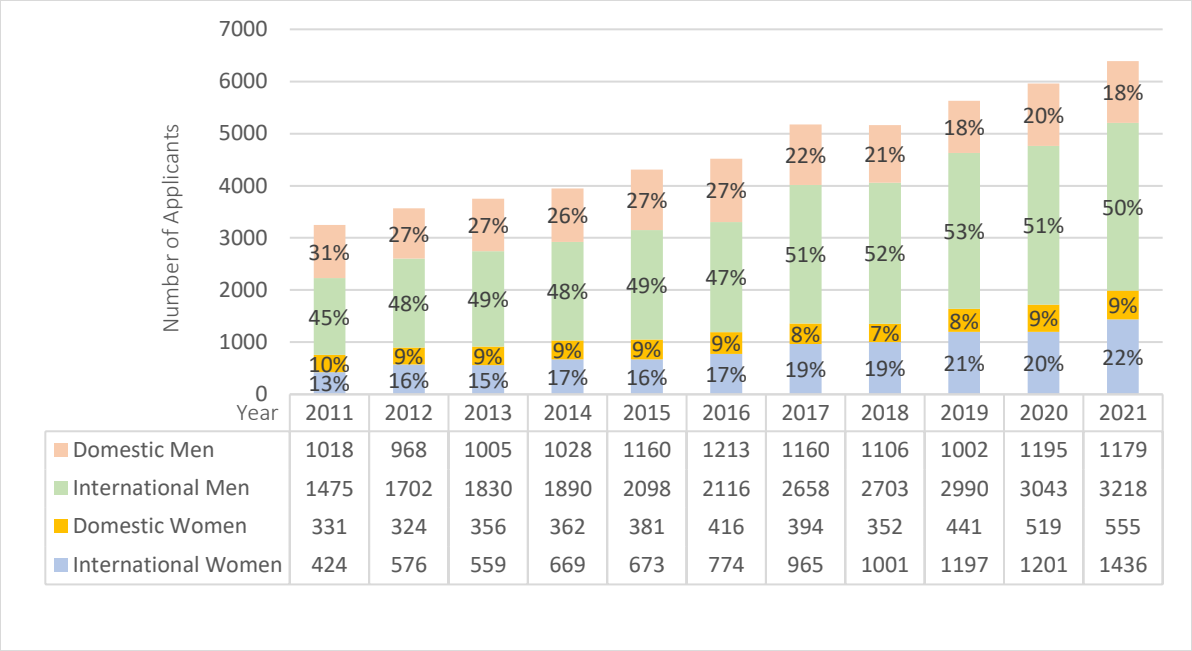
In the following sections, we present and discuss findings from our analyses on the engineering faculty and some engineering departments. The findings were disaggregated whenever allowed for by the data set; the sample size for some of the disaggregated categories (international women, domestic women, international men, domestic men) in each department was not large enough to run the tests.

Findings

We present our findings for application and admission patterns separately. We start each part with results from aggregated data across all engineering departments and graduate degrees before moving to selective examples of more disaggregated analysis to examine the intersectional effects of gender and citizenship status on the patterns in each department and graduate degree.

- ### Application patterns

The number of female applicants in the Engineering faculty has grown more than 2.5 times between 2011 and 2021, at a higher rate than male applicants, which has gone up 1.8 times. However, the proportion of all applicants who are female has only increased by 8% (from 23% to 31% in the same ten-year period). The analysis of disaggregated data over gender and citizenship status shows that the growth in the number of applicants has been chiefly attributed to international female and male students. International men constituted 45-53% of all applicants from 2011 to 2021. International women accounted for 13% to 22% of all applicants, and their number has increased more than 3.3 times within ten years. The proportion of domestic women from the growing number of applicants has remained almost the same, while the proportion of domestic men has declined significantly, from 31% in 2011 to 18% in 2021 (Figure 1).



Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Domestic Men	1018	968	1005	1028	1160	1213	1160	1106	1002	1195	1179
International Men	1475	1702	1830	1890	2098	2116	2658	2703	2990	3043	3218
Domestic Women	331	324	356	362	381	416	394	352	441	519	555
International Women	424	576	559	669	673	774	965	1001	1197	1201	1436

Figure 1: Number and percentage of applicants, across the engineering faculty, by gender and citizenship status

As shown in Table 2 the number of applicants for graduate degrees has grown across all categories and identities from 2011 to 2021. The greatest growth has been in the course-based MEng. This is in keeping with a general trend across the faculty to increase the number of MEng students.

Table 2: Growth rates in the number of applications to graduate degrees (2011-2021)

Degree	**Growth Rate in the number of applications (%)**	
	Female	**Male**
MEng	520	239
MSc	37	17
Ph.D.	61	6

In every engineering department, the number of female applicants has grown at a higher rate than male applicants, with MIE having the highest rate of increase in the number of its female applicants (393%), followed by AER (250%) between 2011 to 2021. MIE has also seen the greatest growth of MEng students across the faculty which is likely driving this sizable change. There are significant differences between the rate of increase in the numbers of female versus male applicants in ECE (105% vs. 35%), MIE (393% vs. 144 %), and CIVIL (113% vs. 49%), the departments with the highest number of applicants. This indicates that women's interest in these highly male-dominated engineering subfields has been growing. However, considering the historically small number of women in these departments, even with these high increases in the number of female applicants, overall, their number remains low compared with the number of male applicants.

