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The Impact of Teacher Skills on Student Performance across Countries*

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Student performance differs greatly across countries, but little is known about the role of teacher quality in explaining these differences. New international data from the PIAAC survey of adult skills allow for the first time to quantify teacher skills in numeracy and literacy, providing country-level measures of teacher subject knowledge. Our student-level regressions with PISA data exploit between-subject variation to overcome bias from unobserved country heterogeneity and control for parent skills to account for the persistence of skills across generations. We find that a one-standard-deviation increase in subject-specific teacher skills raises student performance by 7 percent of a standard deviation in math and 6 percent in reading.

Keywords: teacher skills, student performance, international evidence, PIAAC, PISA

JEL classification: I20, H40, H52

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1. Introduction

The cognitive skills of the population are an important driver of long-run economic growth (e.g., Hanushek and Woessmann 2008). However, numerous international assessment tests have shown that the cognitive skills of students differ greatly across countries, even across developed economies (e.g., Hanushek and Woessmann 2011). While previous studies stressed the importance of institutional features of the schooling systems in explaining these differences (see Hanushek and Woessmann 2011 for an overview), the role of teachers has largely remained unexplored. In particular, there is no evidence on whether differences in teacher quality across countries can explain international differences in students' achievement.

In this paper, we use new international data from the Programme for the International Assessment of Adult Competencies (PIAAC) that allow for the first time to quantify teacher skills in numeracy and literacy, providing country-level measures of teacher subject knowledge. Using math and reading test scores of 15-year-old students from the Programme for International Student Assessment (PISA), we estimate the subject-specific impact of teacher skills on student performance across 22 developed countries. Within-student estimation across math and reading removes bias from unobserved country heterogeneity, thus controlling for any non-subject-specific factors that affect student performance in math and reading in a similar way. Furthermore, the PIAAC data provide a unique way of controlling for the impact of parent skills. In particular, we use PIAAC to compute the numeracy and literacy skills of different groups of adults, defined by the interactions of gender, educational attainment, and number of books at home. We match the average skill levels of these adult groups to the actual parents of students participating in PISA. Controlling for parent skills allows us to account for the likely persistence of performance across generations.

We find substantial differences in subject-specific teacher skills across the 22 countries in our sample. The teacher-skill differences mirror the skill differences of the overall adult populations very closely. Using OLS regressions, we find that teacher skills and student performance are strongly positively associated across countries, even after extensively controlling for student and family background, school inputs, institutional features of education systems, and country-level factors. In contrast to teacher skills, we find only small associations of student performance with teacher salaries. The results are robust to excluding each country individually, to different sets of controls, and especially to including the skills of parents. The impact of subject-specific teacher skills also remains significant in correlated random effects models that exploit within-student variation across subjects. A one-standard-deviation increase in teacher numeracy skills raises student math performance by about 7

percent of a standard deviation. Effects in reading are slightly smaller, but also highly statistically significant. These results are corroborated in conventional first-difference models.

Existing studies investigating international differences in student performance stress the role of student and family background as key factors in international education production functions (e.g. Woessmann et al. 2009). In contrast, the impact of resources such as class size and education expenditure seems to be limited. While adult schooling level in a country explains cross-country differences in student performance in math and science, direct spending on schools is unrelated to student performance differences (Hanushek and Kimko 2000).[1] Institutional features of the school systems have been found to be a rather important source of cross-country variation in student performance. Positive impacts have been estimated especially for school autonomy (especially in developed countries; cf. Hanushek et al. 2013), for external exit exams (Bishop 1997), and for the share of privately operated schools which potentially increase school competition (West and Woessmann 2010).

The quality of teachers as a determinant of international student performance differences has not been studied directly. Instead, researchers have typically relied on different measures of teacher salaries as proxies for teacher quality, implicitly assuming that higher-paid teachers are more effective. In a country panel with international student assessment tests from 1995–2006, teacher salaries – both measured in absolute terms and relative to the wages in a country – are positively associated with student achievement, even after controlling for country fixed effects (Dolton and Marcenaro-Gutierrez 2010). In student-level regressions with a large number of controls, Woessmann (2011) finds country-level indicators of teacher performance pay to be positively related to student performance.[2] Despite the fact that education policy often involves teachers, there is thus far no evidence that teacher quality differences across countries explain student performance gaps.[3]

There is abundant evidence that teachers greatly affect the reading and math performance of students. Numerous within-country studies (mostly from the U.S.) have demonstrated that there is huge variation in teachers' abilities of raising student test scores (Rockoff 2004; Rivkin et al. 2005; Chetty el

[1] See Hanushek (2006) for a review of the effects of school resources.

[2] For a review on teacher performance pay, see Leigh (2013).

[3] In student-level analyses, measures of teacher education are generally positively associated with student performance across countries. Woessmann (2003), for example, uses information from teacher background questionnaires in TIMSS and finds positive associations of student performance with teacher experience and female gender, but a negative relationship with teacher age.

al. 2013).[4] However, only little variation in teacher quality is explained by observable teacher characteristics such as education or experience (except for the first years of teaching experience).[5] In contrast, teachers' academic skills as measured by scores on achievement tests are more strongly associated with student performance (see Eide et al. 2004; Hanushek and Rivkin 2006). While omitted variables and non-random sorting of students to teachers often hamper a causal interpretation of these associations, Metzler and Woessmann (2012) circumvent these problems by exploiting within-teacher within-student variation using data from 6th-grade students in Peru. The authors find a positive impact of teacher subject knowledge on student performance in math, while student reading scores mainly remain unaffected by better teacher knowledge.

Our country-level measures of teacher skills are derived from the PIAAC data. The PIAAC survey, conducted under the auspices of the Organisation for Economic Cooperation and Development (OECD) in 2011-2012, provides internationally comparable data on numeracy and literacy skills of the adult populations aged 16–65 years in 24 countries.[6,7] We define teacher skills as the country-level average of the skills of primary school teachers, secondary school teachers, and "other" teachers (including, e.g., special education and language teachers), using 4-digit occupational classification to identify teachers. On average, country-level teacher skills are based on more than 200 teachers in each country.[8]

Our baseline OLS estimates show that teacher subject knowledge shows a robust positive correlation with student achievement. Parent numeracy skills are also positively associated with student performance in math, while parent literacy skills become insignificant once we account for teacher

[4] Rivkin et al. (2005) estimate that the effect of a costly ten student reduction in class size is smaller than the benefit of moving the teacher quality distribution one standard deviation upwards.

[5] Furthermore, there is no strong evidence that teacher salaries are a good measure of teacher quality (see the overview by Hanushek and Rivkin 2006).

[6] Currently, our sample includes all countries that participated in PIAAC except for Australia and Cyprus. The Australian data are not available to us at the time of writing, while Cyprus did not participate in PISA. Our current country sample includes 16 out of the 28 EU member countries and 21 out of the 34 OECD member countries.

[7] *Literacy* skills comprise the ability to understand, evaluate, use and engage with written texts to participate in society, to achieve one's goals, and to develop one's knowledge and potential. *Numeracy* skills comprise the ability to access, use, interpret, and communicate mathematical information and ideas in order to engage in and manage the mathematical demands of a range of situations in adult life. PIAAC also tested problem-solving skills in technology-rich environments. We do not use this skill domain because it has no counterpart in PISA.

[8] The International Adult Literacy Survey (IALS), collected in the mid-1990s, also tested adults' cognitive skills. However, the IALS dataset is not suitable for measuring teacher skills because of substantially lower sample sizes than in PIAAC. Moreover, the tests in IALS assessed only very basic competencies, thus not allowing to capture teacher subject knowledge.

skills.[9] Although our OLS models control for a large set of observable factors – including student and family background, subject-specific and general school inputs, and institutional features of the school systems – the coefficients on the subject-specific teacher skills might still be biased. One source of bias is that societies and education systems may also differ in other important dimensions that are hard to observe. For example, the attitude toward education in a society is necessarily unobserved and may correlate with both student performance and teacher skills. Similarly, the persistence in the overall quality of an education system would lead to a correlation between the skills of students and the skills of teachers (who went through the same education system one generation earlier). Another potential worry is that teachers with higher subject-specific skills also have higher pedagogical skills that promote student learning. In this case, the coefficients on the subject-specific teacher skills would capture both the subject-specific skill impact and better pedagogical skills.

To tackle the issue that math and reading performance are likely persistent across generations, for example, due to the persistence of the quality of the education system in a country or because of country-specific attitudes toward education, we use the PIAAC data to construct coarse measures of the numeracy and literacy skills of the parents of the PISA students. Using the interactions of gender, highest educational degree, and number of books at home, we define approximately 20 different groups of adults in each country. As these three characteristics are reported both in PIAAC and PISA, we can match the average skills of these adult groups to the actual parents of the PISA students.[10]

Similar to Metzler and Woessmann (2012), we address the potential bias from unobserved heterogeneity by employing a correlated random effects model.[11] This model exploits within-student and within-country variation and identifies the impact of subject-specific teacher skills from differences between the two subjects (math and reading). This means that students in a country should, for example, perform better in math than in reading if their teachers have higher numeracy skills compared to literacy skills. We find that teacher subject knowledge exerts a quantitatively and statistically significant impact on student achievement. A one-standard-deviation increase in subject-specific teacher skills raises student achievement by about 7 percent of a standard deviation in math and by

[9] However, parents‘ education level, occupational status, and number of books at home indicator are still strongly and statistically significantly related to students‘ reading performance.

[10] The number-of-books-at-home measure is a relevant matching variable because this indicator is the single most important predictor of student performance in most countries (Woessmann 2003).

[11] Note that our estimates are not affected by non-random sorting and selection into classrooms and schools because our measures of teacher subject knowledge are aggregated at the country level.

about 6 percent in reading. The correlated random effects model also allows us to test the overidentification restrictions implicit in standard fixed-effects models.

