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Gendered choices of STEM subjects for matriculation are not driven by prior differences in mathematical achievement

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ABSTRACT

Women's under-representation in high-paying jobs in STEM fields (science, technology, engineering and mathematics) mirrors their earlier choices of matriculation electives: male students favour physics, information technology and advanced mathematics; female students favour life sciences. 'Pipeline' theories attribute these patterns to a male advantage in mathematics, but our longitudinal analysis, using administrative data on a full cohort of students in Victoria, Australia, shows that these patterns remain intact after conditioning on prior achievement. Female students require stronger prior signals of mathematical ability to choose male-dominated subjects, and when choosing these subjects earn higher average scores than males, suggesting a possible loss of efficiency. Previous research has shown that socio-economic disadvantage adversely affects boys more than girls, and indeed we find less of a male advantage in physics and advanced mathematics among socially disadvantaged students. We find that students with a language background other than English choose STEM fields with greater frequency than other students, reflecting their comparative advantage, while exhibiting more markedly gendered subject choices, indicating a role for cultural factors. Finally, we find significantly less gender streaming in STEM subjects among female students in all-girl schools than in co-educational schools, but no such difference for male students.

1. Introduction

Increasing the participation of women in science, technology, engineering, and mathematics (STEM) fields in the workplace is a policy goal, supported by both efficiency and equity arguments, in many countries. Efficiency arguments focus on the increasingly important role of technology in economic growth and the relevance of finding the best people to work in technology related fields. Equity arguments point to lower rates of female participation in high-paying jobs, especially in engineering and information technology, as contributing substantially to the wage gap between men and women in advanced industrial economies (Birch, Li, & Miller, 2009; Blau & Kahn, 2000; Groshen, 1991; Mumford & Smith, 2007). In Australia, two thirds of the gender wage gap in the starting salaries of university graduates reflects gaps between better-paid, male-dominant degree fields such as engineering and computer science, and lower-paying female-dominant fields such as nursing and teaching (Graduate Careers Australia, 2014, Table 3).[1]

Subject choices in tertiary education play a key role in forming these patterns. In 2013, women earned 58% of tertiary STEM degrees in OECD countries, but less than 30% of graduates in engineering, and less than 20% in computer science were female; and similar patterns are observed in Australia (OECD, 2013, Table A3.3). Moreover, these choices of university degree programs are shaped, in turn, by earlier subject choices in high school (Riegle-Crumb, King, Grodsky, & Muller, 2012; Turner & Bowen, 1999; Xie & Shauman, 2003; among others). In high school, boys are typically the majority in physics and computers, and girls are the majority in life sciences—a pattern observed in Australia (Collins, Kenway, & McLeod, 2000), the Netherlands (Buser, Niederle, & Oosterbeek, 2014), France (Rapoport & Thibout, 2018), and in Hebrew-language schools in Israel (Ayalon, 1995; Friedman-Sokuler & Justman 2016).[2]

The main question this paper asks is, what shapes early gendered choices of STEM subjects? To answer this question, we use

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[1] There are, of course, other factors contributing to the wage gap. Thus Cobb-Clark and Tan (2011) find that wage gaps within occupations widen over time; and Kee (2006) finds a strong glass-ceiling effect in the private sector.

[2] However Friedman-Sokuler and Justman (2017) find that this pattern is reversed in Israel's Arabic-language schools, and Jackson (2012) finds that in Trinidad-Tobago, girls are a majority in information technology, indicating a role for cultural factors.

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administrative data from a full cohort of seventh-grade students in the state of Victoria, Australia, whom we follow from 2008 through to twelfth grade, in 2013, the last year of high school. We focus our analysis on students' STEM choices during the final two years of high school, when they are relatively independent in organising their curriculum, and aware that the subject choices they make and the scores they achieve will determine in large measure their access to tertiary education. The six principal STEM fields we study are: physics, information technology, the highest and next-highest levels of mathematics (specialist mathematics and mathematical methods), chemistry, and life sciences. Considering these fields separately reveals the heterogeneity of gender effects among STEM subjects.

We explore four factors potentially relevant to the choice of STEM subjects: prior achievement in numeracy and reading; parents' socio-economic status (SES); the role of culture, proxied by having a language background other than English; and, finally, school characteristics, in particular, the gender composition of the school. We find that, after regressing students' STEM subject choices on prior scores, parents' SES, language background and school-level variables, the gendered patterns observed in the raw data remain largely intact. Namely, physics, information technology and specialist mathematics, which open the door to well-paying careers in engineering and digital technologies, remain male-dominated, and life sciences remain female-dominated. We expand on these four factors in the following paragraphs.

First, noting that STEM subjects are mathematically intensive, many have suggested that the under-representation of women in these subjects is driven by a prior male advantage in mathematics.[3] We find that boys do indeed have a significant advantage in mathematics in grades seven and nine, as measured by Australia's National Assessment Program—Literacy and Numeracy (NAPLAN), while girls have a significant advantage in reading. However, while prior test scores are a significant predictor of STEM subject choices, they account for only a small fraction of the gender difference in subject choice.[4] Previous studies attribute gender differences in educational choices to gender differences in risk aversion and competitiveness (Booth & Nolen, 2012a, 2012b; Booth, Cardona-Sosac, & Nolen, 2014; Gneezy, Leonard, & List, 2009; Niederle & Vesterlund, 2010), and, similarly, to girls under-estimating their science skills when choosing their educational and career paths (Rapoport & Thibout, 2018).[5] Supporting this literature, our findings suggest that female students require stronger prior signals of mathematical ability to choose physics, information technology or specialist mathematics, arguably reflecting greater caution on their part. This seemingly greater caution results in female students outperforming their male counterparts not only in these subjects but in all STEM subjects.[6] This is important, because it could lead to a loss of productivity, if the infra-marginal male student specializing in, say, physics, is not as good at physics as the extra-marginal female student choosing not to specialize in physics.