To control for characteristics that correlate with undergraduate students' decision to pursue (or not to pursue) graduate degrees in engineering, we merged graduate students' application records with the undergraduate panel data and awarded degree records. As a result, we could control for characteristics such as baccalaureate origin, citizenship status, and undergraduate academic performance in female and male undergraduate students' decision to apply for graduate degrees.

Baccalaureate origin. Our descriptive analysis shows that 41% of engineering undergraduate students from our research pool who graduated from the researched university applied for engineering graduate degrees at their home university between 2011 and 2021, without any significant differences between men and women. This group constituted 11.5% of all 2011-2021 applicants to graduate engineering degrees, indicating that the baccalaureate origins of 88.5% of applicants were from other universities. The application rate varied by the department; male undergraduate students in MIE and ECE have been applying for graduate degrees at a significantly higher rate than their female counterparts. These two departments have also had the lowest application rates compared with other engineering departments (29.7% of undergraduate female students from ECE and 31% of undergraduate female students from MIE). MMS (59.6%) and ESC (52.6%) had the highest application rates among all engineering departments, without significant differences between men and women.

Citizenship status. Intersectional analysis revealed that application rates vary significantly across identity groups of domestic men, domestic women, international men, and international women. Our regressions show that undergraduate students' citizenship status correlated with their decision to apply for graduate degrees in engineering. International undergraduate engineering students from the researched university applied for engineering graduate degrees at the same university at significantly higher rates than their domestic counterparts. Almost all international undergraduate students, regardless of gender, applied for graduate engineering programs, whereas only 33.9% of domestic male and 30% of domestic female undergraduate students applied. Among domestic undergraduate students in the engineering faculty, men applied for graduate degrees at a higher rate than their female counterparts. Domestic female undergraduate students at ECE and MIE had the lowest rates of application for graduate studies (21.7% and 22%, respectively), followed by domestic male students in ECE (27.2%) and MIE (29%). These results are comparable to the findings from analyzing all applicants' data presented earlier in **Error! Reference source not found.**, where international male and female students have been i ncreasingly applying for graduate degrees in engineering at the researched university at significantly higher rates than their domestic counterparts.

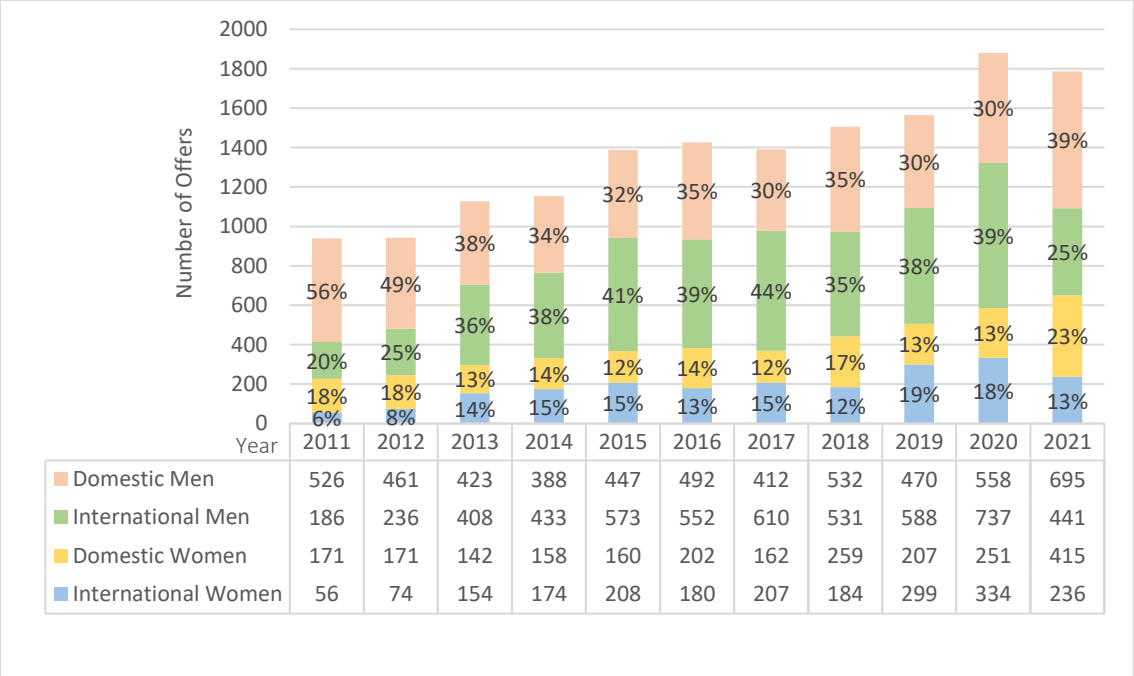
Undergraduate academic performance. Mining the panel data (undergraduate students from the researched university) merged with graduate application data, shows that academic performance is one of the key contributors to undergraduate students' intention to apply (or not) for graduate degrees. As stated in the 'data and methodology' section, we used sessional percentage average points as an indicator of undergraduate students' academic performance. According to the regression results, the grade-based academic performance of those undergraduate students who did not apply for graduate degrees in the engineering faculty has been significantly lower than

that of those who applied, regardless of gender. This shows that lower grades could deter undergraduate students from applying for graduate degrees. Our findings did not show any significant difference in international and domestic applicants' academic performances. However, female applicants had lower grade-based academic performance than their male counterparts. This gender gap is not significant for applicants for MEng degrees, and for all degrees in MIE, CHE, AER, BME, and CIVIL departments.