While the correlated random effects models eliminate unobserved country-level factors that are non-subject-specific, our estimates might still be biased if unobserved country-level factors are subject-specific. For example, countries with a strong culture of reading (e.g. novels) may have teachers with high literacy scores and students with high reading scores, implying a positive correlation between these two, even if subject-specific teacher skills have no causal effect on student performance. While we cannot completely rule out the existence of subject-specific factors at the country level, we believe that more general non-subject-specific factors, such as the general attitude toward education or the overall quality of a country's education system, are more important for the observed cross-country differences in student performance than subject-specific factors.

This paper makes three contributions to the literature. First, we are the first to document that teacher quality – as measured by numeracy and literacy skills – differs greatly across developed countries. Second, this is the first paper that provides evidence that the well-documented international differences in student math and reading performance are partly attributable to differences in teacher skills. Third, we introduce a new control variable into the literature on education production functions: a measure for parents' skills, which proves to be an important determinant of student performance.

The remainder of the paper proceeds as follows. Section 2 introduces the datasets and describes the computation of teacher and parent skills. Section 3 provides graphical results of the association between teacher skills and student achievement at the country level. Section 4 presents student-level results from OLS models as well as robustness checks and discusses potential biases. Section 5 presents results from correlated random effects models and from first-differenced models. Section 6 concludes.

2. Data

This section describes the PIAAC data on adult skills, the computation of teacher and adult skills, and the PISA data on student performance.

2.1 Teacher Skills

Teacher skills are derived from the Programme for the International Assessment of Adult Competencies (PIAAC). Developed by the OECD and collected in 2011 and 2012, PIAAC provides

internationally comparable data about skills of the adult populations in 24 countries,[12] 22 of which can be used in our analysis:[13] Austria, Belgium (albeit just Flanders), Canada, mthe Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Japan, Korea, the Netherlands, Norway, Poland, the Slovak Republic, Spain, Sweden, the United Kingdom (specifically England and Northern Ireland), and the United States. At least 5,000 individuals participated in each country.

PIAAC was designed to measure key cognitive and workplace skills needed for individuals to advance in their jobs and participate in society. In each participating country, a representative sample of adults between 16 and 65 years of age was interviewed at home in the language of their country of residence. The standard survey mode was to answer questions on a computer, but for respondents without computer experience there was also the option of a pencil-and-paper interview.[14] The countries used different sampling schemes in drawing their samples, but these were all aligned to known population counts with post-sampling weightings. We employ sample weights to compute country-specific teacher skills.

The survey included an assessment of cognitive skills in three domains: literacy, numeracy, and problem solving in technology-rich environments.[15] The tasks respondents had to solve were often framed as real-world problems, such as maintaining a driver's logbook (numeracy domain). The domains, described more completely in OECD (2013), refer to key information-processing competencies and are defined as:

Literacy: ability to understand, evaluate, use and engage with written texts to participate in society, to achieve one's goals, and to develop one's knowledge and potential;

Numeracy: ability to access, use, interpret, and communicate mathematical information and ideas in order to engage in and manage the mathematical demands of a range of situations in adult life.

[12] Nine additional countries plan to implement PIAAC in 2014: Chile, Greece, Indonesia, Israel, Lithuania, New Zealand, Singapore, Slovenia, and Turkey.

[13] We do not use data for Australia and Cyprus in our analysis. The Australian data are not available to us at the time of writing and Cyprus did not participate in PISA.

[14] On average across countries, 77.5 percent of assessment participants took the computer-based assessment and 22.5 percent took the paper-based assessment. A field test suggested no impact of assessment mode (OECD 2013).

[15] As we want to explain student performance in reading and math, we only use the cognitive skills in the domains literacy and numeracy. Besides, participation in the problem-solving domain was optional, and some countries did not participate in this domain.

This paper implicitly assumes that the performance of teachers in these tests is strongly correlated with the subject-specific skills that teachers actually need for teaching their students in math and reading. Since this performance measure is therefore only a proxy for the true subject-specific skills, we underestimate the true impact of teacher skills on student performance.

PIAAC measures each of the skill domains on a 500-point scale.[16] All scales are intended to measure different dimensions of a respondent's skill set. IALS, the predecessor of PIAAC, suffered from pairwise correlations of individual skill domains that exceeded 0.9, making it virtually impossible to distinguish between different skills. The score domains in PIAAC are less strongly correlated with an individual-level correlation between numeracy and literacy of 0.85.

Before the skill assessment, all participants responded to a background questionnaire that gathered information about occupation, education, and demographic characteristics of the respondents. In the Public Use File, occupation information is available only at the two-digit occupational code in some countries (Germany, Irleand, Sweden, and the US), and a couple of other countries (Austria, Canada, Estonia, and Finland) do not report any occupational code so far. However, we obtained access to 4-digit occupation codes for all countries at the OECD.

We identify teachers based on the 4-digit occupation code in each country. Teachers are all adults who are either "primary school teacher", "secondary school teacher", or "other teacher" (including, e.g., special education teachers and language teachers). Results are very similar if we drop the category "other teachers". We do not include vocational school teachers since the vast majority of PISA students (15-year-olds) are still in secondary schools, and therefore have not been taught by this type of teachers.

We use the test scores of these teachers in the two domains numeracy and literacy to compute the mean numeracy and literacy teacher skills for each country separately, using individual-level weights provided by the OECD.[17] One obvious drawback is that PIAAC contains no information on the subject a teacher is teaching. In particular, the data do not allow identifying language and math teachers.

As a robustness check, we use information about the tasks performed at work to distinguish math and science teachers from other teachers in secondary school. For example, participants in PIAAC are asked how often they use simple and advanced algebra at work. Having classified teachers according to the frequency and extent of math skills at work, we use only the numeracy scores of the teachers

[16] Throughout, we use the first plausible value of the PIAAC scores in each domain.

[17] Since we cannot match individual students to individual teachers, we only use mean teacher skills in a country, but no other statistics, such as standard deviation or percentiles.

identified as math-related teachers and the literacy scores of all other teachers in secondary school. At the same time, we use both numeracy and literacy skills of all primary school teachers, especially since primary school teachers typically teach both math and language classes.

Table 1 provides summary statistics for the country-specific teacher skills in the 22 countries. Sample sizes range from 127 teachers in Germany to 413 teachers in Denmark and 834 teachers in Canada (which oversampled to obtain regionally reliable estimates), with an average of 222 teachers per country. Teachers in Japan achieve the highest average numeracy score (312 points), and teachers in Italy the lowest (269 points), with a difference in average achievement between these two countries mounting to 89 percent of a standard deviation in test scores in the international sample. Teachers in the United States (288 points in numeracy) score below the mean achievement across all 22 countries (293 points). Both the country ranking and the cross-country variation in test scores are similar to those of all prime-aged workers with full-time employment (see Table 1 in Hanushek et al. 2013). Mean literacy scores are similar to the numeracy scores in each country, although there are some differences. For the analyses, we normalize the country-specific teacher skills over the 22 countries in our sample to have an international mean of zero and standard deviation of one.

We cannot know for sure how representative the teacher skills derived from the PIAAC data are, but we can conduct some plausibility checks. First, we can check for each country separately whether teacher skills fall in a plausible skill range relative to the skills of the entire adult population. Since most teachers in our sample have obtained a degree from a higher education institution, we expect that the mean teacher skills should at least be at the median of the skill distribution of entire adult population (of the same age range). In this regard, we find plausible magnitudes of teacher skills: On average across all 22 countries, teacher skills fall at the 66th (68th) percentile of the numeracy (literacy) skill distribution of all adults, ranging from the 49th to the 78th percentile in both domains across countries. Second, since secondary school teachers teach their students higher levels of math and reading compared to primary school teachers, secondary school teachers should on average have somewhat higher skills than primary school teachers. This is indeed the case: Across all countries, numeracy (literacy) skills is 290 (291) for primary school teachers and 295 (297) for secondary school teachers.

2.2 Parent Skills

The PIAAC data also enable us to control for the numeracy and literacy skills of the parents of the PISA students. We take the numeracy and literacy scores of all 35-59 year-old individuals in PIAAC.

Given their age, these individuals are the potential parents of the 15-year-old PISA students.[18] We create different groups of adults based on interactions of gender, educational attainment (3 categories), and number of books at home (3 categories). To obtain reasonable cell sizes (at least 100 adults per cell), each education level has only two different book categories that are determined by the empirical distribution. For example, only few individuals with a high education level have only few books at home. Therefore, this education level is differentiated by a category comprising "some books" and a category containing "many books". Using a category containing only few and very few books is not fruitful for this group of individuals. The exact cutoffs in the book category for each educational level differ by gender and by country and are purely data-driven to ensure a sufficiently high number of observations in each cell.[19] For each cell, we compute the mean numeracy/literacy skill separately for women and men and separately for each country, using individual-level weights.

The numeracy and literacy skills of the PIAAC adults are then matched to the actual mothers and fathers of the PISA students. The matching is also based on the interactions of gender, educational attainment, and number of books at home of the individuals.[20] To give an example: The mother of a PISA student in the US with a tertiary education degree and more than 500 books at home is assigned the mean numeracy and mean literacy skills of all 35-59 year-old female PIAAC respondents in the US who have a tertiary education degree and more than 500 books at home. In the analysis, we combine the skills of the mother and the father and use the highest skill level of mother and father.

Table 3 presents summary statistics for parent skills in numeracy and literacy by country. The difference between the lowest skill level and the highest skill level is quite large in each country. This implies that there is huge variation in numeracy and literacy skills across the various parent groups within countries, enabling us to effectively control for the impact of parents' skills on their children's achievement in math and reading.

