Girls' comparative advantage in reading can largely explain the gender gap in math-related fields

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Gender differences in math performance are now small in developed countries and they cannot explain on their own the strong underrepresentation of women in math-related fields. This latter result is however no longer true once gender differences in reading performance are also taken into account. Using individual-level data on 300,000 15-y-old students in 64 countries, we show that the difference between a student performance in reading and math is 80% of a standard deviation (SD) larger for girls than boys, a magnitude considered as very large. When this difference is controlled for, the gender gap in students' intentions to pursue math-intensive studies and careers is reduced by around 75%, while gender gaps in self-concept in math, declared interest for math or attitudes toward math entirely disappear. These latter variables are also much less able to explain the gender gap in intentions to study math than is students' difference in performance between math and reading. These results are in line with choice models in which educational decisions involve intraindividual comparisons of achievement and self-beliefs in different subjects as well as cultural norms regarding gender. To directly show that intraindividual comparisons of achievement impact students' intended careers, we use differences across schools in teaching resources dedicated to math and reading as exogenous variations of students' comparative advantage for math. Results confirm that the comparative advantage in math with respect to reading at the time of making educational choices plays a key role in the process leading to women's underrepresentation in math-intensive fields.

gender gap | math-intensive fields | comparative advantage | students' achievement

Women are underrepresented in science, technology, engineering, and mathematics (STEM) university majors and jobs. STEM is however a broad group that includes fields in which women are not underrepresented, such as life science or psychology. Scholars have underlined the necessity to focus more narrowly on the STEM fields which are math intensive, such as computer science or engineering (1–3), as the underrepresentation of women in these fields remains large and has not decreased at all in most developed countries during the two past decades (3–5). For example, over the period 2004 through 2014, the share of bachelor's degrees awarded to women in engineering and computer science in the US has stagnated around 20%, while it has decreased from 46 to 43% in mathematics and statistics and from 42 to 40% in physical science (6).

This underrepresentation of women in math-intensive fields is a source of concern for two main reasons. First, it contributes to gender wage inequality in the labor market as math-intensive jobs pay more (7–9) and are also subject to a smaller gender wage gap (10). Second, it represents a loss of talent that can reduce aggregate productivity (11)—as many talented girls shy away from math-intensive careers—leading to the shortage of workers with math-related skills at a time when the demand for such skills is increasing (12).

Gender differences in math test scores are now very limited in most countries and can only explain a small fraction of this underrepresentation of women in math-intensive fields (refs. 13 and 14 and *SI Appendix*, Table S1). This has pushed scholars to look for other explanations, such as discrimination against women in STEM, or the role of social norms and stereotypes in shaping educational choices. Evidence of direct discrimination is limited (3, 14, 15), and many scholars now emphasize the role of gender differences in preferences, self-concept and attitudes toward math, as well as the social processes and institutions possibly shaping these differences (see references in ref. 1).

We revisit the role of abilities and test scores to explain the gender gap in students' decision to enroll in math-related fields. Our examination is motivated by the idea that students are likely to decide to major in a given field on the basis of their relative (rather than absolute) ability in that field with respect to other fields (16–18). This simple theory is backed-up by studies suggesting that students tend to think in terms of "what they are better at" rather than in terms of "required skills to succeed in a particular career" (19), and that they are encouraged to do so by teachers and their environment (20). Research in social psychology also shows that "people think of themselves as either math persons or verbal persons but not both" (21). Hence, a student that is good at math but even better at reading may favor humanities because she perceives herself as a verbal person. This is despite the fact that her career prospects (which students tend to be unaware of) may be better after math-related studies.

While in most countries, at the age of making irreversible educational choices, girls now perform only slightly worse than boys in math, they however strongly outperform them in reading (18). This gives girls a comparative advantage for disciplines related to reading/literature rather than math. Former studies

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Significance

Women remain strongly underrepresented in math-related fields. This phenomenon is problematic because it contributes to gender inequalities in the labor market and can reflect a loss of talent. The current state of the art is that students' abilities are not able to explain gender differences in educational and career choices. Relying on the Programme for International Student Assessment (PISA) data, we show that female students who are good at math are much more likely than male students to be even better in reading. As a consequence, the difference between 15-y-old students' math and reading abilities, which is likely to be determined by earlier socialization processes, can explain up to 80% of the gender gap in intentions to pursue math-studies and careers.