- **Admission patterns**

The number of graduate admissions from international and domestic women increased by 320% and 140%, compared with 137% for international men and 32% for domestic men, between 2011 and 2021. Despite this rate of increase in the number of offers to women, their proportion from graduate offers went from 24% to 35% (only an 11% increase) for the same time period (see Figure 2), because of the small number of offers to women to start with, in 2011.

Comparing Figure 2 with **Error! Reference source not found.** shows that international applicants have a lower chance of receiving an offer from graduate engineering departments than their domestic counterparts. Figure 3 compares admission success rates for each group of international women, domestic women, international men, and domestic men across the engineering faculty. As we can see, domestic women have had the highest admission success rates.



Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Domestic Men	526	461	423	388	447	492	412	532	470	558	695
International Men	186	236	408	433	573	552	610	531	588	737	441
Domestic Women	171	171	142	158	160	202	162	259	207	251	415
International Women	56	74	154	174	208	180	207	184	299	334	236

Figure 2: Number and percentage of offers, across the engineering faculty, by gender and citizenship status

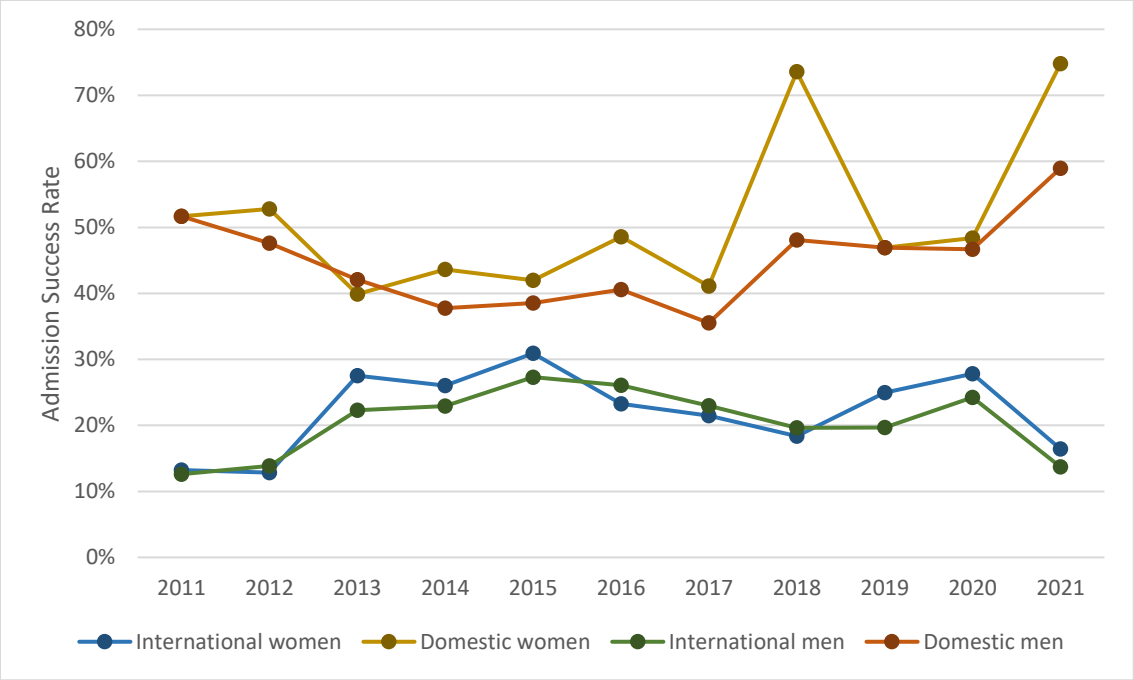


Figure 3: Admission success rate across the engineering faculty, by gender and citizenship status (2011-2021)

Across all graduate degrees, the numbers of admissions to women have increased at higher rates compared with men (Table 3). It is an important finding that MEng degrees account for most of the admission growth rates.

Table 3: Growth rates in the number of admissions to graduate degrees (2011-2021)

Degree	**Growth Rate in the number of admissions (%)**	
	Female	**Male**
MEng	511.6	200.8
MSc	16.6	-9.0
PhD	104.0	17.0

MIE has had the highest number of graduate admissions to female and male applicants, followed by CIVIL and CHE for women and ECE and CIVIL for men. The number of women admitted to graduate studies has increased greatest in MIE (577% compared with 193% for men), followed by MMS (480%), much higher than the increase in the number of female applicants (133%). In AER and ECE, the numbers of women admitted to graduate studies has grown but at much lower rates than the numbers of female applicants.