2.3 Student Performance

International data on student performance come from the Programme for International Student Assessment (PISA), conducted by the Organisation for Economic Co-operation and Development

[18] Students of the PISA 2009 cycle were 15 years old in 2009 and PISA 2012 students in 2012. This means that adults tested in PIAAC (in 2011 and 2012) were between 17 and 44 years old when the PISA students in our sample were born.

[19] In a few cases, the distribution forced us to collapse all books categories and assign only one book category per education level (see table 2).

[20] The number-of-books categories are identical in PISA and in PIAAC. The education categories differ somewhat in the two data sources, and hence are aggregated to three identical categories.

(OECD). PISA tested representative samples of 15-year-old students in math and reading literacy in 2009 and 2012.[21] The tests emphasize understanding as well as flexible and context-specific application of knowledge, containing both multiple-choice and open-answer questions.

We normalize the test scores for each PISA cycle separately across all countries in our sample, such that the mean performance equals zero and the standard deviation equals one in both math and reading in PISA 2009 and 2012. In standardizing test scores, we use the student-level weights provided by the OECD in both surveys. Since we are interested in differences across countries, each country receives the same total weight in each PISA cycle. For the analyses, we always use the first plausible values of the math and reading scores.

Based on background questionnaires, PISA provides extensive information on student background, such as gender, migration status, and number of books at home as well as characteristics on students' parents, such as highest education level attained and occupation, and on school resources, such as lack of qualified teachers. Furthermore, students are also asked about the quality of class instruction in their math class (in PISA 2012) and in their language class (in PISA 2009). This information is used to compute country-specific indicators of the quality of classroom instruction in these two subjects. Students also provide information on the length of weekly math/language instruction. School principals provide information on their schools, most importantly about the lack of qualified math teachers and language teachers.

Table 4 provides summary statistics on student performance and student characteristics.[22] Student performance varies considerably across countries, both in math and in reading. Table 5 presents summary statistics of school and country characterics. Country characteristics include country-level variables that have been used in previous cross-country analysis, including the average salaries of teachers after 15 years of teaching experience; an indicator whether countries use teacher performance pay schemes; the cumulative expenditure on students up to the age of 15; GDP per capita; and school starting age.

[21] Since teachers were tested only in the domains numeracy and literacy, we do not use the student science test scores from PISA. Earlier PISA cycles are not used since the teachers of those student cohorts might differ substantially from the teachers who have been tested in PIAAC.

[22] All statistics are averages across PISA 2009 and PISA 2012 and are weighted with the individual student-level weights provided by the OECD.

3. Visual Evidence of the Importance of Teacher Skills

Before presenting the estimation results, we first provide visual evidence on the correlations between student performance and teacher skills and adult skills, respectively, at the country level.

The following figures show associations between student performance, teacher skills, and adult skills, where all performance measures being aggregated at the country level, using individual-level weights and the student performance being pooled across the PISA 2009 and 2012 samples. Figure 1 shows that student math performance and teacher numeracy skills are positively correlated across countries, with a coefficient of 0.09. This association does not control for any other influences. The correlation for reading is even stronger (coefficient=0.13) for the simple cross-country comparison (figure 2).[23]

To net out the persistence of performance across generations, we control for the skills of the adult population (individuals aged 25-65), i.e. for the mean skills of all adults in a country covering approximately the same age range as teachers. Note that in this exercise we consider the mean skills of adults skills in a country (of a certain age group). This adult skill measure is supposed to capture the performance persistence across generations, and not to control for the impact of students' parents. Controlling for the mean adult skill level in a country does not change the association between student performance and teacher skills. While the math coefficient slightly decreases, the reading coefficient even increases somewhat, though not statistically significantly (figures 3 and 4).

We now look directly at the persistence of performance across generations. To do so, we look at the correlation between student performance and adult skills (again, the mean skills of all individuals aged 25-65). As expected, student performance and adult skills are positively related in both math and reading (figures 5 and 6), with an R squared of 0.13 in both cases. Next, we consider the strength of the correlation between student performance and adult skills at the country level when we net out the impact of teacher skills. Figures 7 and 8 show that controlling for teacher skills substantially reduces the adult skill coefficients for both math and reading, rendering the coefficients statistically insignificant (and even slightly negative for reading).

In sum, these figures show that student performance is significantly positively related to teacher skills and to the level of adult skills. Furthermore, the correlation between student performance and teacher skills is more robust than the relationship between student performance and adult skills, at least at the aggregated country level. The next section investigates whether this robust association between

[23] All correlations in the figures are robust to excluding the two outliers Korea and the Russian Federation.

student performance and teacher skills is also present at the student level when a large set of background factors, especially parents' skills and other country-specific factors, is taken into account.

4. OLS Results

To investigate the impact of teacher skills on student performance, we relate students' performance in math (reading) to the country-speficic mean numeracy (literacy) teacher skills, while controlling extensively for student and family background, parent skills in numeracy (literacy), school inputs, and other country-level factors, such as institutional features of the education systems, potentially affecting student performance. Hence, we run the following OLS model separately for math and reading:

$$y_{ijc} = \alpha_j + \beta_j T_{jc} + \gamma X_{ic} + \delta_j P_{ijc} + \lambda_j school_{ijc} + \phi school_{ic} + \rho_j X_{jc} + \varphi X_c + \varepsilon_{ijc} \qquad (1)$$

where the dependent variable y_{ijc} is the test score of student i in subject j (math or reading) in country c; T_{jc} is the mean skills of teachers in country c in domain j (numeracy or literacy); the vector X_{ic} includes student characteristics, such as age (in months), gender, and migration status, and parent characteristics, such as educational attainment, occupation[24], and number of books at home (six categories); P_{ijc} is the maximum of the numeracy/literacy skills of mother and father; $school_{ijc}$ includes the degree to which the school's capacity to provide instruction is hindered by a lack of qualified math/language teachers; $school_{ic}$ contains school-specific factors that are non-subject-specific, including the location of the school (5 urbanity levels), whether the school is private, school enrollment, autonomy of the school for class content, personnel, and budget[25]; X_{jc} contains a subject-specific indicator on the quality of instruction based on information provided by students on their math/language class.[26] The vector X_c includes five country-level indicators that are potentially

[24] Occupational status contains four categories: white-collar high, white-collar low, blue-collar high, and blue-collar low.

[25] Since France did not administer the school background questionnaire in PISA 2009, we imputed the missing school-level values with all variables of the model (including student performance) and the information from PISA 2012. Thus, we implicitly assume that, for example, the correlation between student performance and school location has not changed between 2009 and 2012.

[26] The background questionnaire of PISA 2009 (focus on reading) asks students about the frequency (on a 4-point scale ranging from "never or hardly ever" to "in all lessons") of the following things their teacher does in the language class: asking students to explain the meaning of a text; asking questions that challenge students to get a better understanding

affecting student performance: teacher salary (after 15 years of experience, measured in PPP terms), cumulative student expenditure, an indicator for the existence of teacher performance pay schemes, school starting age, and GDP per capita.

Results for math performance are reported in table 6. The numeracy skills of teachers are significantly related to student performance in math. A one-standard-deviation increase in teacher numeracy skills is associated with a 0.09 standard deviation increase in student math performance (column 1). Similarly, parent numeracy skills are associated with their children's math performance. Controlling for the number of books at home, the highest educational level of parents, and occupational status, one-standard-deviation increase in parents' numeracy skills (maximum of mother's and father's numeracy skill) is associated with a 0.05 standard deviation increase in their child's math performance (column 2).[27] Since teacher skills vary only at the country level, but parent skills at the student level, the adjusted R squared naturally increases substantially from column 1 to column 2. As expected, relating students' performance to both teacher skills and parent skills simultaneously reduces both coefficients considerably (column 3). Adding student characteristics (age, gender, migrant status, and an indicator for whether the student speaks a language other than the test language at home) and school characteristics (location of the school, private school status, school enrollment, and autonomy level for class content, personnel, and budget) does not affect the coefficient on teacher skills (column 4). The coefficients on all these control variables have the expected signs.

Since teacher skills vary at the country level, adding other country-level factors are more likely to affect the coefficient on teacher skills than do factors that vary strongly within countries, such as student-level or school-level characteristics. Several country-level factors have already been used in existing studies on international student performance, including the level of teacher salaries, whether

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of a text; giving students enough time to think about their answers; recommending books or author to read; encouraging students to express their opinion about a text; helping students relate the stories they read to their lives; and showing students how the information in texts builds on what they already know. Each of these activities seems to be valuable, and hence beneficial for student learning. PISA 2012 (which had a focus on math) asked students (somewhat different) questions about what their teachers do in math class: asking questions that make students reflect on the problem; giving problems that require students to think for an extended time; presenting problems in different contexts so that students know whether they have understood the concepts; helping students to learn from mistakes they have made; asking students to explain how they have solved a problem; presenting problems that require students to apply what they have learnt to new contexts. Again, the answer categories range on a 4-point scale from "never or rarely" to "almost or almost always". Since the quality of reading instruction is only available for 2009 and math instruction only for 2012, we aggregate the mean responses of students for reading in 2009 to the country level, using the mean answer category and weighting students by individual-student-level weights. We then use this country-level indicator for both 2009 and 2012, assuming that the quality of reading instruction has not changed considerably over the course of three years within a country. Similarly, we compute the math instruction indicator from the PISA 2012 cycle and apply it to both PISA cycles.

[27] All models include binary indicators for imputed values.

teachers are incentivized by teacher performance pay schemes, cumulative expenditure on students up to age 15, GDP per capita, and the entry age in primary school. Several of these factors might be correlated with the level of teacher skills in a country, thereby changing the impact of teacher skills on student performance when included as additional controls in the model. Adding these country-level factors increases the impact of teacher skills on student performance (column 5). All else equal, countries with a higher GDP per capita have somewhat lower student performance. Since teacher skills and GDP per capita are rather strongly correlated (around 0.4), including GDP per capita increases the coefficient on teacher skills.