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concluded that this relative advantage could not explain gender differences in STEM choice [e.g., in Sweden in the 1990s (16) and in the United States in the 2000s (22)]. In contrast, we show that in 2012, it can explain a very large fraction of the gender gap in 15-y-old students' intentions to pursue math-intensive studies and careers in virtually all developed countries and several developing countries.

Comparative Advantage and Gender Gap in Intentions to Pursue Math-Related Studies and Careers

Our main analyses are based on data from the 2012 Program for International Student Assessment (PISA2012), an every-3-y international assessment of the knowledge and skills of 15-y-old students in mathematics, reading, and science. PISA2012 takes place in the 34 mostly developed countries belonging to the Organization for Economic Co-operation and Development (OECD) in 2012 and an additional 30 developing countries (see details on all data and analyses in *SI Appendix*). PISA2012 is well-adapted for our purpose for three reasons. First, it allows us to focus directly on math-intensive fields rather than STEM fields. Second, it focuses on a critical age, corresponding to the end of middle school or beginning of high school. In most countries, the majority of students of that age have not yet strongly specialized in a specific field (e.g., in the United States, this PISA assessment occurs before the opportunity to enroll in Advanced Placement courses such as Calculus BC, Physics C, and Computer Science), so that gender differences in abilities are unlikely to capture anterior specialization. However, 15-y-old students in developed countries are also in the process of choosing high school courses that will determine their future major and the gender gap in STEM at universities (23). A final advantage of PISA is its coverage, as it includes students from 80% of the world economy.

The first column of Table 1 shows that boys outperform girls in math by about 10% of a SD. This difference is lower than 25% of a SD in most OECD countries and is not statistically significant at the 5% level in four of them (*SI Appendix*, Table S1 completes Table 1 for all countries). In contrast, girls outperform boys by about a third of a SD in reading. Together, these observations suggest that girls have a comparative advantage in reading, something that appears more strikingly when we look at the gender gap in the difference between math and reading (MR) ability (Table 1, column 3). Worldwide, this gap reaches about 80% of a SD, or equivalently 24 percentile ranks of the variable. The phenomenon occurs in virtually all countries: The gap is larger than 75% in all OECD countries and larger than 60% everywhere else except in Singapore. Such magnitudes are commonly considered as very large by social scientists.

PISA2012 includes questions related to intentions to pursue math-intensive studies and careers. These intentions are measured through a series of five questions that ask students if they are willing (*i*) to study harder in math versus English/reading courses, (*ii*) to take additional math versus English/reading courses after school finishes, (*iii*) to take a math major versus a science major in college, (*iv*) to take a maximum number of math versus science classes, and (*v*) to pursue a career that involves math versus science. Our main measure of math intentions is an index constructed from these five questions (for details, see *SI Appendix*) and available for more than 300,000 students. It captures the desire to do math versus both reading and other sciences. We complete the analysis with the study of the first two variables that capture more specifically the arbitrage between math and reading.

Column 4 of Table 1 shows that the gender gap in math intentions amounts to 22% of a SD worldwide (respectively 26% and 17% among OECD and non-OECD countries). This gap varies across countries. Two OECD (5 non-OECD) countries have no gap or even a small gap in favor of girls (e.g., Turkey, Malaysia or Thailand, see *SI Appendix*, Table S1). Five OECD (11 non-OECD) countries have a small-to-medium gap (between 10 and 20% of a SD). Seventeen OECD (13 non-OECD) countries have large gaps (between 20 and 45% of a SD). Finally, 10 OECD (1 non-OECD) countries have gaps larger than 45% of a SD (e.g., Australia, Germany, Finland).

The gender gap in intentions cannot be explained by differences in math ability across genders. When one controls for math ability in a linear regression of these intentions on a gender dummy, the estimate for the gender dummy is reduced by less than 10% worldwide and in a majority of the studied countries (column 5 of Table 1 and *SI Appendix*, Table S1). Similarly, controlling for reading ability barely affects the gender gap in intentions.