Now we discuss how baccalaureate origin, citizenship status, and academic performance correlate with admission success rates for female and male applicants from the researched university.

Baccalaureate origin. The undergraduate students from the engineering faculty accounted for 23% of all engineering graduate admissions in the researched university. The admission success

rate for this group of applicants has been about 63%, without any significant difference between women and men. This rate is much higher than the admission success rate for all applicants to engineering graduate degrees (35.8% for women and 31.2% for men). This finding shows that the chance to receive an offer for an engineering graduate program in the researched university significantly increases for applicants with undergraduate degrees from the same university.

Citizenship status. Similar to the findings about the admission success rates across all the applicants for graduate degrees in the engineering faculty, domestic applicants stand a higher chance of admission (65.8%) compared with international applicants (57.8%) among those undergraduate students from the researched university who applied to graduate programs (panel data), regardless of gender. This is consistent in most of the engineering departments. Gender was a contributing factor only in MIE, where the admission success rate of international female applicants was significantly lower than their male counterparts.

Academic performance. Mining of the panel data shows that academic performance positively contributes to admission success rates for students of all genders and citizenship statuses. The academic performances of those applicants who received offers have been constantly higher than those who did not (Figure 4). While our findings do not show any significant difference in the academic performances of all undergraduate male and female students (**Error! Reference s ource not found.**), female offer recipients have had lower grade-based academic performance than their male counterparts. This gender gap in academic performance is insignificant for Ph.D. offers for all departments and for all degrees only in MIE, CHE, AER, BME, and CIVIL departments. International students' offer recipients have had higher academic performance compared with their domestic counterparts, independent of gender. Higher grade-based academic performance and being domestic positively contribute to admission success (95% confidence). This indicates that international students need to demonstrate higher academic potential to receive offers for graduate degrees in engineering.

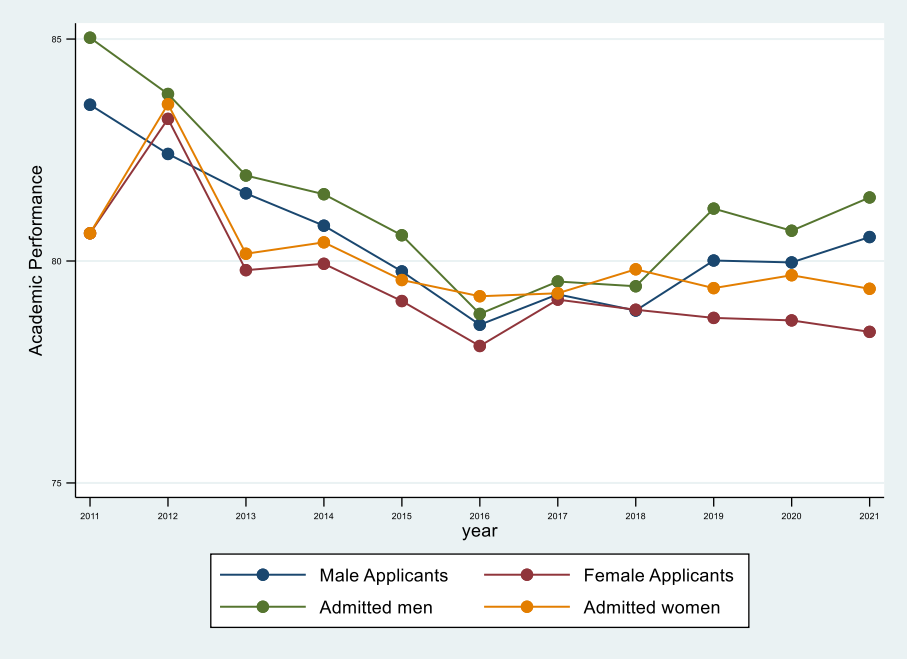


Figure 4: Academic performance of undergraduate students' applicants and offer recipients