Next, measuring SES through parents' education and occupation, we find that socio-economic disadvantage is generally associated with a reduced likelihood of choosing to specialize in physics and specialist mathematics, and also that this negative association is stronger for boys than for girls, as Goldon, Katz, & Kuziemko (2006) found. Consequently, relative gender gaps in the choice of these subjects are more prevalent at low SES levels while absolute gaps increase with SES.

Third, cross-country variation in gender streaming in education highlights the role of culture in constructing gender roles (Nollenberger, Rodríguez-Planas, & Sevilla, 2016). In our Australian cohort from the state of Victoria, this is evident in the more pronounced gendered choice patterns we observe among students with a language background other than English. Furthermore, these students choose STEM subjects with greater frequency than students for whom English is their main language, presumably reflecting their comparative advantage in subjects that require numeracy skills rather than language skills.

Finally, comparing mixed schools to single-sex schools we find significantly less gender streaming in single-sex schools. Female students in single-sex schools are significantly more likely than those in mixed schools to specialize in physics, advanced mathematics and chemistry, and less likely to specialize in biology, whereas male students in co-educational and single-sex schools make similar choices.[7] These findings are at variance with Billger's (2009) conclusion that in the United States, "coeducational public schools yield the least segregated college major choices"; and with Jackson's (2012) finding that girls in single-sex schools in Trinidad-Tobago choose fewer science subjects for matriculation than girls in co-educational schools.

The present analysis is most closely related to two longitudinal studies which look at gender differences in the choice of STEM matriculation electives in Israel and which control for middle-school achievement in Hebrew-language schools (Friedman-Sokuler & Justman, 2016). Although, a priori, it is not clear that we should expect to find similar patterns in distinct education systems, the matriculation choice patterns observed in Israel's Hebrew-language schools are similar to the patterns described here. The main difference is that, compared with boys, girls in Israel have a slight average advantage in eighth-grade standardized mathematics tests, so it is less surprising that conditioning subject choice on prior scores leaves the gender gaps observed in Israel largely intact. Interestingly, Friedman-Sokuler & Justman's (2017) analysis of students' subject choices in Israel's Arabic-language schools finds that they exhibit less gender bias, though they serve a more traditional population with more restrictive gender norms. In these schools, female students choose to matriculate in physics and computer science as frequently as male students.

Less directly related are a number of longitudinal, survey-based studies that follow large samples of high-school graduates through to college. These studies find similar gendered streaming in the choice of STEM college majors after conditioning on prior achievement (Riegle-Crumb & King, 2010; Riegle-Crumb et al., 2012; Turner & Bowen, 1999; Xie & Shauman, 2003). The differences between our findings and these—we find that prior achievement explains less of the observed gender gaps, and find a more limited role for comparative advantage[8]—may stem partly from the different stages of education we study, and partly from methodological differences. We contribute to the literature by taking a full cohort of seventh-grade students as our population framework, hence avoiding selection bias and minimizing sample attrition inherent in survey-based studies that exclude students who do not reach tertiary education, as boys have higher attrition rates in high school. In addition, conditioning tertiary decisions on high-school performance that was itself shaped by gender streaming diminishes the estimated

[3] More generally, evidence of an average male advantage is mixed and depends on age, cultural factors and type of test (Fryer & Levitt, 2010; Ceci et al., 2014; Guiso et al., 2008; Marks, 2008; Bedard & Cho, 2010; Else-Quest et al., 2010; Kane & Mertz, 2012; Bharadwaj et al., 2012, Nollenberger et al., 2016). Additionally, there is stronger evidence that greater variability in male scores makes for a male majority at higher (and lower) levels of achievement (Hedges & Nowell, 1995; Hyde et al., 2008; Ellison & Swanson, 2010; Pope & Sydnor, 2010). Finally, a male *comparative* advantage in mathematics is observed almost everywhere, driven by the substantial female advantage in language skills (Goldin et al., 2006; Fryer & Levitt, 2010; Wang et al., 2013).

[4] Previous research shows that NAPLAN scores accurately predict subsequent performance in final-year exams, suggesting they reliably indicate relevant mathematical ability (Houng & Justman, 2014).

[5] See, also, OECD (2015) for an overview of research on gender differences in attitudes to risk and competition. Additionally, other studies suggest that student choices are affected by teachers' gender biases (Lavy & Sand, 2015); and by the differential impact of institutional design on boys and girls (Joensen & Nielsen, 2016).

[6] Female average scores in these subjects are higher than male averages by 0.11 to 0.30 of a standard deviation.

[7] This suggests that girls have a stronger incentive to attend single-sex schools than boys, and indeed in our cohort 23% of girls and 16% of boys attended single-sex schools in seventh grade.

[8] We find a small effect for specialist mathematics but not for other subjects.