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# Gender and mathematics: Pathways to mathematically intensive fields of study in Australia

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ABSTRACT

Women in Australia have gone from being under-represented to being over-represented in university education, but they are still far less likely than men to engage in mathematically intensive science fields including engineering, information technology and the physical sciences. I aim to contribute to the literature by examining the extent to which secondary school educational experiences and occupational expectations explain the gender gap in the choice of a mathematically intensive university major. I used logistic regression models and the KHB method to analyse the data from the 2003 cohort of the Longitudinal Survey of Australian Youth. Overall, I found that about 28 percent of the gender gap could be explained by students' expectations of a mathematically oriented career while in secondary school, self-assessed mathematical competence in adolescence and engagement in advanced mathematics and physical science subjects in the final year of secondary school. The results of the KHB method demonstrate that the expectation of a mathematically oriented career has the greatest potential to bridge the gender gap.

## 1. Introduction

While women in Australia and overseas have been steadily increasing their participation in tertiary education, men and women around the globe tend to concentrate in different fields of study and employment (Charles & Bradley, 2009; Charles & Grusky, 2004). In line with this trend, Australian tertiary education continues to be strongly segregated by gender (Bell, 2010). Specifically, women are under-represented in mathematically intensive science fields including engineering, information technology and the physical sciences (Sikora, 2014, 2015).[1] This phenomenon has long-lasting and possibly unfavourable consequences. Firstly, subject choice has a direct bearing on the occupational trajectories of men and women. Since the beginning of the twenty-first century, employment opportunities in mathematically intensive fields that require strong quantitative skills have dramatically increased in Australia (Australian Bureau of Statistics, 2014). Women's under-representation in mathematics-related fields of study may not only hinder them from taking up opportunities in the thriving industries (Graduate Careers Australia, 2014) but it may also contribute to the pay gap between men and women (Brown & Corcoran, 1997; Gerber & Cheung, 2008; Mitra, 2002; Paglin & Rufolo, 1990). Across the world in the fields where women are often over-represented, such as teacher training, education and humanities, young workers carry a wage penalty (OECD, 2014). Secondly, gender segregation in fields of study may reinforce the beliefs in innate gender differences, including the view that males are more suitable for mathematically intensive fields of study and careers. Such beliefs, when widely shared across society, steer adolescents towards aspiring to gender-typical occupations (Charles & Bradley, 2009; OECD, 2006). When young women, particularly those who are talented in mathematics, avoid mathematically intensive fields of study because they perceive that those disciplines are not appropriate for their gender, their talents are under-utilised and their individual potentials are wasted.

Given these consequences, however, previous studies have rarely examined from a life course perspective how occupational expectations, self-assessed mathematical competence and subject choice in secondary school influence the decisions of young Australian men and women to engage in mathematically intensive disciplines. As suggested by the stratification theory of gender essentialism, the gender essentialist ideology which puts an emphasis on innate differences between males and females is ubiquitous, particularly in advanced industrial societies which include Australia (Charles & Bradley, 2009). Children internalise gender stereotypical beliefs through socialisation and convert them into gender-differentiated aspirations and preferences that affect their

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[1] I follow Ceci and Williams (2010b); Ceci, Williams, and Barnett, (2009) and use 'mathematically intensive fields' to denote the science fields requiring intensive use of mathematics. They include architecture, engineering, information technology, and the mathematical, earth and physical sciences. These fields are often regarded as masculine, whereas other science fields, such as the biological and environmental sciences, are viewed as feminine (Blickenstaff, 2005).

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subject choice in secondary and tertiary education (Blau et al., 2006; Charles & Bradley, 2009). Such gender differences may emerge in occupational expectations and self-assessed mathematical competence during adolescence (Correll, 2001; Tai, Li, Maltese, & Fan, 2006). Using the theory of gender essentialism, in this study, I assess how occupational expectations, self-assessed mathematical competence and subject choice in secondary school may facilitate gendered choices of mathematically intensive university studies in Australia.

A comprehensive analysis of the factors that affect students' engagement in mathematics and cognate disciplines calls for high quality data that do not only represent the entire cohort of young Australians but also provide information on their occupational expectations and educational experiences regarding mathematics. To this end, I use data from the 2003 cohort of the nationally representative Longitudinal Survey of Australian Youth (LSAY), also known as Y03 (National Centre for Vocational Education Research [NCVER], 2011). This cohort reached age 15 around 2003 and entered the labour market in the decade that followed. I commence my observations of youth from the time when they were age 15 and focus on describing how adolescent boys and girls differ in their occupational expectations, self-assessed mathematical competence and subject choice in secondary school. Following that, I examine how each of these characteristics contributes to the choice of a mathematically intensive major at university along the gender divide.

## 2. Australia's contemporary education system and its mathematics and science curriculum in senior secondary school

To understand how the Australian education system might provide opportunities for students to make gendered educational choices, in this section I discuss Australia's contemporary education system and its mathematics and science curriculum with an emphasis on when and how students make their subject choice.

In Australia, each state or territory is responsible for their own educational administrations and curricula, although the overall structures are similar.[2] The generation of contemporary 15-year-old Australian students in general start their encounter with formal education at the age of 3 or 4 when they participate in early childhood education programs, that is, kindergarten. By the time Australian children reach the age of 5 or 6, they begin their compulsory education from Year 1 to Year 10. In primary school and the first two years of secondary school, students typically follow a general program provided by their school. In the subsequent years of secondary education, they study basic core subjects and select optional subjects. In senior secondary school (Years 11 and 12), most schools offer a broad variety of subjects and students specialise in five or six elective subjects. Students are entitled to choose the combination of subjects that they and their school advisers deem appropriate for their future education and employment (Wernert, Thomson, Ainley, & Schmid, 2012).

Australian schools offer different levels of mathematics subjects and a wide variety of science subjects to Years 11 and 12 students. Every state and territory adopts its own subject labels with varied curricula. Ainley et al. (2008) point out three features regarding subject labels: (1) they may differ between states and territories, although the course content is similar; (2) they may change over time even though there are only minor changes in content; (3) sometimes the same subject label refers to subjects with different content.

Senior secondary mathematics subjects can be classified across states and territories based on their levels of difficulty as elementary, intermediate and advanced, although states and territories do not use these three labels in their subject names (Barrington & Brown, 2005; Forgasz, 2006). Advanced mathematics subjects refer to the prerequisites or assumed knowledge that provide students with the best start in tertiary studies that require significant mathematical preparations, such as engineering, information technology, mathematics and the physical sciences.[3] They encompass calculus, complex numbers, algebra and trigonometric functions, as well as a selection from coordinate geometry, mechanics, logic and proof, sequences and series, vectors and matrices, although the coverage of these topics varies among states and territories (Barrington & Brown, 2005).

Advanced mathematics and physical science subjects in Year 12 are not necessary the prerequisites for the admission to mathematically intensive programs at university. In the past, Australian students who did not study advanced mathematics and physical science in senior secondary school limited their tertiary study options and excluded themselves from further education in mathematically intensive fields. However, this has become less of a problem since the beginning of the twenty-first century. In response to the declining number of students who enroll in advanced mathematics and physical science in senior secondary school, over the last two decades many Australian universities have changed their program prerequisites (Varsavsky, 2010). Today, not all engineering programs across the country require advanced mathematics as some of them have changed the prerequisites from advanced to intermediate mathematics. Many science programs admit students without any senior secondary school mathematics or science. Nevertheless, advanced mathematics and physical science subjects in Year 12 act as a critical filter of intentions to study and engage with those degree programs (Ainley, Kos, & Nicholas, 2008; Varsavsky, 2010).

## 3. Explaining the under-representation of women in mathematically intensive fields

Over the last three decades, Berryman (1983) introduction of the 'leaky pipeline' argument has been widely employed to describe the under-representation of women in the mathematically intensive sciences (Blickenstaff, 2005; Miller & Wai, 2015). According to the logic of this argument, women are more likely than men to leak out from the mathematically intensive 'pipeline' at various stages. Despite the many features the 'leaky pipeline' argument offers, it does not consider how the sociocultural environment interacts with individual characteristics to contribute to the leakage of females from the mathematically intensive pipeline. Therefore, other theories must be called upon to understand why females' participation in mathematically intensive fields still falls short of the desired levels.