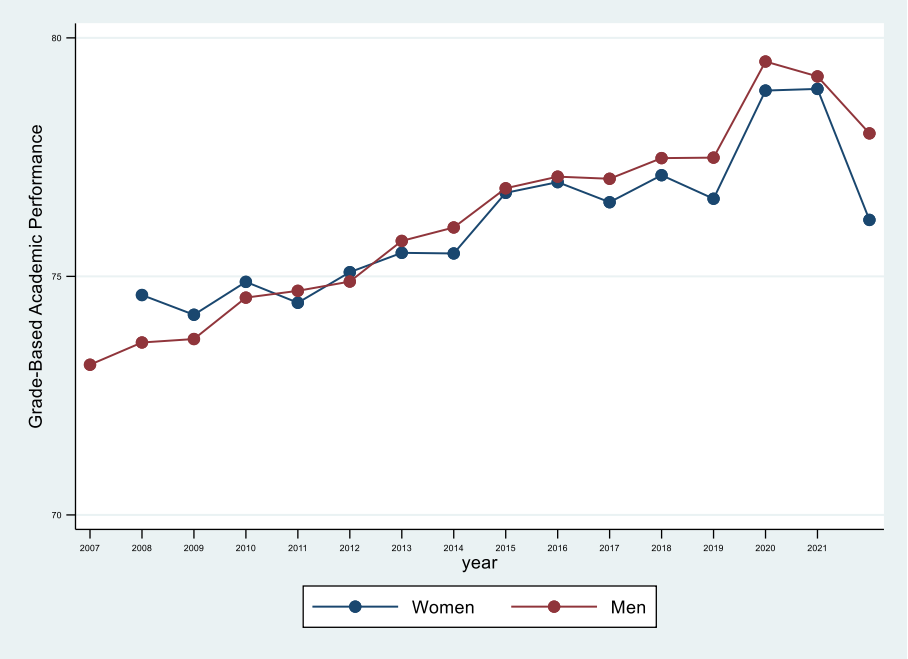


Figure 5: Grade-based Academic performance of undergraduate students across the engineering faculty

Since academic performance was a key indicator of students' intention to apply for engineering graduate degrees and their admission success, we explored how undergraduate students' academic performance changes across their four years of study. Our analysis shows that the studied undergraduate students, generally, had their lowest grades in their first year of undergraduate study and improved in the following years. Across the engineering faculty,

women's grade-based academic performance was significantly lower than men's in their first year of study, however, their academic performance improved at a higher slope compared to men. They closed this gap in their second and third academic years and surpass their male counterparts in their fourth year of study. We observed comparable patterns in every engineering department. Figure 6 shows this growth for female and male undergraduate students in ECE. At ECE, women's academic performance was significantly lower than men's in their first and second years of study. Women closed the gap in their third year of study and outperformed their male counterparts in their fourth year of study. Comparably, in MIE, women scored significantly lower in their first year of study than men. However, they closed the gap in the second year of study and scored significantly higher than men in the third and fourth years of study (Figure 7). In CIVIL and CHE, while there is no significant difference between women's and men's academic performances in the first three years of study, women scored significantly higher than men in their fourth year of study.

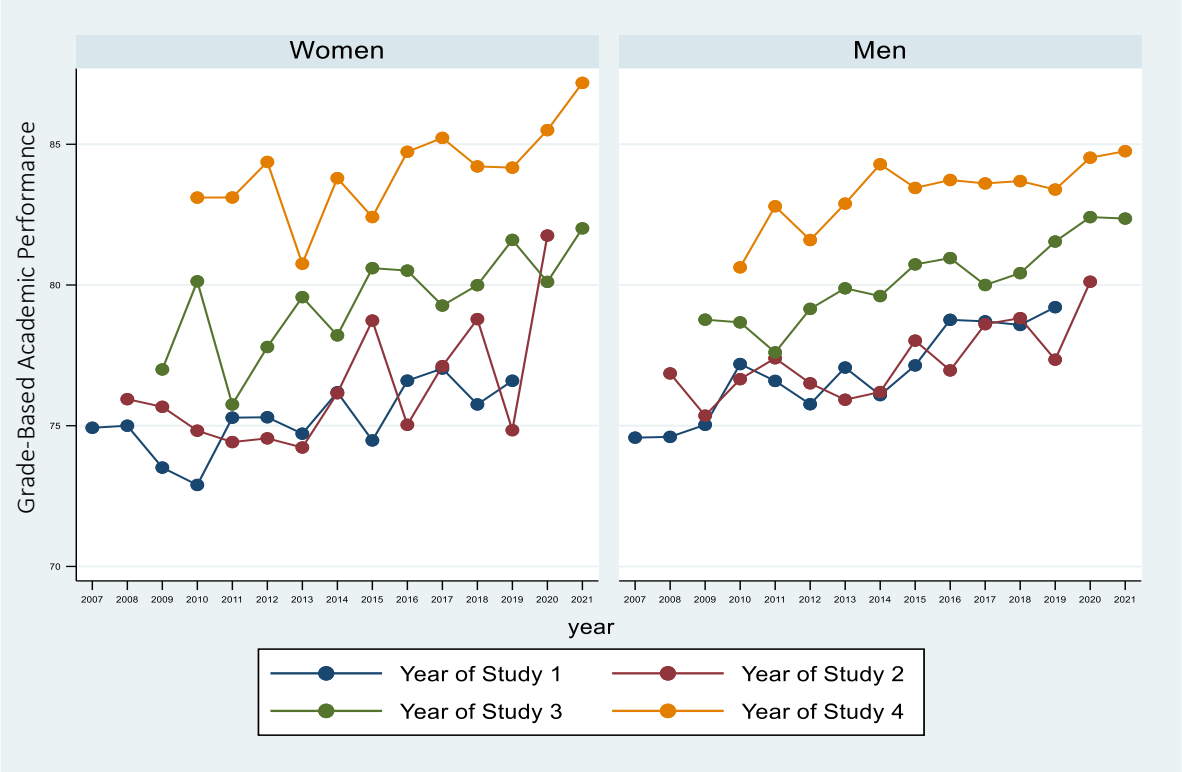


Figure 6: Undergraduate students' grade-based academic performance in each year of study, ECE