In contrast, the gender gap in intentions to pursue math-intensive studies and careers disappears almost entirely when

Table 1. Females comparative advantage in reading and the gender gap in intentions to pursue math-intensive studies and careers

	Gender gaps (girls minus boys, as a fraction of variable SD)				Share of the gender gap in intentions to study math explained by ability in…		
	Math	Reading	Math minus reading	Intentions to study math	Math	Reading	Math minus reading
ALL countries	−0.136	0.351	−0.832	−0.218	0.074	−0.036	0.784
OECD countries	−0.159	0.318	−0.883	−0.258	0.064	−0.002	0.810
Non-OECD countries	−0.11	0.389	−0.775	−0.171	0.087	−0.101	0.768
Selected countries (with a gender gap in intentions to study math larger than 0.25 SD)							
United States	−0.111	0.276	−0.805	−0.292	0.024	0.069	0.881
United Kingdom	−0.124	0.276	−0.889	−0.250	−0.009	0.146	1.026
Canada	−0.159	0.343	−0.841	−0.485	0.031	0.009	0.348
Germany	−0.186	0.45	−1.238	−0.461	0.016	0.032	0.516
France	−0.186	0.323	−0.958	−0.393	0.027	0.02	0.429
Finland	−0.069	0.569	−1.096	−0.494	0.040	−0.138	0.741
Denmark	−0.202	0.336	−0.967	−0.336	0.046	−0.032	0.27
Brazil	−0.195	0.379	−0.914	−0.276	0.073	−0.002	0.625
Russia	−0.005	0.419	−0.659	−0.398	0.002	−0.060	0.419

All variables are standardized to have a weighted mean equal to 0 and a weighted SD equal to 1 in each country. Intentions to study math is an index built from five questions. The total sample includes 301,360 students. See *SI Appendix* for details and statistical significance of each estimate.

one controls for individual-level differences in ability between math and reading. Column 7 of Table 1 shows that MR can explain 78% of the gender gap in intentions worldwide (95% confidence interval = [71%,83%], see *SI Appendix*). The corresponding statistics is 81% for OECD countries only, 88% for the United States, 52% for Germany, 43% for France, and 157% for Japan, a country where conditional on MR, girls become more willing to study in math-intensive fields than boys. Similar results are obtained when we measure math intentions with the two questions that capture more specifically the arbitrage between math and reading (*SI Appendix*, Table S2).

MR is more strongly associated with students' intentions to study math than are math or reading abilities taken in isolation (Fig. 1 and *SI Appendix*, Table S3). This association is large and very similar for boys and girls, implying that the gender gap in intentions is small and almost constant—only ~5% of a SD—along the distribution of MR. In contrast, absolute levels of math or reading abilities leave a large gender gap in intentions unexplained.

The simple difference MR summarizes relatively well the relevant information on abilities that is needed to predict intentions to pursue math-intensive studies and careers. We show in *SI Appendix* that MR alone captures about 75% of the total capacity of the distributions of math, reading, and science abilities to predict intentions to pursue math-related studies and careers. We also show that when we include detailed controls for students' abilities in regression models of these intentions, our results remain qualitatively similar (*SI Appendix*, Table S4).

Our analyses of the relationship between abilities and intentions invite to nuance two ability-based arguments that are sometimes advanced to explain the gender gap in enrolment in STEM: the fact that girls remain underrepresented among high math achievers, hence less able to pursue math-related studies, and the fact that they are more often good in both math and reading, hence less constrained than boys in their choice of study (24).

An underrepresentation of girls among high math achievers is indeed observed in most countries (25), but taken in isolation, this phenomenon is unlikely to be a good explanation for the gender gap in math-intensive fields. Indeed, this gender gap tends to be larger among high math achievers (Fig. 1 and *SI Appendix*, Table S5).

Turning to the second possible explanation, we observe that the gender gap in intentions is not reduced among students that perform above a given threshold in both math and reading (see *SI Appendix*, Table S5 for results based on various thresholds). In contrast, the gender gap in intentions among students that are better in math than in reading (68% of them boys) or better in reading than in math (68% of them girls) is more than twice lower than the average gap.

A possible limitation of the results presented so far is that declared intentions to study math may not capture well actual schooling decisions and gender gaps in enrolments. A first reassuring element is that sex differences in occupational plans in high school have been found to be a strong predictor of actual gender differences in STEM majors (26, 27). Moreover, we show that cross-country variations in gender gaps in intentions to pursue math-intensive studies and careers measured in PISA are well correlated with objective country-level measures of sex segregation by field of study, like (*i*) the percentage of women among STEM graduates in tertiary education ($\rho = -0.52$, see *SI Appendix*), (*ii*) female overrepresentation in humanities ($\rho = 0.39$), or (*iii*) the female-to-male ratio in computer science ($\rho = -0.5$, see *SI Appendix*, Table S8).