Early stratification studies have argued that females are less likely to engage in mathematically intensive fields because they outperform males in verbal skills but fall behind males in mathematics at school (Jonsson, 1999; Van de Werfhorst, Sullivan, & Cheung, 2003). Nevertheless, recent research provides evidence against the early findings. Using national data from three cohorts of high school and tertiary students in the 1980s, 1990s and 2000s, an American study shows that the advantage boys had in mathematics and girls had in verbal achievement does not explain satisfactorily why women are far less likely than men to engage in mathematics-related tertiary studies (Riegle-Crumb, King, Grodsky, & Muller, 2012). Reviews of prior studies conducted from the 1980s to the 2000s and mostly in the United States also point out that the male advantage in mathematical and spatial ability does not adequately explain why men are largely over-represented in mathematically intensive fields (Ceci & Williams, 2010a, 2010b). These findings suggest that other factors than mathematics achievement contribute

[2] Australia is a federation of six states – New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia – and two territories – the Australian Capital Territory and the Northern Territory.

[3] This definition was drawn from previous Australian research on school mathematics enrolment (Barrington, 2006; Barrington & Brown, 2005; Dekkers & Malone, 2000; Forgasz, 2006; Fullarton et al., 2003).

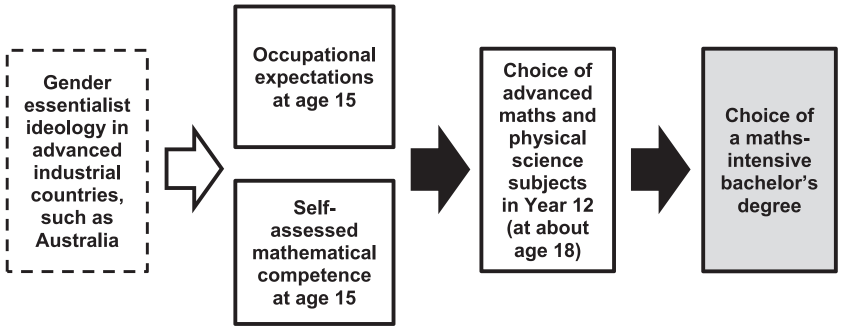


**Fig. 1.** Key factors that may influence a student's chance of choosing a mathematically intensive university major in Australia: gender-essentialist ideology, occupational expectations, self-assessed mathematical competence and subject choice in Year 12.
Note: Boxes with solid lines contain the variables I measure in my analysis. I do not directly measure the variable in the box with dashed lines or model the causal relationships represented by the white arrow.

to the under-representation of women in mathematically intensive fields.

In Fig. 1, I present the theoretical framework of this study. The theory of gender essentialism suggests that in advanced industrial societies, such as Australia, students' engagement in mathematically intensive fields of study is shaped by gender stereotypical beliefs and self-expressive values that flourish in comprehensive educational systems and service economies (Charles & Bradley, 2009; Charles, Harr, Cech, & Hendley, 2014). The gender essentialist ideology involves the widely shared stereotypical beliefs that males and females are fundamentally and inherently different by nature. These stereotypes, subtly communicated and omnipresent, seep into the minds of young people to facilitate an acceptance of the beliefs that females are naturally good at care and inter-human communication while males excel at abstract problem solving and in technology (Barone, 2011). Children internalise such gender stereotypical beliefs, including the belief that it is natural to expect males to surpass females in mathematics and technology. Such internalisation happens through socialisation and is likely to manifest itself in gender-differentiated expectations and preferences (Blau et al., 2006; Charles & Grusky, 2004; Correll, 2001, 2004).

Gender stereotypical beliefs are reinforced when the culture underscores and legitimises individual self-expression in making educational choices, and therefore young people can engage in fields of study that fit in with their gendered identities. Specifically, young men tend to dominate mathematically intensive fields because they construe mathematics as a means of proving their masculine abilities (Mendick, 2003, 2005b). Young women must negotiate this cultural boundary which makes it harder for them to engage and remain engaged in mathematics and related fields, as well as to feel competent and comfortable (Mendick, 2005a). Mathematical and technical work is often depicted as abstract, rigid, tedious, offering few opportunities for interacting with other humans and allowing for an emphatic creativity or the expression of individual personalities into the work process (Faulkner, 2007; Osborne, Simon, & Collins, 2003). Thus the popular perception of mathematical fields is that they are less likely than other work to be perceived as enjoyable and self-expressive (Charles et al., 2014). Previous studies in the United States have demonstrated that students who value people-oriented jobs and working with other people have a low chance of entering male-dominated professions (Cech, 2013) and showing interest in science careers, including those in the mathematically intensive fields (Diekman, Brown, Johnston, & Clark, 2010). As females tend to rate their level of people orientation higher than males (Su, Rounds, & Armstrong, 2009), the implications of these perceptions should not be underestimated.

The theory of gender essentialism also suggests that the structural features of the educational system and the labour market in Australia contribute to gender segregation in fields of study (Charles & Bradley, 2002, 2009). The comprehensive education system in Australia offers plentiful options not only in secondary school curricula but also in university majors for students, and encourages students to pursue only fields of study they are good at and interested in. This enables women to have a higher chance of engaging in female dominated specialisations, such as the humanities, social sciences and life sciences, than students in developing or transitioning countries in which their educational systems usually do not provide a wide range of curricular options (Charles & Bradley, 2009). The Australian service economy provides abundant job opportunities that are perceived to be self-expressive, social and people-oriented. When the gender essentialist ideology and the system of self-expressive values converge, as is arguably the case in Australia, the expected consequence is that females will be less likely to pursue mathematically intensive fields when cultural stereotypes that link these fields to self-expression and social interactions are absent (Charles & Bradley, 2009). Instead, abundant female-labelled opportunities exist in areas other than mathematics in education and the labour market. These opportunities attract young women's attention also because they are already dominated by other women.

### 3.1. Gender-typed occupational expectations

The theory of gender essentialism suggests that the occupational expectations of students reflect their perceptions of stereotypes regarding mathematics and the gender roles expected of them, as well as opportunities and constraints, which are shaped by socialisation that takes place in the family, school and society (Charles et al., 2014). Children may internalise the gender stereotypical beliefs that certain occupations and job tasks, such as those related to the mathematically intensive sciences, are more suitable for men than for women. In line with this argument, early research has demonstrated that gender differences in occupational expectations emerge in childhood and adolescence (McMahon & Patton, 1997; Tai et al., 2006). Although very often students change their occupational expectations during adolescence and early adulthood (Rindfuss, Cooksey, & Sutterlin, 1999), in the early 1990s American adolescent boys were found to be more likely than girls to continue to expect science and engineering careers (Mau, 2003).

Not only do teenage occupational expectations predict adult educational attainment (Beal & Crockett, 2010), but they may also have a strong impact on the field of study choices of young men and women. Recent Australian studies have shown that students who expected a career in the physical sciences were more likely to engage in relevant fields of study in post-secondary education (Sikora, 2014, 2015). As men were more likely to expect a physical science career, their chances of enrolling in related fields were enhanced at the post-secondary level (Sikora, 2014, 2015). Two American studies using data from the early 1990s and early 2000s respectively have found that some of the gender gaps in choosing and attaining a bachelor's degree in science could be explained by students' occupational expectations in high school (Legewie & DiPrete, 2014; Morgan, Gelbgiser, & Weeden, 2013). Along the same lines, a recent study has shown that over one-third of the gender gap in college field of study enrolment in Germany could be explained by gendered vocational interests in social, artistic and practical tasks when students entered college (Ochsenfeld, 2016). Thus, in this study, I contribute to the Australian literature by examining whether teenage occupational expectations have a prolonged impact on gender differences in field of study choices.