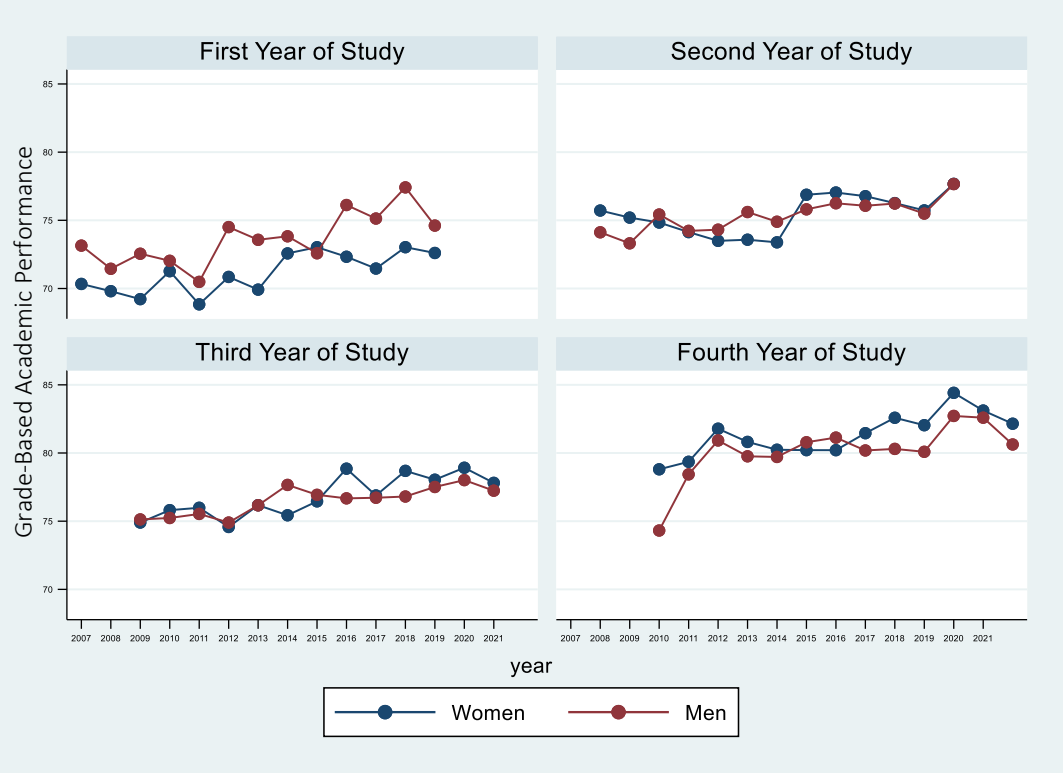


Figure 7: Female and male undergraduate students' academic performance in each year of study, MIE

- **Admission Gender-Equality Index**

To further examine gender equality in the graduate admission process based on available institutional data, we examined the percentage of women admitted in comparison with their percentage of applications. This comparison helps us to understand if women's admission success rate is lower or higher than that of men. We do not have information about the quality of graduate application packages and, thus, cannot confirm why the admission success rate of an identity group has been lower than the other. Follow-up qualitative and quantitative research is required to explore if such inequality has been due to explicit or implicit gender biases or if male applicants, in general, had stronger applications. Tackling the former would entail addressing cultural norms, while the latter requires systematic changes in the admission requirements or targeted reach-out programs to undergraduate students. Regardless of the reason behind this gender inequality, the first step is to identify it.

We created and calculated the Admission Gender-Equality Index (AGEI) to explore gender equality in the admission patterns across the engineering faculty. AGEI equates with the proportion of one particular identity group from admissions over their proportion from applications. If the AGEI for women in an engineering department is larger than one, women's proportion from offers is more than their proportion from applications in that department. For instance, in MIE women accounted for 34.1% of graduate admissions and 30.4% of graduate applications in 2021. Therefore, the AGEI for women in 2021 in MIE was 1.12. Since our gender

data is binary, an AGEI of larger than 1 for women indicates a higher admission success rate for women compared with men. **Error! Reference source not found.** shows that the AGEI for w omen across the engineering faculty has been larger than one between 2011 and 2021. Therefore, women have been experiencing a higher chance of admission than men, considering all other factors, such as the quality of applications, remain the same for men and women. We observed similar patterns in all graduate degrees (Ph.D., MEng, and MSc degrees) and most of the engineering departments. For example, in MIE and CIVIL departments, AGEI has been constantly better for women than men from 2011 to 2021. However, this was not the case for all the engineering departments.

Women's AGEI index has been constantly lower than one and lower than men's at ECE during the same timeline, indicating that women's proportion from graduate admissions has not been keeping up with the increase in their proportion from applicants, particularly in the research-based master's degree (see Figure 9). Therefore, women have had lower chance of admission to MSc degrees in ECE between 2011 and 2021. In some departments, such as CHE and BME, there has not been a significant difference between the AGEI for women and men. In AER and MMS, the AGEI for women has fluctuated significantly from year to year. This fluctuation is due to the exceptionally small number of women in graduate degrees in these departments; having a few more or less women among applicants or offer recipients changes the index and admission success rate significantly.