Finally, we want to control for subject-specific factors that might impact the performance of students in math and reading differently. One such factor is the quality of teaching instruction in class. Fortunately, the background questionnaires of PISA asked students several questions of what their teacher was doing in language class (PISA 2009) and in math class (PISA 2012), respectively. Based on the answers of several questions, we computed an index at the country level (see footnote 26) that allows us to coarsely control for the instructional quality in math instruction in a country. This seems important since student performance is affected both by the subject-specific skills of a teacher and by the way she is teaching student (pedagogical skills). Surprisingly, better instructional quality (based on this index) seems to be negatively associated with student performance across countries (column 6). This does not mean, however, that this math instruction index is of bad quality. Using the same model, the PISA 2012 data only, and the same index disaggregated at the student level (where it had been elicited), we find that the instructional quality in math is strongly *positively* correlated with math student performance, with a coefficient of 0.08 (results available from the authors upon request). These findings suggests that the math instruction index is a strong predictor for student performance at the student level, but the aggregated index does not explain differences in math performance across countries.

Another subject-specific determinant of student math performance is the shortage of qualified math teachers at a school. Having a shortage of math teacher is significantly negatively related to math performance (column 6). Furthermore, we control for the amount of math instruction per week, as reported by students. As expected, students who receive more instruction in math have higher math

performance.[28] Including the math-specific control variables reduces the impact of teachers' numeracy skills, but only slightly.[29]

The results on reading performance are reported in table 7. Overall, the findings are similar to those of math performance. Teacher literacy skills are strongly related to student reading performance, even about 50 larger stronger than for math. Similarly, the literacy skills of parents are positively related to student reading performance, but somewhat weaker than for math. Simultaneously controlling for teacher and parent skills reduces the impact of teacher skills substantially and decreases the impact of parent skills to zero, while the coefficients on the level of parents' education and number of books at home are still large and highly statistically significant. Adding student characteristics, school characteristics, country-level factors, and the subject-specific factors affect the impact of teacher literacy skills only very little. In contrast to math, the instruction quality indicator for reading shows the expected positive sign; the coefficient is even large, but statistically insignificant. In the model with all control variables, numeracy skills and literacy skills of teachers seem to be equally important for the performance of students (the coefficient on literacy skills is somewhat larger, but this difference is not big).

In sum, the results of the OLS models suggest that teacher skills have a considerable impact on student performance, both in math and in reading. In these models, we extensively control for family background, including parents' skills, school characteristics, and other country-level factors that are potentially affecting student performance.

In this paper, we are not interested in whether teacher quality is important per se, but rather in the more narrow question whether differences in subject-specific skills can account (at least partly) for the student performance gaps across countries. In this respect, the OLS results might still be biased, even after controlling for the numerous other factors. One particular important reason for bias is omitted variables, that is, other factors that affect student performance and are correlated with the level of (subject-specific) teachers skills are ignored in our model. In particular, there are two mean sources of omitted variables. One important factor omitted from our model is the pedagogical quality of teachers (which is not captured by our instruction quality indicators). It is likely that teachers with higher subject-specific skills also possess higher pedagogical skills. In this case, a positive coefficient on

[28] Teacher shortage is reported by school principals in both PISA 2009 and 2012 for both math and language teachers. Similarly, the amount of instruction time is reported by students in both PISA 2009 and 2012 for both math and language classes.

[29] The estimated coefficients on parent and school characteristics are reported in Table A-1 for math and in Table A-2 for reading. All coefficients have the expected signs and expected magnitudes, as reported in previous studies.

subject-specific skills does not only capture the impact of higher subject-specific skills, but does also incorporate the impact of better pedagogical skills. One reason why subject-specific skills and pedagogical skills might be positively correlated could be that countries with a high-quality teacher training produce teachers with both high subject-specific skills and high pedagogical skills. Another important omitted factor is the general attitude of a population toward education. A positive attitude toward education means probably both teachers with higher subject-specific skills and parents strongly supporting their children at home. If this parental support is not entirely captured by parents' skills, then the coefficient on teacher skills likely also incorporates the impact of parental support.

To tackle the potential issues of omitted variables bias, the next section employs another identification strategy, exploiting variation across the two subjects math and reading.

5. Estimating the Impact of Subject-Specific Teacher Skills

5.1 The Correlated Random Effects Model

We estimate the following education production functions for math and reading:[30]

$$y_{i1c} = \beta_1 T_{1c} + \theta U_c + \gamma_1 X_{i1c} + \mu_{ic} + \vartheta_c + \varepsilon_{i1c} \quad (2a)$$

$$y_{i2c} = \beta_2 T_{2c} + \theta U_c + \gamma_2 X_{i2c} + \mu_{ic} + \vartheta_c + \varepsilon_{i2c} \quad (2b)$$

where y_{i1c} and y_{i2c} are the test scores of student i in country c in math and reading, respectively. T_{jc} is the average skill of teachers in country c in subject j (numeracy or literacy). U_c contains observable non-subject-specific teacher characteristics in country c, such as mean age, mean experience, share of female teachers, share of teachers with master degree. X_{ijc} contains both non-subject-specific and subject-specific characteristics of students, parents, schools, and countries. Non-subject-specific characteristics include, for example, student gender, parental education, school location, and GDP per capita. Subject-specific factors are parent skills in numeracy/literacy, weekly instruction in math/language class, and instruction quality indicators for math/language teachers. The composite error consists of a student-specific error term μ_{ic}, a country-specific error term ϑ_c, and an idiosyncratic subject-specific error term ε_{ijc}.

[30] Note that the notation differs somewhat from the notation in equation (1).

We are interested in the β coefficients which reflect the impact of the subject-specific teacher skills. As discussed above, simple OLS estimates of Eqs. (2a) and (2b) may be biased because of unobserved country traits. We follow Metzler and Woessmann (2012) and model the potential correlation between the unobserved country effect ϑ_c with the observed inputs, in particular the subject-specific teacher skills:

$$\vartheta_c = \eta_1 T_{1c} + \eta_2 T_{2c} + \sigma U_c + \varphi X_{i1c} + \varphi X_{i2c} + \omega_c \qquad (3)$$

where ω_c is uncorrelated with the observed inputs.

The unobserved country effect ϑ_c might be correlated with subject-specific teacher skills for several reasons. One reason might be that teachers with higher subject-specific skills also possess higher pedagogical skills, an important omitted factor from our model. Again, we allow that numeracy skills and literacy skills of teachers are differently correlated with unobserved. Another reason for a positive correlation between the unobserved country effect and country-level teacher skills is the general attitude toward education in a country. A general positive attitude toward education is probably related with higher subject-specific teacher skills. But at the same time a positive attitude toward education also means that parents strongly support their children at home in education issues. Although we control for parent skills, it is unlikely that we entirely capture country-specific differences in education attitude.

While we allow for the possibility that numeracy and literacy skills of teachers are correlated with the unobserved country effects to different degrees, we assume that the coefficients on the subject-specific characteristics of students, parents, schools, and countries are the same across subjects. Even more, we assume that the impact of unobserved country effect is the same for students' math and reading performance. This means that if the unobserved country effect is more important for one subject than the other, then the effect of the subject-specific teacher skills would still be biased. This bias would arise, for example, if teachers' pedagogical skills were more important for math than for reading (or vice versa). Similarly, the impact of subject-specific teacher skills would be biased if the attitude toward education is not general, but subject-specific.

Plugging equation (3) into equations (2a) and (2b) and collecting terms yields the correlated random effects (CRE) model:

$$y_{i1c} = (\beta_1 + \eta_1) T_{1c} + \eta_2 T_{2c} + (\theta + \sigma) U_c + (\gamma_1 + \varphi) X_{i1c} + \varphi X_{i2c} + (\mu_{ic} + \omega_c + \varepsilon_{i1c}) \qquad (4a)$$

$$y_{i2c} = \eta_1 T_{1c} + (\beta_2 + \eta_2) T_{2c} + (\theta + \sigma) U_c + \varphi X_{i1c} + (\gamma_2 + \varphi) X_{i2c} + (\mu_{ic} + \omega_c + \varepsilon_{i2c}) \qquad (4b)$$

where the expression in the last bracket is the new composite error term which is uncorrelated with the teacher skills in numeracy and literacy. Both subject-specific teacher skills enter the equation of both subjects. While the β coefficients reflect the true impact of the subject-specific teacher skills (in the same domain), the η coefficients reflect the degree of bias if we ignored unobserved country traits. Equations (4a) and (4b) are estimated via seemingly unrelated regressions (SUR) which allows for different error variances in each equation and for correlation of the errors across equations.

The correlated random effects model nests as a special case the first-differenced model, whose overidentification restrictions can be tested within in the CRE specification (Ashenfelter and Zimmerman 1997). After estimating equations (4a) and (4b), we can test the assumptions implicit in first-differenced models: $\beta_1 = \beta_2 = \beta$ and $\eta_1 = \eta_2 = \eta$. If both of these conditions hold (i.e., cannot be rejected), we can estimate a first-differenced model that regresses the difference in student performance on the difference in teacher skills across the two subjects math and reading, eliminating any non-subject-specific bias due to student and country heterogeneity. If the conditions $\beta_1 = \beta_2 = \beta$ and $\eta_1 = \eta_2 = \eta$ hold, equation (4b) can be subtracted from equation (4a), yielding the first-differenced model:

$$y_{i1c} - y_{i2c} = \beta(T_{1c} - T_{2c}) + \gamma_1 X_{i1c} - \gamma_2 X_{i2c} + (\varepsilon_{i1c} - \varepsilon_{i2c}) \qquad (5)$$

5.2. Results from the Correlated Random Effects Model

The results of the correlated random effects model (equations (4a) and (4b)) are presented in table 8. All specifications include the impact of teachers' numeracy and literacy skills, as well as all all subject-specific control variables, such as parents' skills in both numeracy and literacy. The impact of teachers' numeracy skills on student math performance, implied $\beta_{Numeracy}$, is the difference between the coefficient on teacher numeracy skills in the math model minus the coefficient on teacher numeracy skills in the reading model, and vice versa for the impact of teacher literacy skills (implied $\beta_{Literacy}$). The coefficients in math are very similar to the coefficients in the OLS model, while the reading coefficient is about one third smaller than in the OLS model with full controls, suggesting bias in the OLS coefficient.