### 3.2. Gender-biased self-assessment of mathematical and verbal abilities

Another critical reason why females are under-represented in mathematically intensive fields of study is that they have lower self-assessment of mathematical task competence compared to males (Correll, 2001). Previous stratification studies in the United States suggest that the stereotypical belief that males perform better in mathematically intensive fields than females may increase males' self-assessment of their mathematical abilities and interest in pursuing careers in those fields but lower those characteristics of females (Correll, 2001, 2004). Along the similar lines, psychological research has argued that the stereotypical belief that mathematics is masculine and more appropriate for males may enhance the confidence of males in mathematics while increasing females' anxiety (Niederle & Vesterlund, 2010; Spencer, Steele, & Quinn, 1999; Steele, 1997). Females who strongly believe in this stereotype tend to avoid mathematics and related disciplines (Nosek & Smyth, 2011). Psychology scholars often regard one's perception of their abilities or competencies in mathematics as mathematics self-concept (Marsh, 1986, 1990). Even when boys and girls perform equally well in mathematics, boys tend to have higher self-concept in the subject (Wilkins, 2004). Although students' mathematics self-concept tends to decline when they progress to higher years of study in secondary school, the gender gap in mathematics self-concept remains unchanged (Nagy et al., 2010). In Australia, the gender gap in mathematics self-concept has remained stable over the last two decades (Parker, Van Zanden, & Parker, 2018). A study using student data collected in Germany from the 2000s shows that male advantage in mathematics self-concept in high school facilitated male dominance in mathematically intensive tertiary education (Parker, Nagy, Trautwein, & Lüdtke, 2014).

Gender differences in self-assessment of verbal abilities may also contribute to the under-representation of females in mathematically intensive disciplines. Using nationally representative student data from the 1990s, an American study shows that students who had higher self-assessment of their English abilities were less likely to enrol in high school calculus and engage in mathematically intensive tertiary education (Correll, 2001). Consistent with the stereotypical belief that females are better in verbal skills, girls had higher self-assessment of their English abilities than boys. Such gender-biased self-assessment may further lower the chance of females to choose mathematically intensive fields. Another study using the German student data from the late 2000s demonstrates that self-assessment of the comparative advantage between technical and language proficiency contributes to the gender gap in the choice of a technical field of tertiary education, including those in the mathematically intensive sciences (Lörz, Schindler, & Walter, 2011).

### 3.3. Advanced mathematics and physical science course-taking in secondary school

Research in the United States has shown that students who pursue mathematically intensive tertiary studies tend to have taken relevant subjects in high school (Correll, 2001). As boys are more likely than girls to enrol in advanced mathematics and physical science subjects in Australian secondary schools (Kennedy, Lyons, & Quinn, 2014), one may expect that subject choice in secondary school facilitates gendered engagement in mathematically intensive university studies. Thus far, however, existing studies have arrived at mixed conclusions. During the late 2000s, young Australians, particularly women, were more likely to pursue post-secondary education in the physical sciences if they studied a relevant subject in Year 12 (Sikora, 2014). Using the American student data from the 1980s, Ethington and Woffle (1988) found that the number of mathematics and science courses girls selected in high school increased their likelihood of pursuing tertiary studies in the mathematically intensive sciences. On the contrary, using the same data, an American study demonstrates that the proportion of women selecting engineering would only increase a little even if girls' enrolment in high school mathematics and science courses rose (Frehill, 1997).

In Australia, the study of advanced mathematics and physical science subjects in Year 12 provides students with comprehensive preparation for many tertiary fields of study that involve calculus and knowledge in the physical sciences (Ainley et al., 2008; Fullarton, Walker, Ainley, & Hillman, 2003). Students who study physical science subjects also tend to enrol in advanced mathematics subjects (Lamb & Ball, 1999). Some students, however, enrol only in physical science subjects without choosing any advanced mathematics subject (Kennedy et al., 2014). Recent studies have found that students who study physical science subjects in Year 12 have a high chance of choosing similar studies in post-secondary education (Sikora, 2014, 2015). We do not know, however, whether enrolment in the common subject combination – advanced mathematics and physical science subjects – is more differentiated by gender than enrolment in only physical science subjects, and whether the common subject combination further enhances gender differences in university major choices. Therefore, in the present study, I assess how enrolment in advanced mathematics and physical science subjects in secondary school may contribute to the gendered choices of mathematically intensive university studies.

### 3.4. The role of significant others

Prior research has demonstrated that parents, who are the primary and one of the most influential socialising agents in childhood and adolescence, may be more likely to encourage males to pursue mathematically intensive fields. Not only do parents tend to overrate boys' mathematical abilities (Tiedemann, 2000), but they are also more likely to believe that it is more important for boys than girls to engage in advanced mathematics subjects (Eccles & Jacobs, 1986; Eccles, Jacobs, & Harold, 1990). In line with these early findings, a recent study which used cross-national student data has shown that parents rate mathematical competence as more important for sons than for daughters (Stoet, Bailey, Moore, & Geary, 2016). Another recent study using student data from Israel has also found that parents are more likely to encourage their sons than their daughters to study mathematically oriented science subjects in high school (Gabay-Egozi, Shavit, & Yaish, 2015). Girls are conscious of the lower expectations and valuation of mathematics from their parents and may thus lower their aspirations and reduce their interest and effort with respect to mathematics learning (Eccles & Jacobs, 1986; Jacobs & Eccles, 1992). These gender-specific socialisation practices continue to influence the educational decisions of students as they progress through the tertiary education system (Camp, Gilleland, Pearson, & Putten, 2009).

Teachers and peers may also influence the decisions of adolescent boys and girls to pursue mathematically intensive disciplines. At school, teachers may be inclined to overrate boys' mathematical competence and to have higher expectations for boys in mathematics education (Li, 1999). When girls are aware of the gender bias in their teachers' perceptions of their mathematical competence and expectations, they may adjust their attitudes and expectations regarding mathematics-related education correspondingly. In Germany, in classrooms where strong masculinity norms are present, girls perform worse in mathematics, while in classrooms where traditional masculinity norms are weak or absent, girls perform equally well with boys in mathematics (Salikutluk & Heyne, 2017). During the 1990s in the United States, girls' decisions to engage in advanced mathematics were more likely than those of boys to be influenced by the performance of the same-sex peers around them (Riegle-Crumb, Farkas, & Muller, 2006). More recently in Israel, boys were more likely than girls to have friends who chose mathematically oriented science subjects (Gabay-Egozi et al., 2015). In summary, significant others, including parents, teachers and peers, play an important role in the field of study choices of young men and women.

## 4. Research question

As discussed in the previous section, prior research has shown that occupational expectations, mathematics self-concept and secondary school preparation in the early stage of life are the key factors that influence gendered participation in mathematically intensive university education. Nevertheless, the relative importance of these factors has not yet been examined in the Australian context. Therefore, in my analysis, I assess the relative contributions of these factors and focus on the following research question:

- What is the relative importance of students' occupational expectations, mathematics self-concept, and choice of advanced mathematics and physical science subjects in secondary school in explaining the gender gap in the choice of a mathematically intensive university major?

## 5. Data and variables

### 5.1. Data

The LSAY Y03 data was built on the Australian sample from the Programme for International Student Assessment (PISA) 2003 of the Organisation for Economic Co-operation and Development (OECD, 2005). The primary focus of PISA 2003 was an assessment of mathematical literacy among 15-year-old students enrolled in school. A two-stage stratified sampling design was used for PISA. In the first stage, schools were sampled, and then in the second stage, a sample of 15-year-old students within the school was selected (Thomson, Cresswell, & De Bortoli, 2004). The Australian sample was designed to be a representative of 15-year-old students across all states/territories and school sectors in Australia, using state/territory, school sector and region (metropolitan or non-metropolitan) as strata (National Centre for Vocational Education Research NCVER, 2011). A total of 10,370 Australian students who participated in the 2003 cycle of PISA were included in Y03. Due to the sampling design of PISA, the Y03 sample is age-based and most 15-year-old students were attending Year 10 in 2003 while some were attending other grade levels.

While PISA contains contextual background information and educational achievement data from participating students and schools, Y03 extends the PISA survey by collecting information about students' educational and occupational experiences annually until 2013. Data from more recent cohorts of LSAY (2006, 2009 and 2015) do not provide as comprehensive information on students' mathematics learning as the 2003 data because their foci were on science or reading.