To discuss more directly the effect of MR on actual schooling decisions, we use an auxiliary dataset for France. It includes ability measures in math and reading as well as information on both intentions to study STEM and future enrolment in STEM (see *SI Appendix* for details). We find that the correlation between intentions to specialize in STEM in grade 11, declared in grade 10 during the period January–March (corresponding to the same age as that of PISA students), and actual enrolment in grade 11 is strong but not perfect (78%). However, and crucially to us, MR is a good predictor of both intentions to study STEM and STEM enrolment, and it reduces the gender gaps in these variables to the same extent (46% for intentions and 49% for actual enrolment in STEM, which also corresponds to what we find for France with PISA, see *SI Appendix*, Table S6). From these observations and more detailed analyses presented in the *SI Appendix*, we conclude that our results

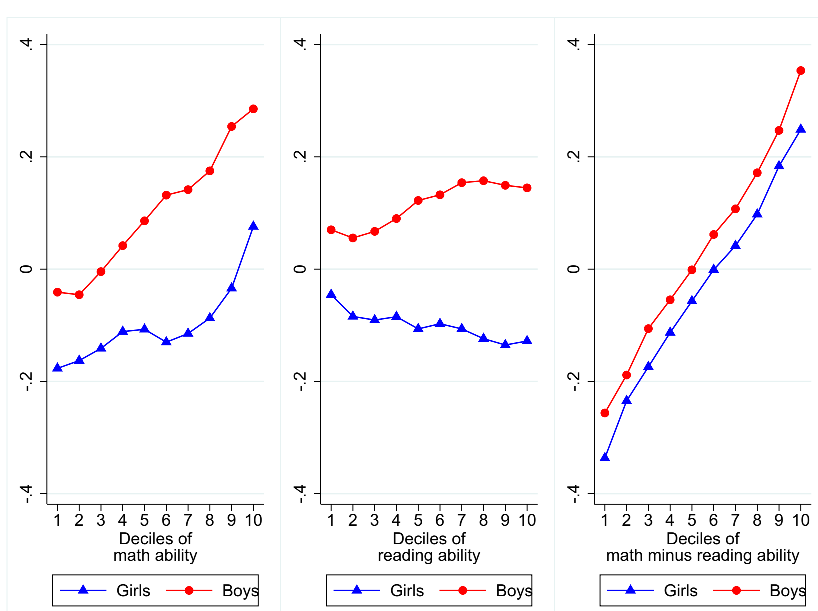

Fig. 1. Intentions to pursue math-intensive studies and careers as a function of ability in math, reading, and the comparative advantage in math versus reading.

on students' intentions of study are likely to generalize to their actual course choices in high school and at universities (the latter being strongly related to the former; ref. 23).

Finally, our analysis of the relationship between abilities and intentions highlights a "better self-selection" of boys in math-intensive fields. Indeed, if the relation between MR and math intentions is similar for boys and girls, the relation between math ability and math intentions is larger for boys than for girls (Fig. 1 and *SI Appendix*). Boys take more into account their math ability when they intend to pursue math studies. This leads to a higher gender gap in intentions to study math among students performing above the median in math (*SI Appendix*, Table S5) and to a larger gender gap in math performance among individuals who intend to choose math studies over reading (*SI Appendix*). These selection patterns are likely to result in an overperformance of boys in math-intensive studies. Similarly, we show in *SI Appendix* that girls self-select better in humanities and are likely to overperform boys in university humanity majors even more than they do before specialization occurs. These likely larger gender gaps in performance after specialization, which are generated by gender differences in the self-selection process across fields of study, can feed the stereotype that math is not for girls and humanities not for boys.

Comparative Advantage and Gender Gaps in Math Self-Concept, Interest for Math, and Other Math-Related Attitudes

Gender differences in math self-concept (i.e., how students perceive their math ability and their ability to learn math quickly) is one of the most commonly advanced explanations for the gender gap in math enrolment (1, 28, 29). A series of questions in PISA2012 makes it possible to build an index to measure this concept at the student level (*SI Appendix*). The gender gap in math self-concept is indeed large (around 30% of a SD) but nevertheless three times smaller than the gender gap in MR (Table 2, column 1 for results worldwide and *SI Appendix*, Table S7 for results on a selection of countries/regions). Interestingly, gender differences in the way students perceive their math ability are barely reduced when this ability is controlled for in a linear regression model, while they almost entirely disappear when one controls for MR (Table 2, columns 2 and 3 and Fig. 2). We then perform the opposite exercise and show that gender differences in MR cannot be directly explained by gender differences in math self-concept (Table 2, column 4). Such results are fully in line with Marsh's Internal/External (I/E) Frame of Reference model (30) according to which people compare their performances across domains (in particular math versus reading) to reach conclusions about their ability.