The results suggest that an increase in teacher numeracy skills by one standard deviation raises student math performance by 7.3 percent of a standard deviation. Similarly, an increase in teacher

literacy skills by one standard deviation raises student reading performance by 5.8 percent of a standard deviation. Both effects are highly statistically significant. This effect size for math is remarkably similar to the impact of teacher numeracy skills in Peru, which were also identified in a CRE model, exploiting knowledge differences across individual teachers within one country (Metzler and Woessmann 2012). In contrast, they find only a small impact of teacher literacy skills.

The overidentification tests in the full specification (model 5) do not reject the hypothesis that the selection terms and the implied betas are identical, thus permitting to estimate a standard first-differenced model. For reasond of completeness, we run first-differenced models for the same specifications than in Table 8 for the correlated random effects models. The impact of subject-specific teacher skills on student performance is remarkably robust across all specifications. A one-standard-deviation increase in subject-specific teacher skills raises student performance by 7.3 percent of a standard deviation. Interstingly, the effect size is identical in the first model that does not control for any other influences and in the last model that includes all controls.

In sum, the findings of the correlated random effects model and the first-differenced models indicate that both subject-specific teacher skills have a considerable impact on student performance. The effect size for math is similar to the coefficient in the OLS model, suggesting little bias. In contrast, the impact in reading is substantially smaller in the CRE models.

6. Conclusion

Student performance differs greatly across countries, but little is known about the role of teacher quality in explaining these differences. In this paper, we use new international data from the Programme for the International Assessment of Adult Competencies (PIAAC) that allow for the first time to quantify teacher skills in numeracy and literacy. Using math and reading test scores of 15-year-old students from PISA, we estimate the subject-specific impact of teacher skills on student performance across 22 developed countries. Furthermore, the PIAAC data provide a unique way of controlling for the impact of parent skills. In particular, we use PIAAC to compute the numeracy and literacy skills of different groups of adults, defined by the interactions of gender, educational attainment, and number of books at home. We match the average skill levels of these adult groups to the actual parents of students participating in PISA. Controlling for parent skills allows us to account for the likely persistence of performance across generations.

We find substantial differences in subject-specific teacher skills across the 22 countries in our sample. The teacher-skill differences mirror the skill differences of the overall adult populations very closely. Using OLS regressions, we find that teacher skills and student performance are strongly positively associated across countries, even after extensively controlling for student and family background, school inputs, institutional features of education systems, and country-level factors. In contrast to teacher skills, we find only small associations of student performance with teacher salaries. The results are robust to excluding each country individually, to different sets of controls, and especially to including the skills of parents. The impact of subject-specific teacher skills also remains significant in correlated random effects models that exploit within-student variation across subjects. A one-standard-deviation increase in teacher numeracy skills raises student math performance by about 7 percent of a standard deviation. Effects in reading are slightly smaller, but also highly statistically significant. These results are corroborated in conventional first-difference models.

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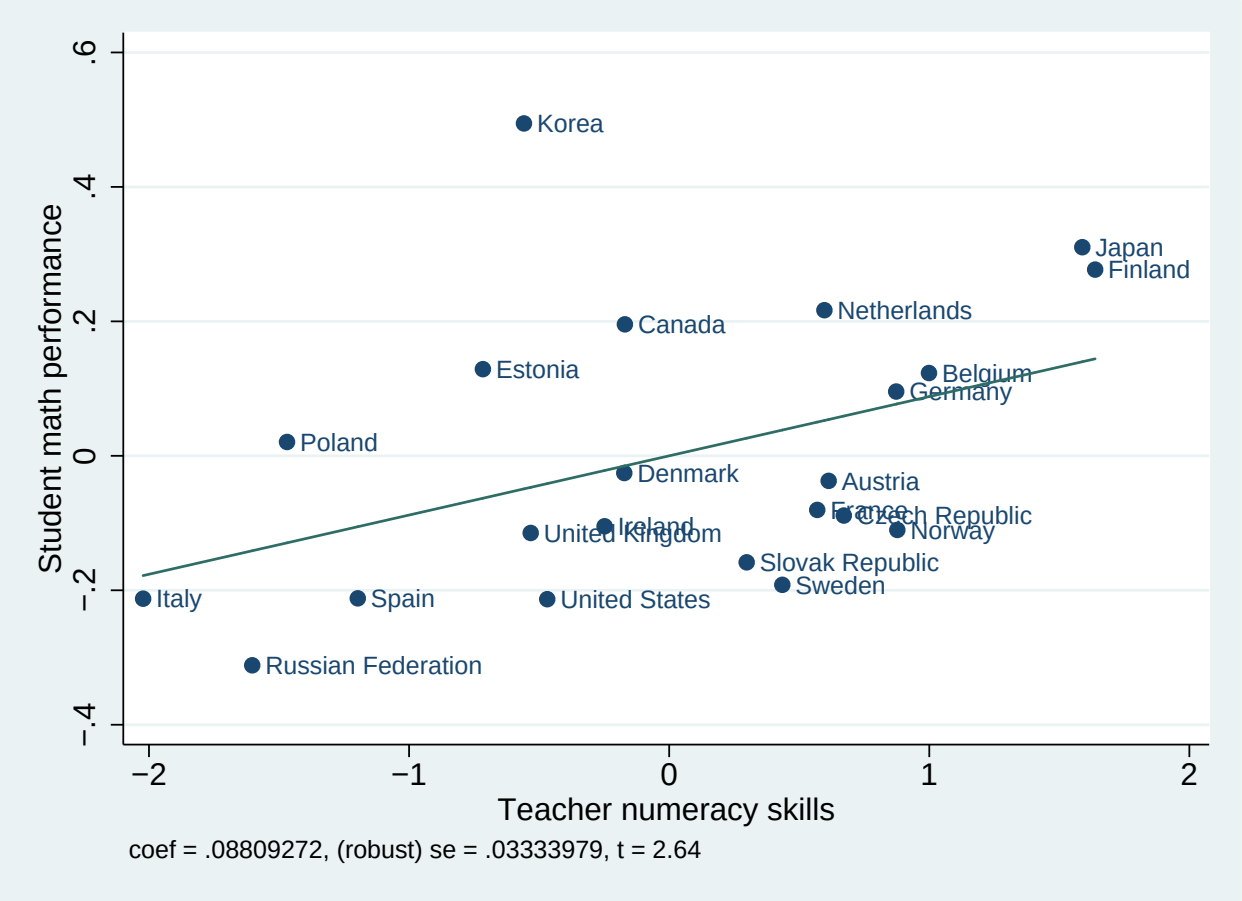
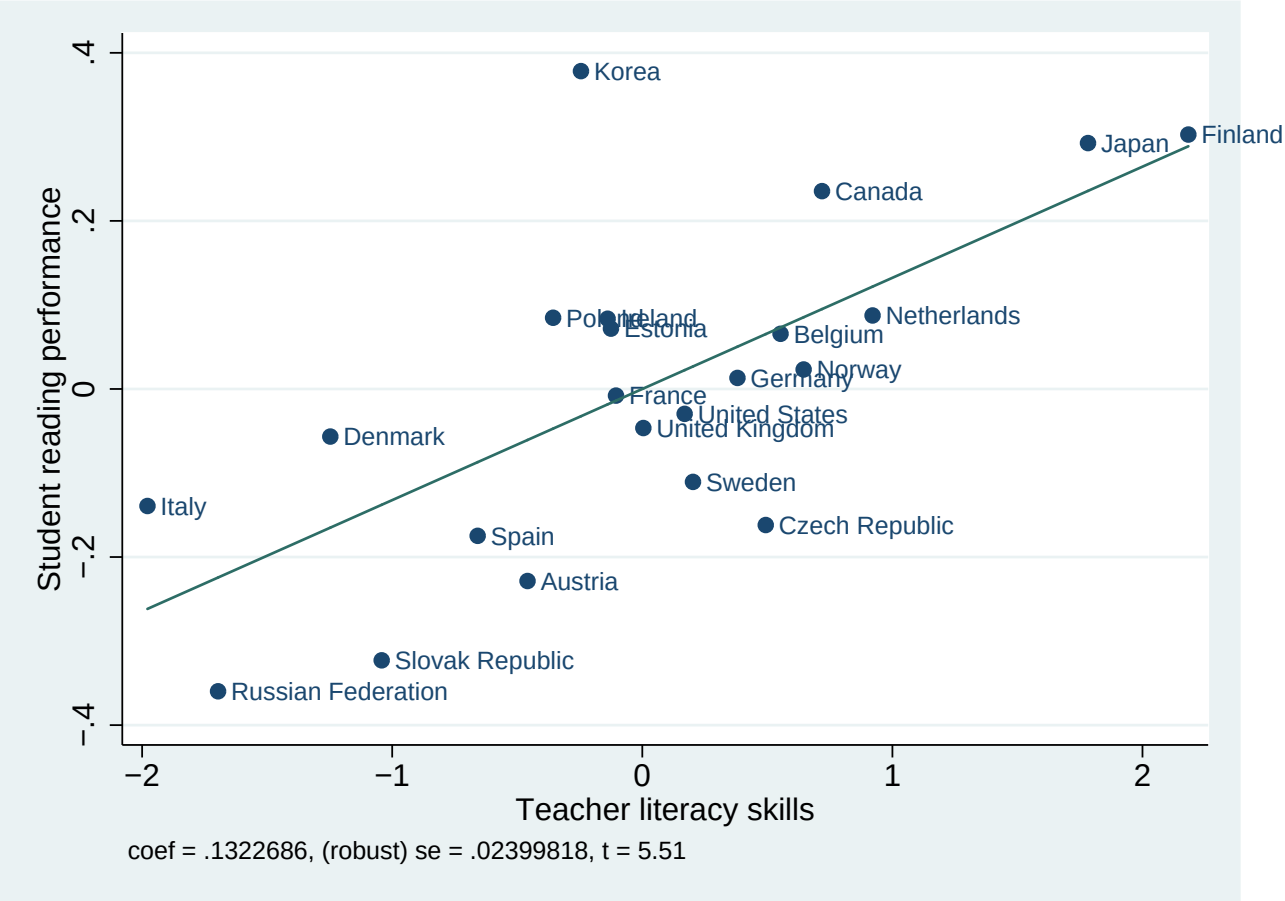
Figures and Tables