In this study, I examine the educational pathways of men and women from age 15 through Year 12 to the engagement in mathematically intensive fields at university. Therefore, I restricted the sample for analyses to participants who reported that they completed Year 12, enrolled in a bachelor's degree program between 2004 and 2013, and provided information about their fields of study. Specifically, I selected participants who completed Year 12 and 6747 participants met this criterion. Among these participants, 3712 enrolled in a bachelor's degree program after completing Year 12. They comprise about 36 percent of the 10,370 respondents in the original Y03 sample. A total of 210 participants did not report their fields of study, and therefore the resulting pooled sample for the analyses comprises 3502 participants, which is about 34 percent of the original sample size of Y03. These percentages are comparable to the data provided by the Australian Bureau of Statistics (2017): about 35 percent of the Australian population aged between 25 and 29 years in 2013 attained a bachelor's degree or higher.[4]

Although Y03 provides a wealth of information about students' occupational expectations and educational experiences regarding mathematics, a drawback of using the Y03 data is attrition bias, which is a common issue in longitudinal surveys. The rate of attrition in Y03 was approximately 10 percent in every follow-up survey after the first wave (National Centre for Vocational Education Research NCVER, 2011). Attrition was more common among respondents from families of lower socioeconomic status and respondents with lower achievement scores (Department of Education & Training, 2014; Lim, 2011). As participants withdrew from Y03, the remaining sample becomes different from the one in the first wave. Statistical methods, such as the use of sampling weights and imputation, are helpful in resolving some of the attrition bias (Lim, 2011). These methods will be discussed in Section 5.3.

### 5.2. Variables

#### 5.2.1. Dependent variable: majoring in the mathematically intensive sciences

The dependent variable is students' enrolment in a bachelor's degree program in mathematically intensive science fields. They encompass all subfields within the following broad categories listed in the Australian Standard Classification of Education (ASCED) (Trewin, 2001): mathematical sciences, physics and astronomy, chemical sciences, earth sciences, information technology, engineering and related technologies, and architecture and building.[5] These fields of study are dominated by men and they require high-level mathematical knowledge involving calculus.

#### 5.2.2. Key independent variables

Whether a student chooses mathematically intensive university studies depends on a combination of student and school background. I emphasise here the specific characteristics of the teenage educational

[4] The Y03 participants were about 15 years old in 2003. They became about 25 years old in 2013, and therefore in the same year they belonged to the age group 25-29 years in the data provided by the Australian Bureau of Statistics (2017).

[5] Some architecture and building programs in Australian universities require or recommend the study of Year 12 advanced mathematics, and in the present study architecture and building are regarded as mathematically intensive. As discussed in Section 2, not all mathematically intensive university programs in Australia, including engineering, list advanced mathematics as their prerequisite study for admission. The current admission criteria of each bachelor's degree program can be obtained from the website of the Universities Admissions Centre (https://www.uac.edu.au/).

experiences and occupational expectations that may enhance the chance of enrolling in mathematically intensive university studies. With this objective in mind, I use the following students' characteristics as predictors:

*5.2.2.1. Female*. The focal independent variable is gender (female) where 1 denotes females and 0 denotes males.

*5.2.2.2. Mathematics achievement at age 15*. I measure students' mathematics achievement by PISA's five plausible values that capture students' numeracy at age 15 (OECD, 2005). The testing time in PISA is restricted to reduce student burden and minimise interruptions to the school schedule (Von Davier, Gonzalez, & Mislevy, 2009). Therefore, participating students do not answer all test items that are necessary to cover the topics specified in the PISA assessment framework document. Instead, the mathematics performance of individual student is measured with a subset of the total item pool. Such a measurement contains a substantial amount of measurement error. To account for the measurement error and obtain unbiased population estimates, PISA generates five plausible values based on the students' response to the subset of items they answer using multiple imputations. These plausible values are not test scores; they represent the likely distribution of a student's proficiency in mathematics and they have a mean of 500 and a standard deviation of 100 (OECD, 2005; Von Davier et al., 2009). In the logit models, I standardised mathematics achievement to a mean of 0 and a standard deviation of 1.

*5.2.2.3. Occupational expectations – expected a mathematically intensive career at age 15*. In PISA 2003, students were asked what occupations they expected to have when they would be about 30 years old (OECD, 2005). The responses were coded to four-digit International Standard Classification of Occupations (ISCO-88) codes (International Labour Office [ILO], 1990). Using the ISCO-88 codes, Sikora and Pokropek (2012a) classified some of the occupations under the field of computing, engineering or mathematics. I identified whether those occupations in their classification would be mathematically intensive by matching them with the occupations that call for a mathematically intensive degree listed in the guides for students to the job market in Australia (Australian Mathematical Sciences Institute, 2015, 2016).[6] The examples of such an occupation include computer programmers, engineers, mathematicians, physicists and statisticians (see Appendix A).

*5.2.2.4. Mathematics self-concept at age 15*. I measure mathematics self-concept by a PISA scale that comprises students' self-evaluation in response to the following five statements: 'I am just not good at mathematics', 'I get good marks in mathematics', 'I learn mathematics quickly', 'I have always believed that mathematics is one of my best subjects', and 'In my mathematics class, I understand even the most difficult work'. Higher values indicate more positive self-concept in mathematics. In Australia, Cronbach's alpha for this scale is 0.89 (OECD, 2005).

*5.2.2.5. Relevant subject choice in Year 12*. To better understand the broader context in which young people make decisions about transitioning from secondary to university education, I examine specialisation in advanced mathematics in the context of enrolment in other subjects. In particular, it is important for me to consider whether the gender gap in the choice of a mathematically intensive university major is fostered by the possibility that boys and girls tend to select different combination of subjects in secondary school. As discussed in Section 3.3, Australian students who are engaged in mathematically intensive tertiary fields of study tend to have studied physical science subjects in conjunction with advanced mathematics in Year 12 (Lamb & Ball, 1999). Nevertheless, some students enrol in physical science subjects only but do not study any advanced mathematics subject (Kennedy et al., 2014). It is possible that boys may supplement their choice of physical science with more advanced mathematics subjects. This may be less the case for girls. Therefore, apart from the abovementioned predictors, I include an additional set of independent variables to denote the subject choice related to the mathematically intensive sciences in Year 12 when the majority of students turned 18 years old and were about to enter tertiary education.

To identify whether different subject combinations in secondary school are relevant to the gender gap in selecting a mathematically intensive university major without unnecessarily complicating my analysis, I classify subject choice related to mathematically intensive fields into three categories: (1) the first comprises students who enrolled in at least one subject in advanced mathematics and at least one subject in physical science, (2) the second comprises students who took at least one subject in physical science but did not enrol in advanced mathematics, and (3) the third comprises students who took at least one subject in advanced mathematics but did not enrol in physical science. In the logit models, I compare these students to others who took other subject combinations belonging to my reference category in the language of regression analysis. These combinations include enrolment in at least a subject in life science only without any enrolment in physical science courses, and no enrolment in science.

Every Australian state and territory adopts its own subject labels with different curriculum content (Ainley et al., 2008). Nevertheless, across all states and territories in Australia, advanced mathematics subjects contain significant calculus content which prepares Year 12 students for further education in the mathematically intensive sciences (Barrington & Brown, 2005; Fullarton et al., 2003). Appendix B lists all the subjects which have been categorised by Ainley et al. (2008, pp. 26–28) as advanced mathematics between 2003 and 2006, that is, in the time period in which the Y03 cohort were attending Year 12. Appendix B also presents all the physical science subjects taught between 2003 and 2006 that I have classified as being related to the mathematically intensive sciences. This classification is a matter of judgement and subject to possible adjustments, but I have relied on a number of previous studies to guide me (Ainley et al., 2008; Sikora, 2014). Therefore, I am confident that this conceptualisation represents a realistic and valid approach to understanding how secondary school subject choice may affect the transition of students to the tertiary study of mathematically intensive degrees.

*5.2.3. Key control variables*

*5.2.3.1. Family's socioeconomic status*. Earlier Australian studies have shown that students from privileged families, who are likely to attend schools in high socioeconomic communities, tend to enrol in advanced academic subjects which include advanced mathematics and physical science (Ainley et al., 2008; Lamb, Hogan, & Johnson, 2001; Teese, 2007). Therefore, I control for the socioeconomic status of a student's family by including the PISA index of economic, social and cultural status. This index was derived from three variables related to students' family background at age 15: the highest educational level of both parents, the highest occupational status of both parents and the number of home possessions that encompass cultural possessions, computer facilities and educational resources at home. The index was standardised to a mean of 0 and a standard deviation of 1 across the member countries of the OECD that participated in PISA 2003. Larger values indicate higher socioeconomic status. In Australia, Cronbach's alpha for this index is 0.61 (OECD, 2005).

[6] *MATHS ADDS: A guide for students to the job market* is an annual publication of the Australian Mathematical Sciences Institute that highlights the specific job opportunities available to students with a mathematically intensive degree in Australia.