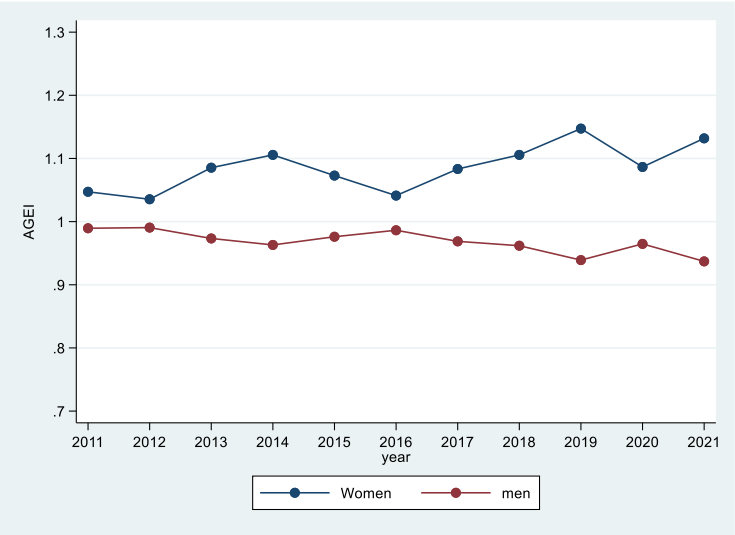


Figure 8: Admission Gender-Equality Index (AGEI) across the engineering faculty

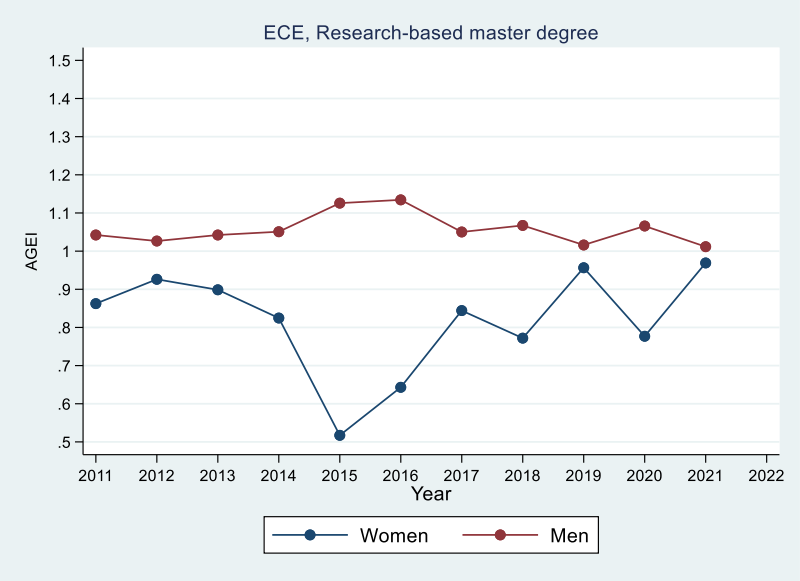


Figure 9: AGEI at ECE, research-based master's degree

Discussion and conclusion

The findings, as discussed above, revealed that despite the rise in the number of female applicants and offer recipients in graduate degrees in engineering between 2011 to 2021, their proportion of all applicants and admissions has only increased by less than 12% in ten years. This indicates that the number of women in engineering graduate degrees has remained low, and gender disparity is still present. To better understand and address the issue, we examined the intersectional effects of citizenship status and gender in the admission and application patterns in engineering graduate studies. This is one of the few studies to focus on gender patterns, intersecting with citizenship status, in the application and admission processes in each engineering department and graduate degree. Such disaggregated analysis helped identify the potential spaces for effective interventions to address gender disparity and some of its root causes. Here, we elaborate on four areas that, based on our findings, could potentially address gender disparity in the engineering faculty.

1. Support first-year undergraduate students

We showed that the decision to apply for graduate degrees and the admission success rate correlate with grade-based academic performance. The average of applicants' grades has been significantly higher than all undergraduate students. In addition, applicants with higher grades have had a significantly higher chance of receiving an offer to graduate programs. We also observed that undergraduate students, particularly women, had their lowest grade-based academic performance in their first year of study, negatively affecting their application packages.

The first year has a greater impact on female students academic performance. Lower undergraduate grades can affect women's pursuit of graduate degrees in two ways. First, it

impacts their self-evaluation of their chance of admission success and, therefore, their decision to apply for graduate programs. Second, even though their grades in their final years of studies have advanced significantly, the negative impact of the first-year grades is reflected in their undergraduate grade average point, which lowers their chances of admission. Therefore, providing support and making efforts to improve first-year undergraduate students' grades in engineering, with particular attention to female students, can build a pathway for women into graduate degrees.