Figure 1: Student Performance vs. Teacher Skills (Math)



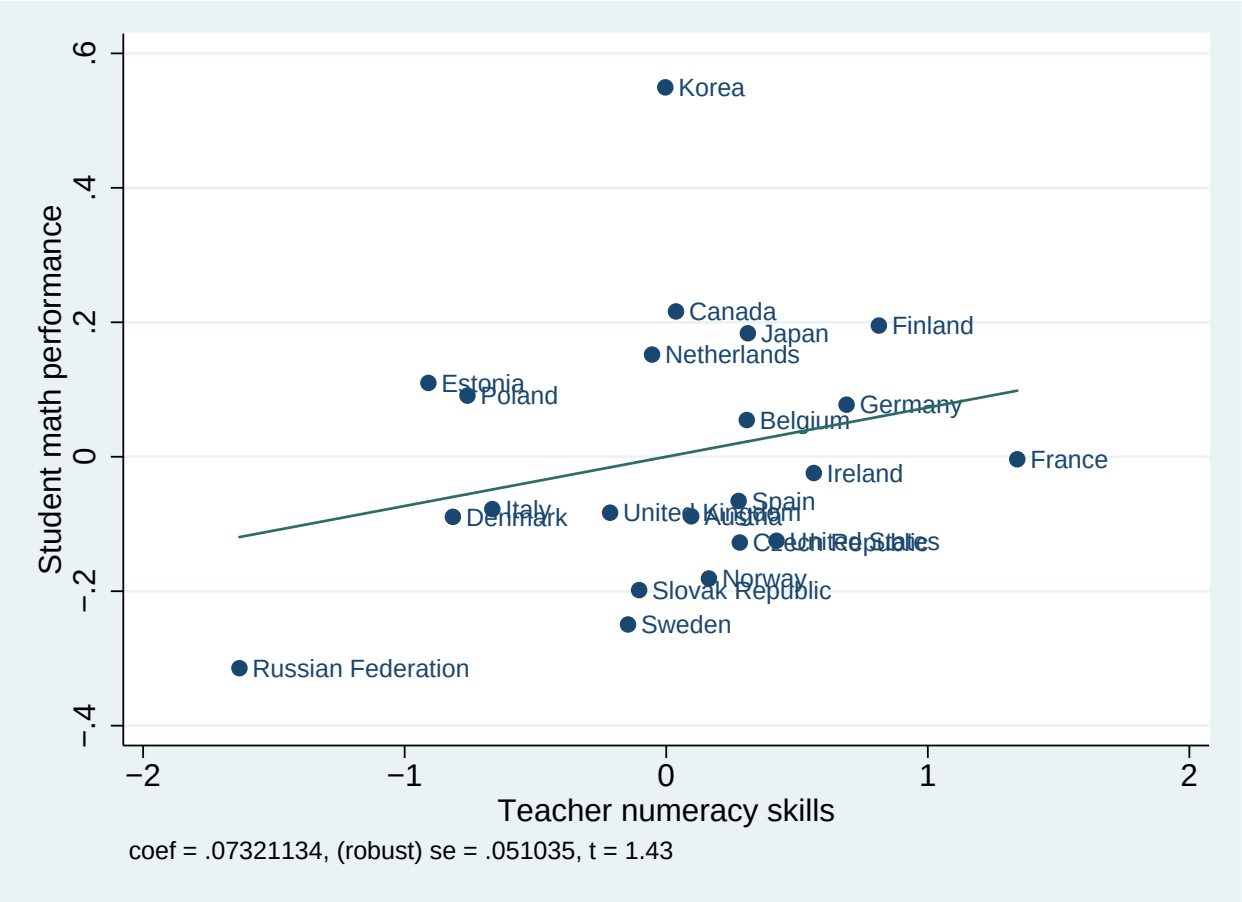
Notes: Student performance aggregated at country level and pooled across PISA 2009 and 2012. No further controls.

Figure 2: Student Performance vs. Teacher Skills (Reading)



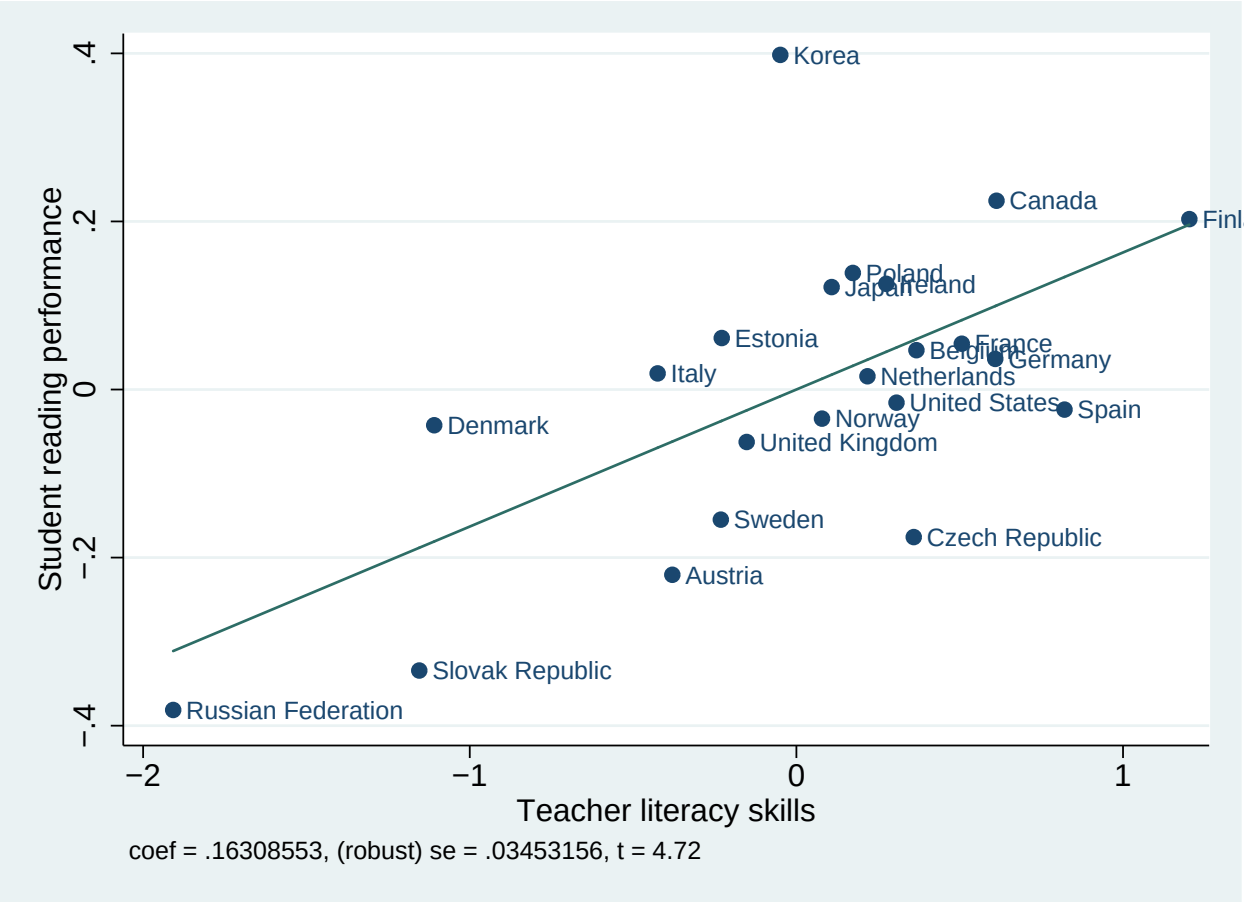
Notes: Student performance aggregated at the country level and pooled across PISA 2009 and 2012. No further controls.