*5.2.3.2. Maternal and paternal employment in science.* Parental employment in science should be taken into consideration because it is a source of cultural capital that increases children's engagement in science (Sikora & Pokropek, 2012b; Sikora, 2014). In addition, mothers' occupational field should be taken into account along with fathers' because mothers' occupational field may have a greater influence on children's field of study choices than fathers' (Van der Vleuten, Jaspers, Maas, & van der Lippe, 2018). In PISA 2003, students reported their parents' occupations and a description of their occupations (OECD, 2005). The responses were coded to four-digit ISCO-88 codes (International Labour Office ILO, 1990). The OECD (2007) developed a broad definition of science-related careers which include not only those 'that involve a considerable amount of science, but also careers that are beyond the traditional idea of a scientist as someone who works in a laboratory or academic environment. As such, any career that involves tertiary education in a scientific field is considered science-related.' (p.150). In this study, two dichotomous variables were created as the measures of maternal employment in science and paternal employment in science. Based on the OECD's (2007) definition and list of science-related careers (Table A10.4 in OECD, 2007), I used a '1' to indicate that the mother or the father of a student was employed in science and a '0' to employment in other fields or unemployment.[7] Appendix A lists the science occupations.

### 5.3. Method

#### 5.3.1. Use of weights to adjust for the sampling design of Y03

Applying appropriate weights when analysing Y03 data is necessary to account not only for the two-stage stratified sampling of PISA but also for the attrition of respondents in each subsequent follow-up survey of Y03 (Lim, 2011). As the PISA 2003 and Y03 samples are age-based, students of the same age attended different grade levels in particular Australian states and territories. Students also commenced their university degrees at different ages. I obtained the information about students' enrolment in mathematically intensive fields of study at university from different LSAY waves between 2004 and 2013. Therefore, neither the PISA nor LSAY weights, which are wave-specific, are suitable for the analysis of the pooled sample.

To obtain unbiased estimates without using the LSAY weights, the best procedure is to follow the strategy suggested in the LSAY technical report (Lim, 2011). Specifically, Lim (2011), p.19) point out that '[an] alternative approach to directly applying weights is to include all the variables used to create the weights as independent variables. This will result in an unbiased estimate, correct standard errors and inferences.' Following this suggestion, in the descriptive statistics and in the logit models, I included as controls all variables that were used to construct the LSAY weights.[8] The control variables were state or territory in which the schools were located, the school sector (Catholic, independent and government), family structure – denoted by an indicator of whether a family was a nuclear one or some other form, such as a single-parent family – and students' immigration status that distinguished between Australians born to Australian parents and those born to foreign parents.[9]

[7] Unemployed parents include a total of less than 2 percent of respondents whose father was a student, social beneficiary or responsible for home duties and a total of less than 6 percent of respondents whose mother was a student, social beneficiary or responsible for home duties.

[8] To obtain unbiased estimates of descriptive statistics, for continuous variables, I obtained their descriptive statistics using OLS regression and including the variables used to create the LSAY weights as controls. For dichotomous variables, I obtained their descriptive statistics using logistic regression and including the controls. These analyses were adjusted for school clustering.

[9] Three other control variables that were used to construct the LSAY weights – gender, mathematics achievement and family's socioeconomic status – are also the independent variables in the multivariate analyses as presented in Sections 5.2.2 and 5.2.3.

#### 5.3.2. Multiple imputation of missing values

To use maximum information in multivariate analyses, I used Stata 14 to impute missing values on the independent variables resulting from nonresponses by chained equations (Royston & White, 2011). In the sample, 2811 participants provided complete information on the independent variables. Among the remaining 691 participants, missing values were present in at least one of the independent variables. These variables include occupational expectations, mathematics self-concept, relevant subject choice in Year 12, family's socioeconomic status, maternal and paternal employment in science, family structure and immigration status (see Appendix C). The missing values in these variables were imputed.

As PISA allocates five plausible values to each student to denote mathematics achievement, I created five sets of imputed data and assigned a different plausible value to each set of imputed data. I followed the PISA recommendations on analyses with plausible values by performing multivariate analyses independently on each set of imputed data and aggregating the results from these imputed data to obtain the final estimates of the statistics and their respective standard errors (OECD, 2005, 2009).

#### 5.3.3. Logistic regressions and decomposition using the KHB method

The Y03 data are clustered by school and hence the correct procedure is to take this sampling design into account. Thus, when I applied logistic regression models and the KHB method, I adjusted my analyses for school clustering. I used the KHB decomposition method (Karlson, Holm, & Breen, 2012), which is implemented in a user-written Stata routine called 'khb' (Kohler, Karlson, & Holm, 2011), to identify the extent to which each of these factors – students' occupational expectations, mathematics self-concept, and relevant subject choice in Year 12 – contributes to the gender gap in choosing a mathematically intensive university major. The option 'disentangle' in the Stata routine 'khb' that shows how much of the gender gap can be explained by each factor separately cannot be used for multiply imputed data. Therefore, I applied the KHB method and obtained the percentage of the gender gap explained by each factor in each set of imputed data.

## 6. Results

Prior to the multivariate analysis, I present the descriptive statistics with respect to the entry and completion rates of mathematically intensive degrees. The descriptive statistics also reveal whether young men and women differ in their occupational expectations, achievement and self-concept in mathematics, subject choice in their final year of secondary school and family background.

### 6.1. How many men and women choose and complete a mathematically intensive degree?

Table 1 shows that in the Y03 cohort, men were about 4 times more likely than women to select a mathematically intensive bachelor's degree program (28 percent versus 7 percent). This is similar to the gender gap in attaining a mathematically oriented degree: men were 4.5 times more likely than women to complete the degree (27 percent versus 6 percent). Juxtaposing these two gender gaps makes it clear that the gender imbalance in the composition of the student population in these degrees is created at entry to university and persists, largely unchanged, up to the point of completion. In other words, Table 1 does not indicate that women who enrolled in mathematically intensive degrees drop out of them at significantly higher rates than men. This in itself could be considered encouraging. Nevertheless, being outnumbered by men by such a high ratio, women are likely to be affected by their low representation in mathematically intensive fields and are at all times a definite minority.

There is a striking gender difference in occupational expectations: 25 percent of men expected a mathematically intensive career when

**Table 1**
Respondent characteristics by gender: proportions and means.
Source: Y03

| | Men | Women | Min. | Max. | *N* |
|---|---|---|---|---|---|
| ***Dependent variable*** | | | | | |
| Entry into a mathematically intensive science degree after completing Year 12[a] | 0.28 | 0.07 | 0 | 1 | 3502 |
| ***Other information*** | | | | | |
| Attainment of a mathematically intensive degree[a,b] | 0.27 | 0.06 | 0 | 1 | 2282 |
| ***Career expectations*** | | | | | |
| Expected a career in the mathematically intensive sciences at age 15[a] | 0.25 | 0.07 | 0 | 1 | 3248 |
| ***Mathematics*** | | | | | |
| Mathematics achievement at age 15[a] | 603.70 | 575.35 | 258.79 | 842.37 | 3502 |
| Mathematics self-concept at age 15[a] | 0.55 | 0.32 | −2.12 | 2.42 | 3500 |
| ***Relevant subject choice in Year 12*** | | | | | |
| Studied advanced mathematics and physical science[a] | 0.18 | 0.10 | 0 | 1 | 3229 |
| Studied physical science only | 0.26 | 0.23 | 0 | 1 | 3229 |
| Studied advanced mathematics only | 0.04 | 0.03 | 0 | 1 | 3229 |
| ***Key control variables: family background*** | | | | | |
| Socioeconomic status | 0.64 | 0.61 | −2.86 | 2.15 | 3493 |
| Mother has a science job | 0.17 | 0.17 | 0 | 1 | 3396 |
| Father has a science job | 0.21 | 0.19 | 0 | 1 | 3379 |

Note: This table contains weighted estimates before multiple imputations of missing data.
[a] indicates that the difference between men and women in that variable is statistically significant at $p < 0.05$.
[b] The large difference in the sample size between entry into and attainment of a mathematically intensive degree is mainly caused by LSAY attrition.

they were 15 years old, whereas only 7 percent of women expected such a career. On average, men performed slightly better than women in mathematics when they were in secondary school. Men had considerably higher self-concept in mathematics than women when they were 15 years old. While men were more likely than women to enrol in advanced mathematics in conjunction with physical science in Year 12, men and women did not differ significantly in their enrolment rates in physical science or advanced mathematics.