2. Targeting populated engineering departments with a high number of female applicants

Achieving gender parity in the most populated engineering departments has the greatest impact on gender parity in the engineering faculty. MIE and ECE, followed by CIVIL in the researched university, have received the highest number of graduate applicants and students in the engineering faculty. These departments have the opportunity to choose from a larger pool of applicants in their graduate admission process. As discussed earlier, women's admission success rate, and therefore their AGEI (Admission Gender-Equality Index), in some of these departments (MIE and CIVIL) have been higher than their male counterparts throughout most of the years between 2011 and 2021. In contrast, women's AGEI at ECE has been constantly lower than men's. In addition, graduate applicants have had the lowest admission success rates at ECE (17% to 20%), particularly women. For instance, in 2015, AGEI for women for research-based master's degrees at ECE was as low as 0.5. In more detail, women accounted for 20.3% of 508 applicants to the MSc degree, but only 10.5% of 76 offer recipients were women. We argue that the large pool of non-selected female applicants allows the department to find and select competent applicants. This process might require revising the admission criteria, diversifying admission requirements, or implementing reach-out programs to targeted undergraduate students or specific interventions to boost female undergraduate students' academic performance. The main point is to leverage the substantial number of female applicants to enhance gender parity in graduate degrees.

The emphasis here is on the importance of considering each department and degree as the unit of analysis to identify the critical stages that women are negatively affected on their way to graduate studies. These stages vary department by department and degree by degree. For instance, in some departments and degrees, despite high growth rates in the number of female applicants or women's higher admission success rate compared with men's, the numbers of female applicants and offer recipients have remained small, and gender disparity exists. For instance, despite the 250% growth in the number of female applicants to graduate degrees at AER from 2011 to 2021 and women's higher admission success rate than men's in 2021, they still accounted for only 16% of all applicants in 2021. Therefore, effective interventions need to focus on increasing the number of women who decide to apply for graduate degrees. In comparison, CIVIL has had a relatively large pool of female applicants to graduate degrees, and women's admission success rates have also been constantly higher than men's. However, only 51% of admitted women enter their graduate programs. Therefore, tackling existing gender

disparity in CIVIL department calls for strategies to make graduate studies more responsive to women's needs, so more female offer recipients decide to register for their graduate programs.

3. Learning from positive deviants

Our findings show that some of the departments have been able to nearly achieve gender parity in women's admission success rate in their graduate degrees. These examples could serve as role models for other departments or for other graduate degrees in the same department. For instance, the AGEI for women in research-based master's degrees in MMS has been rising since 2015 (except in 2021 when the index fell again). This rise has happened even though the number of women in graduate degrees has historically been exceptionally low, AGEI for women has been lower than that for men in many years between 2011 and 2021, and the admission success rate has been low (20-30%) in this department. Investigating factors involved in such a significant increase in women's admission success rate can have valuable lessons for other engineering departments. Despite the rise in the number of offers to female recipients, women's entry rate (proportion of female offer recipients who entered the graduate program) has been declining since 2018, keeping the number of women in graduate degrees low in MMS. Therefore, efforts to understand why a high percentage of admitted women to graduate degrees at MMS do not enter the program and address those issues can effectively improve gender parity in the department.

4. Enhance domestic students' application rate and international applicants' admission success rate

As discussed in the finding section, international students were significantly more prone to apply for graduate programs than domestic students. The graduate application rates varied significantly for domestic and international undergraduate students. While only 30% of domestic female and almost 34% of domestic male undergraduate engineering students at the researched university applied for engineering graduate studies at their university, almost all international undergraduate students, regardless of gender, applied for graduate programs. The number of international female applicants has had the highest growth rates compared with applicants from other intersectional identity groups. International applicants accounted for more than 68% of all applicants and only 49% of all admissions in engineering between 2011 and 2021. International applicants' admission success rates have been constantly lower than their domestic counterparts (21% versus 47% for all graduate engineering admissions). The high number of international male and female applicants and their low admission success rates call for revising admission strategies for international students.

The admission process is also more competitive for international applicants than domestic applicants. The admitted international students had also higher grade-based academic performance compared with their domestic counterparts. International students have primarily been admitted and entered course-based master's of engineering programs (Meng), where they do not receive funding from the university. Financial burdens for the university and international applicants can lead to untapped talents from a diverse competent population. Therefore,

systematic changes in providing more financial support for international students can improve gender and race parity in the engineering departments.

The declining proportion of domestic men and stagnant proportion of domestic women from the total number of applicants to graduate degrees, as well as domestic undergraduate students' low application rate, call for interventions to encourage domestic undergraduate students to apply for graduate degrees in engineering. This is the case particularly in ECE and MIE, where domestic female undergraduate students had the lowest rates of application to graduate degrees (21.7% and 22%, respectively).

In sum, gender rarely was a direct factor negatively affecting admission success rate. However, in intersection with other factors, such as citizenship status, baccalaureate origin, and undergraduate first years of study academic performance, admission and application patterns in graduate engineering departments varied by gender. The mining of institutional data identifies but does not fully explain these patterns in the graduate application and admission processes. These findings have informed the next phases of this research project, including one-on-one interviews with faculty, staff members, and students in engineering, a students' survey, and focus groups with engineering students. These multimodal approaches provide a holistic understanding of the challenges and barriers women face on their way to pursue graduate studies in their respective subfields of engineering and suggest targeted alternatives to address those challenges.

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