Similar results are obtained when we replace math self-concept by other well-known proximate sources of the gender gap in math-related fields, such as gender differences in declared interest for math, instrumental motivation for math, anxiety with respect to math, willingness to get involved in math-related activities, or having a strong "math environment" (i.e., family support for doing math and friends being positive about math). There is a gender gap in the variables that attempt to capture these concepts (Table 2 and *SI Appendix* for details), but (*i*) these gaps are 3 to 8 times smaller than the gender gap in MR, (*ii*) they get close to zero when one conditions on MR (except for the involvement in math-related activities), and in contrast (*iii*) they barely explain the gender gap in MR.

We finally show that the math self-concept and our variables capturing other possible mechanisms are related to students' intentions to study math (Table 2, column 5) but account for a much smaller share of the gender gap in these intentions than does MR (Table 2, columns 6 and 7 for the gender gap in intentions conditional on each variable separately and together with MR). MR is not more strongly associated with intentions than are the other studied variables (Table 2, column 5). This implies that the larger explanatory power of this variable is mostly due to the fact that it is subject to a very large gender gap.

Even if all our analyses so far are only descriptive and not causal, they consistently point to an important role of the comparative advantage of boys in math versus reading for the understanding of women's underrepresentation in math-intensive fields. This does not rule out the operation of other (perhaps earlier-occurring) factors, of course. Math and reading abilities at 15 y old are likely to be determined by earlier socialization processes that shape preferences and investment in the different fields. These processes are themselves likely to be influenced by countries' socioeconomic environment and culture (25, 31) or institutions such as parents and schools, which jointly determine future abilities, interests, and self-concepts. For example, we observe that the gender gap in MR at 15 y old is larger in countries where the stereotype associating math with men is stronger (*SI Appendix*, Table S8). We also observe that the

Table 2. Comparing the explanatory power of the comparative advantage with that of other possible determinants of the gender gap in math-intensive fields

	Gender gap in each variable (fraction of a SD)				Intentions to study math (Standardized)		
Variable (standardized)	Absolute	Conditional on math ability	Conditional on MR	Gender gap in MR conditional on the variable	Association with each variable	Gender gap conditional on each variable (raw gap is −0.218 SD)	Gender gap conditional on each variable plus MR
Math minus reading ability (MR)	−0.832	n.a.	n.a.	n.a.	0.215	−0.047	n.a.
Math self-concept	−0.270	−0.231	−0.012	−0.780	0.372	−0.132	−0.033
Declared interest for math	−0.174	−0.160	−0.003	−0.802	0.396	−0.150	−0.046
Instrumental motivation for math	−0.104	−0.088	0.007	−0.820	0.352	−0.182	−0.049
Math anxiety (opposite of)	−0.174	−0.129	−0.020	−0.824	0.228	−0.192	−0.033
Math involvement	−0.293	−0.288	−0.150	−0.789	0.227	−0.155	−0.018
Math environment	−0.096	−0.101	−0.034	−0.827	0.174	−0.202	−0.041

All variables are standardized to have a weighted mean equal to 0 and a weighted SD equal to 1 in each country. See *SI Appendix* for details on the construction of variables and statistical significance of each estimate. n.a., not applicable.

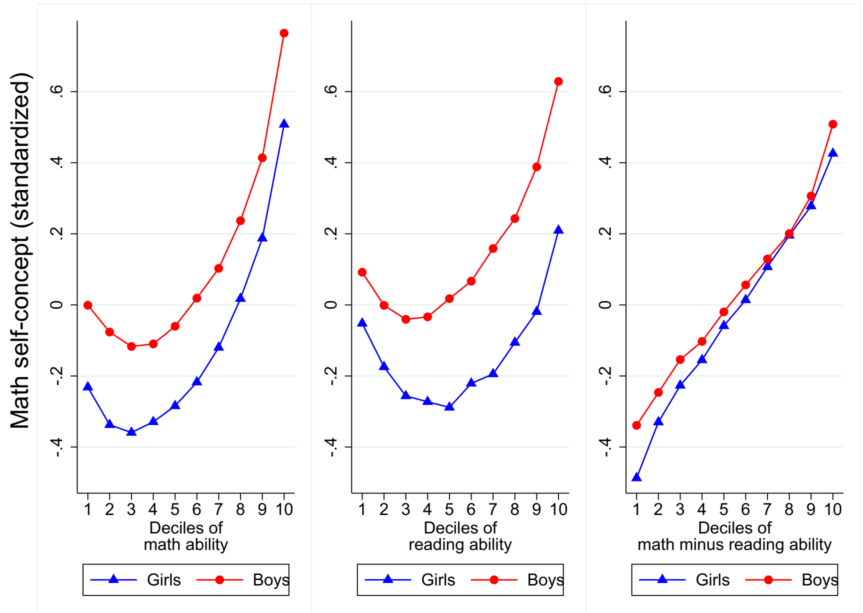

Fig. 2. Math self-concept as a function of ability in math, reading, and the comparative advantage in math versus reading.