The gender gap in the choice of a mathematically intensive degree does not seem to be related to the family background of men and women in this study because men did not differ from women in family background when they were 15 years old. On average, men and women had similar levels of family's socioeconomic status. Similar proportions of men and women lived in families in which parents worked in science.

### 6.2. Logit models and the KHB method

My multivariate analysis comprises four nested models that enable me to understand what portion of the gender gap in the choice of a mathematically intensive degree program is explained by the addition of particular explanatory variables to the model (Table 2). All the models included the variables which were used to construct the LSAY weights as controls. In Model 1, I considered the overall size of the gender gap controlling for students' family's socioeconomic status, maternal and paternal employment in science, and mathematics achievement. With these controls, Model 1 indicates that women are less likely than men to choose a mathematically intensive field of study at university. Next, I added students' occupational expectations to Model 2. The results of the KHB method show that, compared to Model 1, adding students' expectations of a mathematically oriented career at age 15 to Model 2 reduces the gender gap in choosing a mathematically intensive major by 18 percent. The addition of students' mathematics self-concept at age 15 to Model 3, together with students' occupational

**Table 2**
Factors affecting enrolment in mathematically intensive university degree programs: (1) coefficients from logit models and (2) percentage of the gender gap explained by Models 2–4 from the KHB method.
Source: Y03

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| | Coefficient | Standard error | Coefficient | Standard error | Coefficient | Standard error | Coefficient | Standard error |
| ***Individual characteristics*** | | | | | | | | |
| Gender (female) | −1.595*** | (0.113) | −1.318*** | (0.118) | −1.251*** | (0.118) | −1.192*** | (0.119) |
| Mathematics achievement at age 15 | 0.384*** | (0.066) | 0.324*** | (0.068) | 0.165* | (0.069) | 0.044 | (0.074) |
| Expected a mathematically intensive career at age 15 | | | 1.580*** | (0.110) | 1.530*** | (0.109) | 1.418*** | (0.116) |
| Mathematics self-concept at age 15 | | | | | 0.520*** | (0.063) | 0.370*** | (0.065) |
| Relevant subject choice in Year 12 | | | | | | | | |
| Studied advanced mathematics and physical science | | | | | | | 1.169*** | (0.168) |
| Studied physical science only | | | | | | | 0.551*** | (0.129) |
| Studied advanced mathematics only | | | | | | | 0.150 | (0.280) |
| Constant | −1.180*** | (0.147) | −1.638*** | (0.162) | −1.900*** | (0.162) | −2.220*** | (0.176) |
| ***Percentage (%) of the gender gap explained (compared to Model 1)*** | | | 18.0 | | 24.1 | | 28.1 | |

Note: The sample for these analyses contains 3502 students in 310 schools with multiple imputations of missing data. * $p < 0.05$, *** $p < 0.001$.
Model 1: Female + Family's socioeconomic status + Maternal and paternal employment in science + Mathematics achievement at age 15.
Model 2: Model 1 + Expected a mathematically intensive career at age 15.
Model 3: Model 2 + Mathematics self-concept at age 15.
Model 4: Model 3 + Relevant subject choice in Year 12.
All analyses were undertaken using appropriate weights (as described in the main text in the method section) and adjusted for school clustering. I do not present the logit coefficients of students' family socioeconomic status, maternal employment in science and paternal employment in science because they are not the focus of this study. With the inclusion of these three predictors, in Model 1 individuals who come from high-status families and those who have mothers or fathers employed in science fields do not differ from others in their chances of selecting a mathematically intensive major at university. The logit coefficients of all independent variables are available upon request.

**Table 3**
Percentage of the gender gap in the choice of a mathematically intensive major explained by each factor: the KHB method.
Source: Y03

| | Imputed data | | | | |
|---|---|---|---|---|---|
| | 1st set | 2nd set | 3rd set | 4th set | 5th set |
| ***Total percentage of gender gap explained*** | 28.1 | 28.0 | 27.6 | 28.2 | 28.5 |
| ***Percentage of gender gap explained by each factor*** | | | | | |
| Expected a mathematically intensive career at age 15 | 16.1 | 15.8 | 14.7 | 15.6 | 15.8 |
| Mathematics self-concept at age 15 | 4.8 | 4.9 | 5.3 | 5.1 | 5.2 |
| Relevant subject choice in Year 12 | | | | | |
| Studied advanced mathematics and physical science | 6.1 | 6.2 | 6.4 | 6.3 | 6.4 |
| Studied physical science only | 1.0 | 1.0 | 1.1 | 1.1 | 1.0 |
| Studied advanced mathematics only | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

Note: The sample for these analyses contains 3502 students in 310 schools with multiple imputations of missing data. Each set of imputed data contains a different plausible value that represents students' numeracy at age 15. To ensure that the decomposition results are reliable with the multiply imputed data, I also applied the KHB method to the observed data (i.e. the non-imputed data with listwise deletion of missing data) (see Appendix D). In summary, the decomposition results using the multiply imputed data and the observed data produced similar results.

expectations, reduces the gender gap by 24 percent. With the inclusion of students' occupational expectations, mathematics self-concept and relevant subject choice in Year 12 in Model 4, the gender gap declines by 28 percent.

### 6.3. *KHB method: what are the relative contributions of students' occupational expectations, mathematics self-concept and subject choice in secondary school to the gender gap in university major choices?*

The intention of considering students' occupational expectations, mathematics self-concept and subject choice in Year 12 is to capture the cumulative effects of secondary school experiences that contribute to individual educational biographies and to identity formation which underpins crucial educational choices about specialisation at university. Nevertheless, each of these elements has a specific dimension that must be considered, as discussed in the literature review in Section 3. Occupational expectations may reflect students' achievement and self-concept at school. Mathematics self-concept of students is arguably linked closely to their academic achievement and is likely not only to affect their subject choice but also to reflect or shape their occupational expectations. Relevant subject choice is very likely a reflection of students' occupational expectations, prior mathematics achievement and the degree of confidence students feel in their numeracy skills. Thus, all of these factors are closely interconnected and reciprocally affect each other over time.

I applied the KHB method to Model 4 and assessed to what extent each of these factors – students' occupational expectations, mathematics self-concept and relevant subject choice in Year 12 – would explain the gender gap in the choice of a mathematically intensive major at university (Table 3). Students' expectations of a mathematically oriented career at age 15 holds the most promise of bridging the gender gap in mathematical majors between young men and women who enter university because such occupational expectations explain about 15–16 percent of the gender gap (14.7–16.1 percent in Table 3). The second most important factor that reduces the gender gap is students' enrolment in advanced mathematics in conjunction with physical science in Year 12. Such a subject combination explains about 6 percent of the gender gap (6.1–6.4 percent in Table 3). Although mathematics self-concept does not appear as influential as occupational expectations and relevant subject choice in explaining the gender gap in choosing a mathematically intensive field of study, it explains about 5 percent of the gender gap (4.8–5.2 percent in Table 3).

## 7. Discussion and conclusion

In this study, I considered the extent to which students' occupational expectations, self-assessed mathematical competence and subject choice in secondary school would contribute to the gender gap in enrolling in a mathematically intensive university major. Overall, I found that those three characteristics of students could explain about 28 percent of the gender gap. In other words, the gender gap could be reduced by about 28 percent if women were as likely as men to expect mathematically oriented careers in adolescence, to have more confidence in their mathematical abilities in secondary school and to engage at higher rates in advanced mathematics and physical science subjects in Year 12. I found that the expectation of a mathematically intensive career in adolescence has the greatest potential to reduce the gender gap. The study of advanced mathematics and physical science subjects in Year 12 is the second most important factor that bridges the gender gap. Self-assessment of mathematical abilities appears to be the least important factor, but it still explains part of the gender gap.

Various considerations should be kept in mind when interpreting the findings of the present study. First, students' occupational expectations and self-assessed mathematical abilities could be endogenous to the choice of a mathematically intensive field of study. Prior research has shown that gender differences in beliefs, expectations and preferences may emerge in childhood and early adolescence (Correll, 2001; McMahon & Patton, 1997; Tai et al., 2006). Therefore, in this study, students might have already formed their gendered beliefs, expectations and preferences before they reported their occupational expectations and self-assessed mathematical abilities at age 15 when their information was collected by PISA. Specifically, some students might have expected not to engage in any mathematically intensive studies in senior secondary and tertiary education prior to providing information on their occupational expectations and self-assessed mathematical abilities. Such students might feel less confident of their mathematical abilities and they might not expect mathematically intensive careers in the future. With this endogeneity bias in mind, I provide some policy suggestions that aim to narrow the gender differences not only in teenage occupational expectations and self-assessed mathematical competence but also in engagement in mathematics and related disciplines.