Figure 3: Student Performance vs. Teacher Skills, Conditional on Adult Skills (Math)



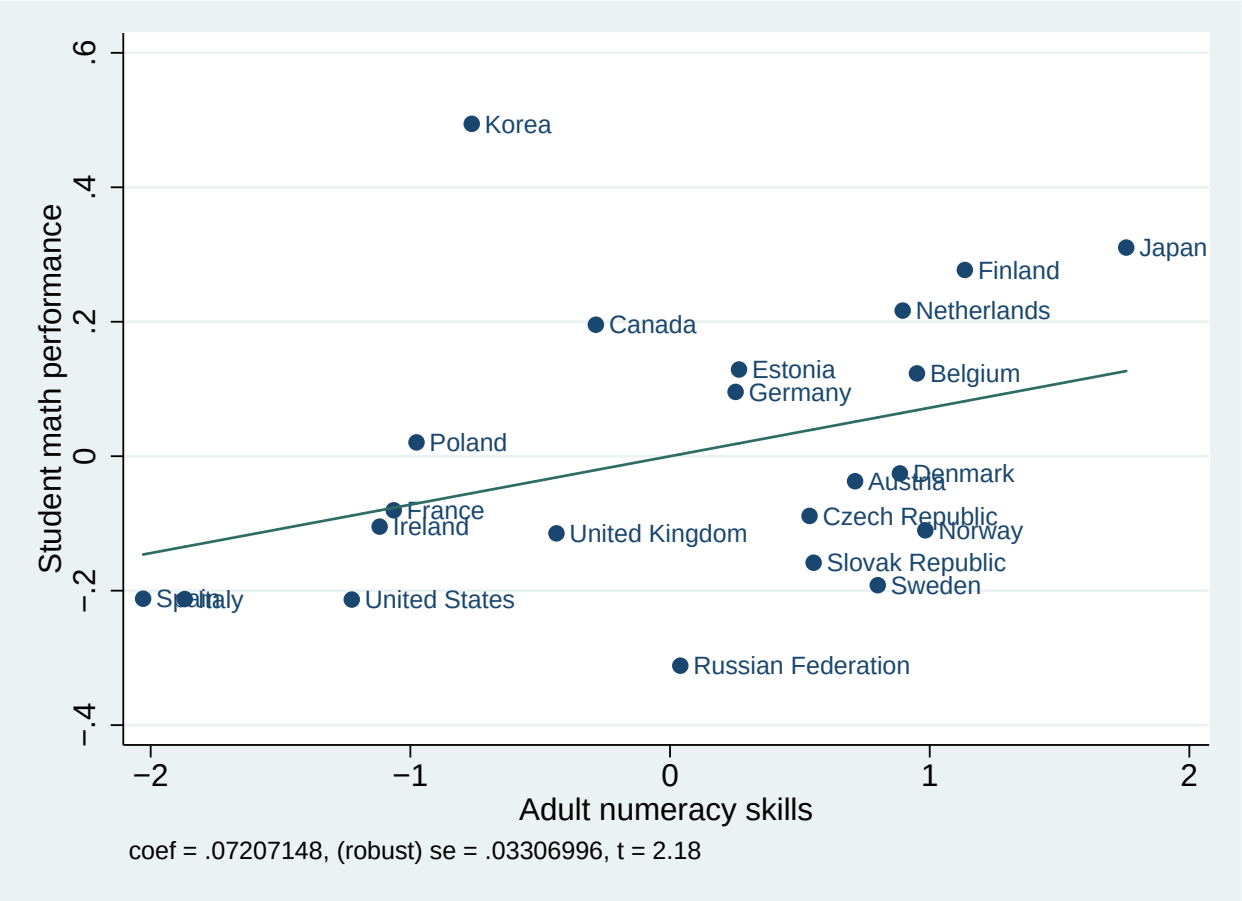
Notes: Student performance aggregated at the country level and pooled across PISA 2009 and 2012. Added-value plot conditioning on adult numeracy skills. Adult skills are numeracy skills of all 25-55 years-old aggregated at the country level, using individual-level weights.

Figure 4: Student Performance vs. Teacher Skills, Conditional on Adult Skills (Reading)



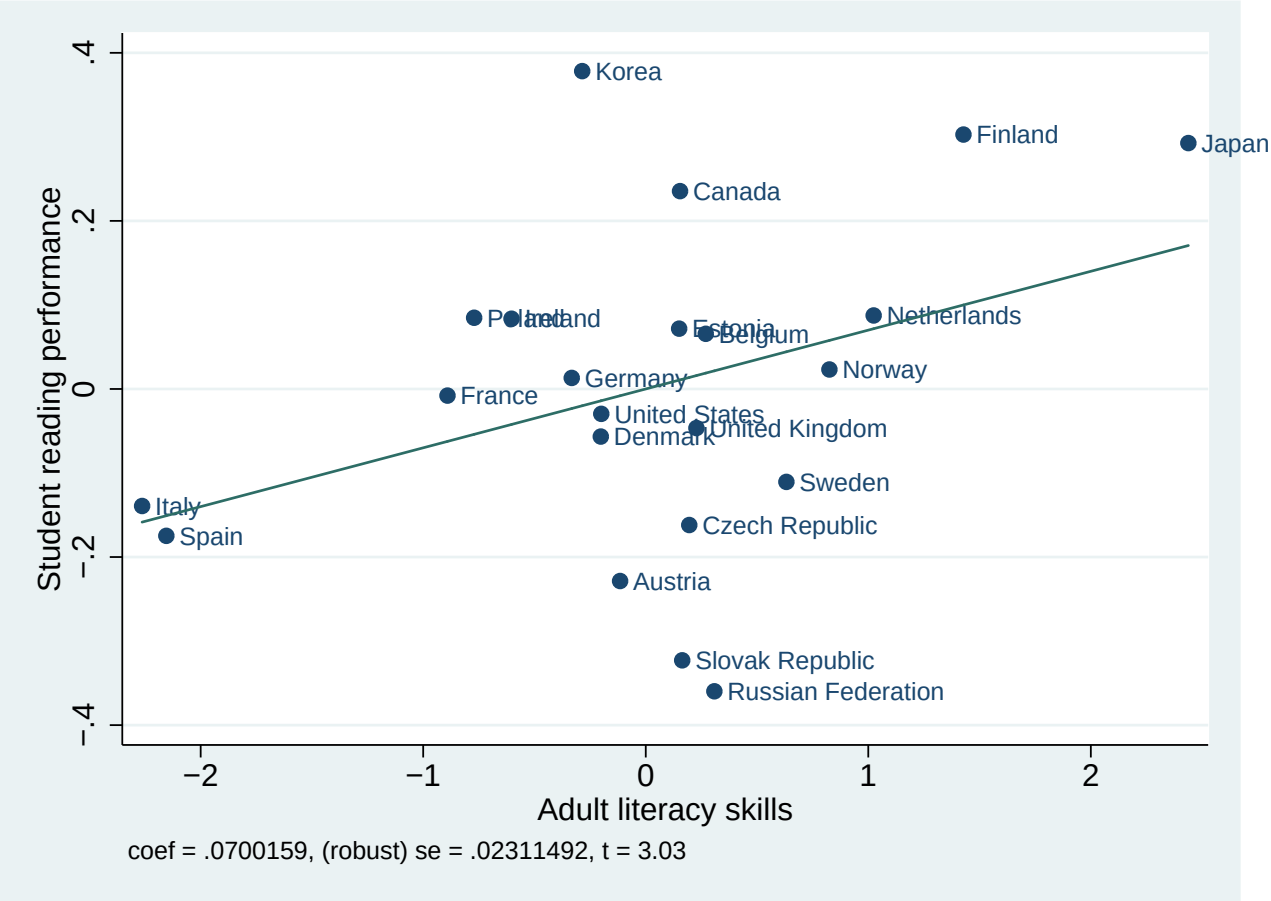
Notes: Student performance aggregated at the country level and pooled across PISA 2009 and 2012. Added-value plot conditioning on adult literacy skills. Adult skills are literacy skills of all 25-55 years-old aggregated at the country level, using individual-level weights.

Figure 5: Student Performance vs. Adult Skills (Math)



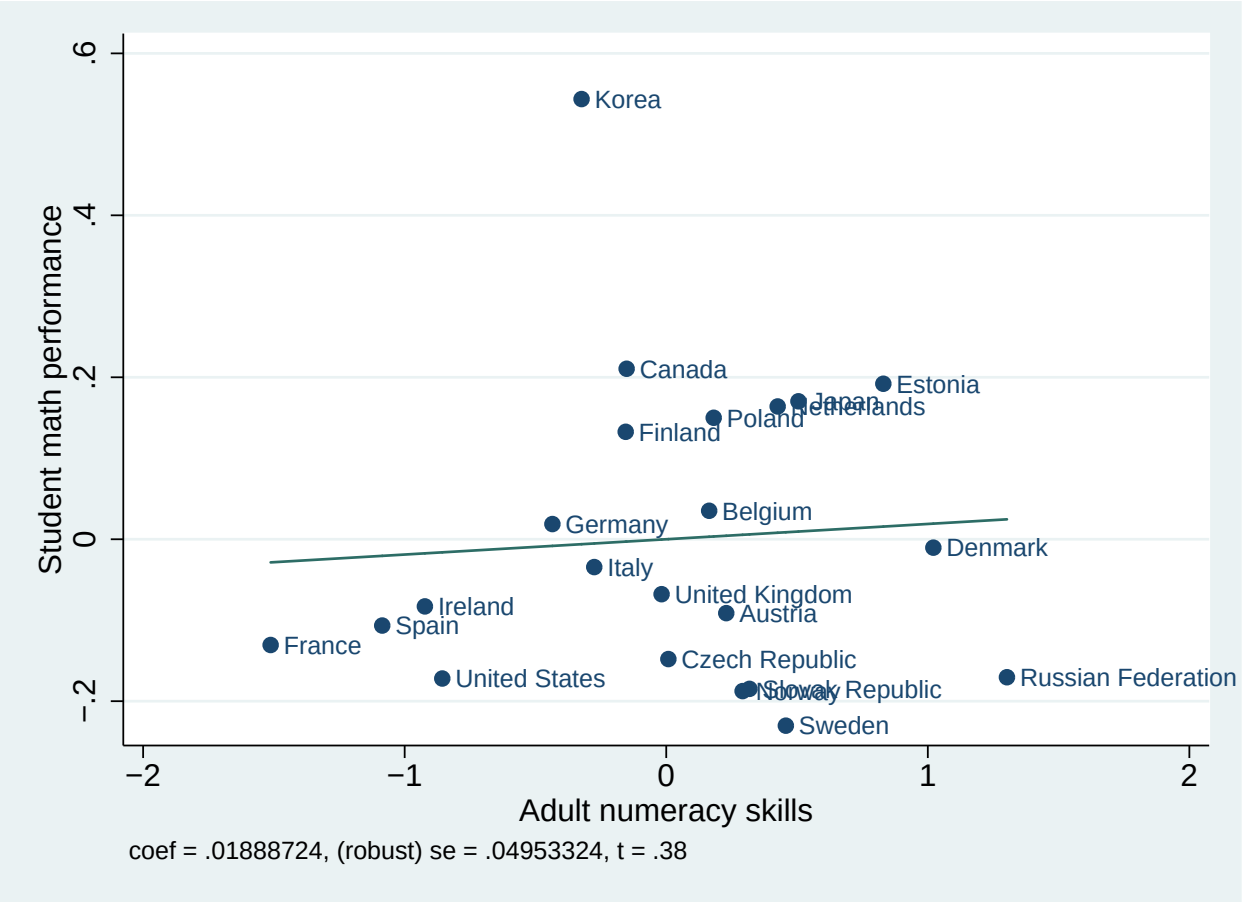
Notes: Student performance aggregated at country level and pooled across PISA 2009 and 2012. No further controls.