gender gap in MR at 15 y old is larger in educational systems in which horizontal stratification by field of study is higher or occurs earlier, and in which mandatory standardized tests are less frequent (*SI Appendix*). These observations and more broadly all our analyses are entirely consistent with the choice models developed by Eccles and coworkers in which educational decisions involve intra-individual comparisons of achievement, self-beliefs and motivation in different subjects, as well as cultural norms, in particular surrounding gender (32, 33). As such, the present paper provides additional supporting evidence for these models.

Instrumental Variables and Causal Inference

While the codetermination of the variables examined here has to be kept in mind, it is not contradictory with our hypothesis that the comparative advantage is an important independent determinant of educational choices, so that exogenous variations in this advantage (e.g., due to educational policies) can lead students to change their choice of study. We suggest that this is indeed the case by exploiting differences across schools in the availability or shortage of resources to learn math. We show, for example, that in schools that experience a shortage of math teachers but not of reading teachers, both girls' and boys' comparative advantage in math is significantly lower.

The majority of 15-y-old students go to the closest school from where they live and those who do otherwise might struggle to observe shortages in some types of teachers or the quality of math teachers. As a consequence, we assume that quantity and quality of math teachers in their school is to a certain extent exogenous to students' initial intentions to study math. Based on this assumption, we use these school-level variables as instruments for students' comparative advantage in math and show that variations in this comparative advantage that solely arise from differences of "math resources" across schools do affect girls' and boys' intentions to study math (even more than non-instrumented variations, see *SI Appendix*, Table S9).

Our approach would fail to show causality if the students with a large comparative advantage selected into better schools that are likely to have more math resources. For this reason, we include controls for school quality and use as instrumental variables resources devoted to math relative to other subjects rather than absolute math resources (which are more directly correlated with school quality, see all details in *SI Appendix*). Finally, we show that the results also hold on the subsample of schools that mostly recruit students based on the geographical location as a self-selection of students in these schools based on their prior comparative advantage appears less likely.

Policy Implications

The analysis above suggests that external factors influencing students' comparative advantage are likely to have consequences for their educational choices. As a consequence, any educational policy that could reduce the gender imbalances in comparative advantage is likely to limit the underrepresentation of women in math-intensive fields. As the gender gap in reading performance is much larger than that in math performance, policymakers may want to focus primarily on the reduction of the former. Systematic tutoring for low reading achievers, who are predominantly males, would be a way, for example, to improve boys' performance in reading. A limitation of this approach, however, is that it will lower the gender gap in math-intensive fields mostly by pushing more boys in humanities, hence reducing the share of students choosing math. In a context of high and increasing demand for math-intensive skills, improving boys' performance in reading without also improving girls' performance in math can therefore be detrimental for the economy and the latter should also be considered as a valuable option.

The general organization of a country's educational system can also play an important role to limit gender imbalances in comparative advantage. As mentioned above, educational systems with early tracking or specialization are associated with larger gender gaps in comparative advantage, possibly because stereotypes and social norms have a stronger influence on choices at younger age. Delaying the time of making hard-to-reverse educational choices may therefore limit gender gaps in comparative advantage and gender segregation across fields.

Another option in terms of policy is to better inform students regarding the returns to different fields of study, something that is likely to trigger large effects on educational choices (34). As labor market opportunities and earnings are significantly higher in math-related careers (11), many (mostly female) students who have a comparative advantage in reading but are nevertheless talented in math would have better career prospects in math-related fields.

Hence, adequate information campaigns on future career prospects may be a welfare-improving way (because students can make better informed choices) of reducing the importance of the comparative advantage in students' decision making and, therefore, the gender gap in enrolment in math-related fields (35). Similarly, interventions involving teachers or parents targeted at limiting the role of the comparative advantage in educational choices could also be effective. Of course, these options should complement rather than replace interventions directly aimed at limiting the negative effects of gender stereotypes.

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