My results demonstrate that teenage occupational expectations are strongly associated with the gender gap in the choice of a mathematically intensive major. Therefore, not only should we strengthen career education in secondary school and signal to both adolescent boys and girls that they can engage and succeed in mathematically intensive fields of study and employment (Cheryan, Ziegler, Montoya, & Jiang, 2017), but we should also do so in novel and more effective ways. Adolescents are known to change their occupational expectations quite often (Rindfuss et al., 1999), and therefore secondary school years seem particularly promising in offering opportunities to foster girls' interest in mathematically intensive fields of study and employment. It is particularly important, however, to strengthen career education in secondary school in ways that effectively help adolescent boys and girls not only to gain accurate career information but also to combat gender stereotypes that affect perceptions of various occupations and fields of study. Attempts to promote female engagement in mathematically intensive fields are likely to be less effective when undertaken at a stage when females have already disengaged from mathematics and related disciplines.

Not only do my results show that enrolment in advanced mathematics in conjunction with physical science in Year 12 is more differentiated by gender than enrolment in only advanced mathematics or physical science, but such a subject combination also explains a substantial portion of the gender gap in choosing a mathematically intensive university major. In Australia, not all mathematically intensive university programs require the study of advanced mathematics and physical science in Year 12 for admission. Nevertheless, students who choose a mathematically intensive major at university tend to have taken relevant subjects in Year 12, as evident in my results. In line with previous findings, the study of advanced mathematics and physical science in Year 12 serve as a filter for intentions to study related degree programs (Ainley et al., 2008; Varsavsky, 2010).

The key implication of my analysis is that the gender gap in the choice of a mathematically intensive field of study must be seen as a continuation of the gendered patterns in teenage occupational expectations and subject choice in secondary school. Compared to the gendered patterns in occupational expectations, enrolment in Year 12 advanced mathematics and physical science is less segregated by gender. Once students leave school, however, young women are more likely than their male peers to leak from the mathematically intensive science pipeline by turning to the pursuit of non-mathematical qualifications. My analysis shows that this process affects education in mathematics and related disciplines just as it was shown to affect physical and life science education at the post-secondary level in Australia (Sikora, 2014) in accordance with the 'leaky pipeline' argument (Blickenstaff, 2005; Xie & Shauman, 2003).

Another opportunity to further narrow the gender gap in mathematically intensive studies at university lies in finding more effective ways to enhance girls' self-confidence in their mathematical abilities. My results show that although secondary school girls almost catch up with their male peers in mathematics performance, they continue to have significantly lower levels of confidence in their mathematical abilities. Such low levels of self-confidence in mathematical abilities, rather than mathematics achievement, are related to the under-representation of women in mathematically oriented university studies, as presented in my results. Undeniably the world of work and academia itself are segregated by gender, so it might take significant changes to successfully counteract the deeply entrenched and widely diffused gender stereotypical beliefs that males are more talented in mathematically intensive fields and those fields are male domains. Nevertheless, the significant others of adolescents, such as parents, school teachers, counsellors, can help girls to build up and sustain their confidence in mathematics and related disciplines (Gabay-Egozi et al., 2015; Oliver, Woods-McConney, Maor, & McConney, 2017). These significant others can systematically signal to girls that their mathematical abilities are as good as those of boys and they can have great achievement in mathematically intensive disciplines and careers. It is also possible to encourage boys to be more positive towards girls in mathematics classrooms and to behave in a manner that does not result in an unintended, or perhaps sometimes intended, intimidation of female classmates. There are also opportunities for mathematics teachers to create student-centred and 'mistake friendly' learning environments that allow girls to feel more comfortable and confident engaging with mathematics (Prinsley, Beavis, & Clifford-Hordacre, 2016).

The second consideration that should be taken into account is that girls do not only have lower self-assessment of their mathematical competence compared to boys but they may also rate their verbal abilities higher than do boys. As discussed in Section 3.2, girls may have higher self-assessment of their verbal abilities and may thus be more likely to opt for non-mathematical disciplines (Correll, 2001; Lörz et al., 2011). This study, however, did not measure the potential gender bias in self-assessment of verbal abilities and therefore could not determine whether such gender bias would also be associated with the under-representation of women in mathematically intensive disciplines in Australia.

Third, while the inclusion of students' teenage occupational expectations, self-assessed mathematical competence and subject choice in Year 12 in my regression models explains about 28 percent of the gender gap in choosing a mathematically oriented university major, a considerable portion of the gap remains unexplained by my models. An important goal for future research is to understand in more depth what factors can bridge this remaining portion of the gender gap. Stereotypical beliefs that define the appropriate occupational roles for males and females may not only emerge in teenage occupational expectations and self-assessment of mathematical competence but also appear in other domains of social life, such as life-style preferences and family plans. Perhaps mathematics-related fields of study and occupations are perceived as incompatible with certain life styles, such as travelling, interacting with other people, and family plans that not only young women but also some young men may have. Future studies should further explore these factors and identify other factors that are possibly important contributors to the gender gap in selecting a mathematically intensive major at the tertiary level. Identifying the factors helps bring more equity to Australian mathematics and science education.

The findings of this study have implications for other advanced industrial countries which also underscore students' self-expression in making educational decisions and have comprehensive school systems that allow students to make their own subject choices in high school, such as Canada, New Zealand, the United Kingdom and the United States. Similar factors – occupational expectations, self-assessed mathematical competence and relevant subject choices in high school – may also explain a substantial portion of the gender gap in the choice of a mathematically intensive major in these countries. Some countries, such as Hungary and Uruguay, are moving towards comprehensive educational systems and increasing the use of ability streaming in mathematics education (OECD, 2013). Australia is representative of what the future of mathematics and science education might look like for these countries. The findings of this study also have implications for them.

Given the prevalence of gender egalitarian ideology since the 1970s, Australian women have been encouraged to pursue tertiary educational credentials and professional occupations. While many women thrive in their careers, the integration of women into the mathematically intensive sciences has remained slow. This study implies that talented women who could be successful in mathematically intensive fields of study and employment already start disengaging from mathematics and related disciplines early in their educational career. This phenomenon is not only a waste of individual talents and potential but also a loss for society as the Australian economy has a huge demand for skilled workers with strong quantitative skills (Australian Academy of Science, 2016; Australian Industry Group, 2013). The policy suggestions for increasing female engagement in mathematically intensive fields made here may not be novel and I am aware that they alone will not bring about gender equality in Australian mathematics and science education. As suggested by the theory of gender essentialism, the under-representation of females in mathematically intensive disciplines has deep societal and structural roots that will not be transformed by a few isolated policy interventions. To fully unleash the potential of females in mathematics-related areas, ultimately we need to alleviate the gender stereotypical beliefs and social barriers associated with mathematics learning and careers. An increase in the representation of females in mathematically oriented fields along the educational pathway would not only lessen gender segregation in fields of study, but it may also enhance the level of gender equality in the labour market (Smyth & Steinmetz, 2008).

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## Appendix A

See Table A1

**Table A1**
ISCO-88 coding of science occupations.
Source: Australian Mathematical Sciences Institute (2015, 2016); ILO (1990); OECD (2007); Sikora and Pokropek (2012a); Y03

| ISCO-88 code | Occupation |
|---|---|
| ***Mathematically intensive sciences*** | |
| 1236 | Computing services department managers |
| 1237 | Research and development department managers |
| 2100 | Physical, mathematical and engineering science professionals |
| 2110 | Physicists, chemists and related professionals |
| 2111 | Physicists and astronomers |
| 2112 | Meteorologists |
| 2113 | Chemists |
| 2114 | Geologists and geophysicists including geodesists |
| 2120 | Mathematicians and statisticians |
| 2121 | Mathematicians and associated professionals |
| 2122 | Statisticians including actuaries |
| 2130 | Computing professionals |
| 2131 | Computer systems designers and analysts including software engineers |
| 2132 | Computer programmers |
| 2139 | Computing professionals not elsewhere classified |
| 2140 | Architects, engineers and related professionals |
| 2141 | Architects, town and traffic planners including landscape architects |
| 2142 | Civil engineers including construction engineers |
| 2143 | Electrical engineers |
| 2144 | Electronics and telecommunications engineers |
| 2145 | Mechanical engineers |
| 2146 | Chemical engineers |
| 2147 | Mining engineers, metallurgists and related professionals |
| 2148 | Cartographers and surveyors |
| 2149 | Architects engineers and related professionals not elsewhere classified |
| 3100 | Physical and engineering science associate professionals |
| 3141 | Ships engineers |
| 3144 | Air traffic controllers |
| 3434 | Statistical, mathematical etc. associate professionals |

(*continued on next page*)

Table A1 (*continued*)

| ISCO-88 code | Occupation |
|---|---|
| ***Other sciences*** | |
| 1221 | Production managers agriculture and fishing |
| 1222 | Production managers in manufacturing including factory managers |
| 1223 | Production managers in construction |
| 2200 | Life science and health professionals |
| 2210 | Life science professionals |
| 2211 | Biologists, botanists and zoologists |
| 2212 | Pharmacologists, pathologists and biochemists |
| 2213 | Agronomists |
| 2220 | Health professionals (except nursing) |
| 2221 | Medical doctors |
| 2222 | Dentists |
| 2223 | Veterinarians |
| 2224 | Pharmacists |
| 2229 | Health professionals except nursing not elsewhere classified |
| 2230 | Nursing and midwifery professionals including registered nurses and midwives |
| 2445 | Psychologists |
| 3000 | Technicians and associate professionals |
| 3110 | Physical and engineering science technicians |
| 3111 | Chemical and physical science technicians |
| 3112 | Civil engineering technicians |
| 3113 | Electrical engineering technicians |
| 3114 | Electronics and telecommunications engineering technicians |
| 3115 | Mechanical engineering technicians |
| 3116 | Chemical engineering technicians |
| 3117 | Mining and metallurgical technicians |
| 3118 | Draughts persons including technical illustrators |
| 3119 | Physical and engineering science technicians not elsewhere classified |
| 3130 | Optical and electronic equipment operators |
| 3131 | Photographers and electronic equipment operators |
| 3132 | Broadcasting and telecommunications equipment operators |
| 3133 | Medical equipment operators including x-ray technicians |
| 3139 | Optical and electronic equipment operators not elsewhere classified |
| 3140 | Ship and aircraft controllers and technicians |
| 3142 | Ships deck officers and pilots including river boat captains |
| 3143 | Aircraft pilots and related associate professionals |
| 3145 | Air traffic safety technicians |
| 3200 | Life science and health associate professionals |
| 3210 | Life science technicians and associate professionals |
| 3211 | Life science technicians including medical laboratory assistant |
| 3212 | Agronomy and forestry technicians |
| 3213 | Farming and forestry advisers |
| 3220 | Modern health associate professionals except nursing |
| 3221 | Medical assistants |
| 3222 | Sanitarians |
| 3223 | Dieticians and nutritionists |
| 3224 | Optometrists and opticians including dispensing optician |
| 3225 | Dental assistants including oral hygienist |
| 3226 | Physiotherapists and associate professionals |
| 3227 | Veterinary assistants including veterinarian vaccinator |
| 3228 | Pharmaceutical assistants |
| 3229 | Modern health associate professionals except nursing not elsewhere classified |
| 3230 | Nursing and midwifery associate professionals |
| 3231 | Nursing associate professionals including trainee nurses |
| 3232 | Midwifery associate professionals including trainee midwives |

Note: Occupations in the mathematically intensive sciences include those related to engineering, computing, and the mathematical and physical sciences. Occupations in other sciences include those related to biology, agriculture, health and the life sciences, and those associated with engineering, computing and the physical sciences but do not require the level of advanced high school mathematics.

## Appendix B

See Table B1

**Table B1**
Advanced mathematics and physical science subjects in Year 12 by state and territory (2003–2006).
Source: Ainley et al. (2008); Sikora (2014); Y03

| State/territory | Advanced mathematics subjects | Physical science subjects |
|---|---|---|
| Australian Capital Territory | Mathematics Extension (in 2003 and 2004) Specialist Mathematics (in 2005 and 2006) | Chemistry, Earth Science (including Geology, Oceanography and Meteorology), Physics (including Electronics) |
| New South Wales | Mathematics Extension | Chemistry, Earth and Environmental Science, Physics |
| Northern Territory | Specialist Mathematics | Chemistry, Physics |
| Queensland | Mathematics C | Chemistry, Earth Science, Physics |
| South Australia | Specialist Mathematics | Chemistry, Geology, Physics |
| Tasmania | Mathematics Specialised | Chemistry, Physical Science, Physics |
| Victoria | Specialist Mathematics | Chemistry, Physics |
| Western Australia | Calculus | Chemistry, Geology, Physical Science, Physics |

Note: This coding is based on the curriculum contents rather than the name of the subject.

## Appendix C

See Table C1

**Table C1**
Number of missing values in each independent variable.
Source: Y03

| | *N* | Number of missing values | | |
|---|---|---|---|---|
| | | Total | Men | Women |
| ***Career expectations*** | | | | |
| Expected a mathematically intensive career at age 15 | 3248 | 254 | 122 | 132 |
| ***Mathematics*** | | | | |
| Mathematics achievement at age 15 | 3502 | 0 | 0 | 0 |
| Mathematics self-concept at age 15 | 3500 | 2 | 1 | 1 |
| ***Relevant subject choice in Year 12*** | | | | |
| Studied advanced mathematics and physical science | 3229 | 273 | 106 | 167 |
| Studied physical science only | 3229 | 273 | 106 | 167 |
| Studied advanced mathematics only | 3229 | 273 | 106 | 167 |
| **Control variables** | | | | |
| ***Family background*** | | | | |
| Socioeconomic status | 3493 | 9 | 5 | 4 |
| Mother has a science job | 3396 | 106 | 54 | 52 |
| Father has a science job | 3379 | 123 | 44 | 79 |
| ***Family structure*** (reference = nuclear family) | | | | |
| Other family structure | 3484 | 18 | 10 | 8 |
| ***Immigration status*** (reference = native students) | | | | |
| First-generation students | 3470 | 32 | 12 | 20 |
| Second-generation students | 3470 | 32 | 12 | 20 |
| ***State/territory*** (reference = New South Wales) | | | | |
| Australian Capital Territory | 3502 | 0 | 0 | 0 |
| Northern Territory | 3502 | 0 | 0 | 0 |
| Queensland | 3502 | 0 | 0 | 0 |
| South Australia | 3502 | 0 | 0 | 0 |
| Tasmania | 3502 | 0 | 0 | 0 |
| Victoria | 3502 | 0 | 0 | 0 |
| Western Australia | 3502 | 0 | 0 | 0 |
| ***School sector*** (reference = government school) | | | | |
| Catholic school | 3502 | 0 | 0 | 0 |
| Independent school | 3502 | 0 | 0 | 0 |

## Appendix D

See Table D1

**Table D1**
Percentage of the gender gap in the choice of a mathematically intensive major explained by each factor: the KHB method (sample: 2811 students without any imputation of missing data).
Source: Y03

| | Measure of mathematics achievement | | | | |
|---|---|---|---|---|---|
| | 1st plausible value | 2nd plausible value | 3rd plausible value | 4th plausible value | 5th plausible value |
| ***Total percentage of gender gap explained*** | 28.8 | 28.8 | 29.3 | 29.5 | 29.3 |
| ***Percentage of gender gap explained by each factor*** | | | | | |
| Expected a mathematically intensive career at age 15 | 15.6 | 15.6 | 15.4 | 15.6 | 15.7 |
| Mathematics self-concept at age 15 | 4.1 | 4.2 | 4.5 | 4.5 | 4.4 |
| Relevant subject choice in Year 12 | | | | | |
| Studied advanced mathematics and physical science | 7.8 | 7.7 | 8.0 | 8.0 | 8.0 |
| Studied physical science only | 1.2 | 1.2 | 1.3 | 1.3 | 1.1 |
| Studied advanced mathematics only | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

Note: After listwise deletion of missing data, the sample for these analyses contains 2811 students in 306 schools. I assigned a different plausible value of mathematics achievement to the sample because five plausible values were allocated to each student to represent their numeracy.

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