Figure 6: Student Performance vs. Adult Skills (Reading)



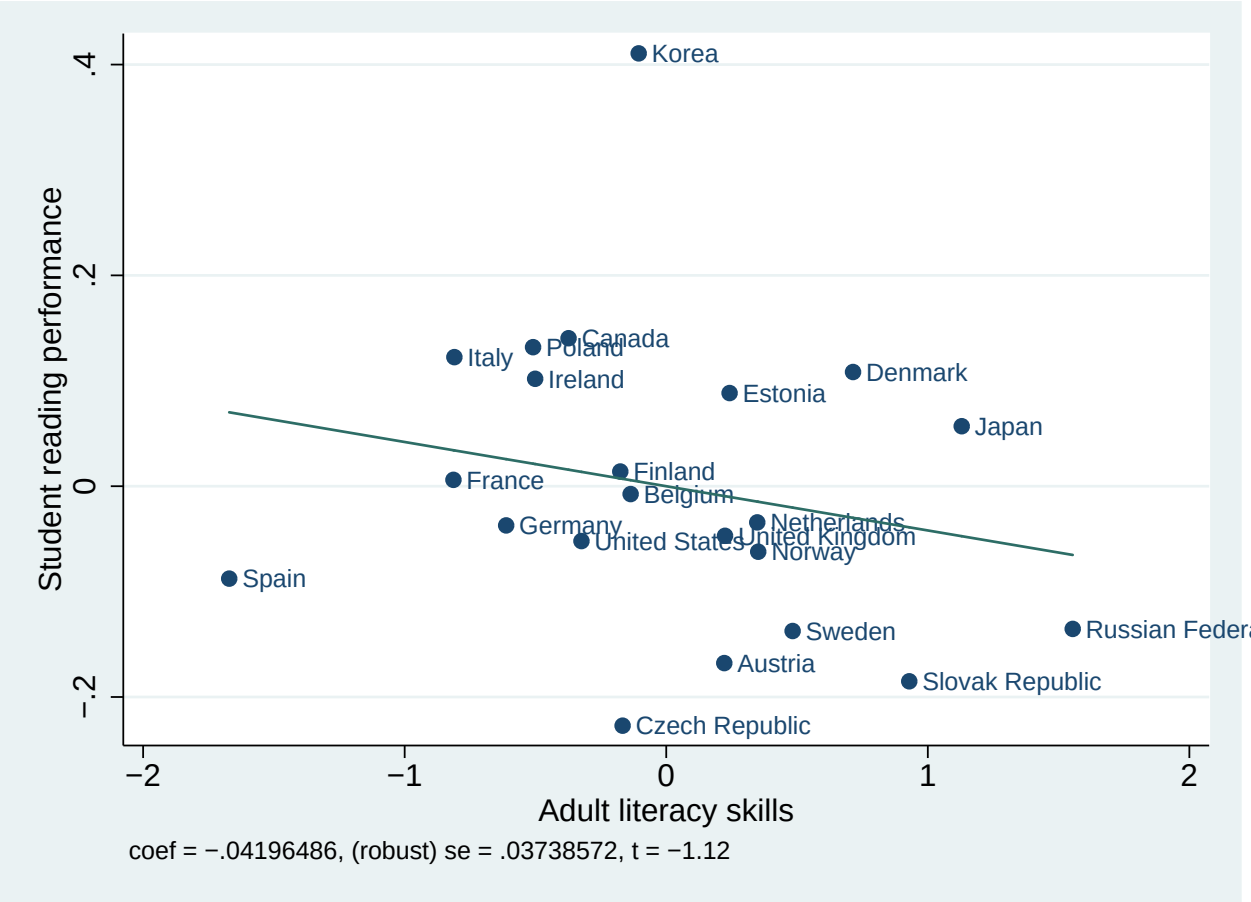
Notes: Student performance aggregated at the country level and pooled across PISA 2009 and 2012. No further controls.

Figure 7: Student Performance vs. Adult Skills, Conditional on Teacher Skills (Math)



Notes: Student performance aggregated at the country level and pooled across PISA 2009 and 2012. Added-value plot conditioning on teacher numeracy skills. Adult skills are numeracy skills of all 25-55 years-old aggregated at the country level, using individual-level weights.

Figure 8: Student Performance vs. Adult Skills, Conditional on Teacher Skills (Reading)



Notes: Student performance aggregated at the country level and pooled across PISA 2009 and 2012. Added-value plot conditioning on teacher literacy skills. Adult skills are literacy skills of all 25-55 years-old aggregated at the country level, using individual-level weights.

Table 1: Teacher Skills

	Pooled	Austria	Belgium	Canada	Czech R.	Denmark	Estonia	Finland	France	Germany	Ireland	Italy
Numeracy	293	299	305	291	301	304	291	279	285	313	299	287
Literacy	297	291	303	304	302	301	285	291	296	319	295	297
Difference	-4	8	3	-13	-1	3	7	-12	-11	-6	4	-10
Rank numeracy	66	70	64	72	69	71	56	73	63	72	78	65
Rank literacy	68	71	69	71	77	72	59	78	67	73	76	66
Observations	4875	188	215	834	141	413	188	221	163	127	180	124
		Japan	Korea	Netherl.	Norway	Poland	Russia	Slovak R.	Spain	Sweden	U.K.	U.S.
Numeracy		290	269	312	287	301	304	276	274	297	299	288
Literacy		296	278	315	295	306	304	294	280	287	299	299
Difference		-5	-8	-3	-8	-6	0	-18	-6	10	-1	-11
Rank numeracy		75	67	69	72	63	65	63	49	64	56	68
Rank literacy		74	71	67	73	66	67	72	49	58	60	70
Observations		147	217	197	279	199	137	133	183	147	310	132

Notes: Teachers skills are the country average of the skills of primary school teachers, secondary school teachers, and "other" teachers (including, for instance, special education and language teachers). Rank refers to the position of teachers in the skill distribution of the population of adults aged 25-65. Observations refer to the number of individual teachers used to construct country-level measures of teacher skills. *Data source:* PIAAC.

Table 2: Parent Skills: Number of Observations by Cell

	Pooled	Austria	Belgium	Canada	Czech R.	Denmark	Estonia	Finland	France	Germany	Ireland	Italy
						MALES						
No. of cells	5.7	6	6	6	3	6	6	6	6	6	6	5
Mean	286	206	220	1086	412	364	301	241	308	208	204	207
Min	75	88	115	501	265	252	146	189	193	75	103	85
Max	1916	317	324	1916	505	588	471	290	478	288	379	413
Observations	34940	1237	1322	6513	1237	2185	1806	1445	1845	1246	1223	1034
						FEMALES						
No. of cells	5.7	6	6	6	4	6	6	6	6	6	6	5
Mean	343	224	230	1335	423	391	412	249	331	242	272	251
Min	104	104	107	648	145	242	225	141	188	143	124	112
Max	2365	318	308	2365	742	690	783	418	591	330	432	531
Observations	42237	1341	1379	8010	1691	2347	2474	1491	1985	1451	1634	1255
		Japan	Korea	Netherl.	Norway	Poland	Russia	Slovak R.	Spain	Sweden	U.K.	U.S.
						MALES						
No. of cells		6	6	6	6	3	5	5	6	6	6	
Mean		245	293	229	228	173	114	260	285	197	296	178
Min		95	87	133	105	79	106	97	108	101	199	101
Max		411	504	379	401	306	119	428	765	286	375	264
Observations		1225	1755	1371	1365	1035	342	1300	1427	1181	1777	1069
						FEMALES						
No. of cells		5	6	6	6	6	3	5	5	6	6	6
Mean		309	363	245	221	205	312	331	326	205	436	229
Min		143	140	148	105	139	194	272	115	110	335	131
Max		404	681	524	417	335	396	515	877	336	489	318
Observations		1544	2175	1471	1326	1227	935	1657	1629	1227	2617	1371

Notes: Parent skills are constructed using skills of adults aged 35-65 with at least one child by gender, educational attainment, and number of books at home. Table reports descriptive statistics of the number of observations by education-books cell separately for males and females. Observations refer to the number of parents used to construct measures of parent skills. *Data source:* PIAAC.

Table 3: Parent Skills

	Pooled	Austria	Belgium	Canada	Czech R.	Denmark	Estonia	Finland	France	Germany	Ireland	Italy
						NUMERACY						
Mean	282	293	299	281	279	281	291	261	277	298	275	280
Std. Dev.	25	17	21	21	23	26	21	26	17	19	28	21
Min	195	256	246	217	257	231	240	222	239	249	220	222
Max	325	316	322	305	314	319	319	294	301	316	311	309
Max-Min	75	60	76	88	57	88	79	73	62	68	91	87
						LITERACY						
Mean	280	280	287	283	276	272	277	262	273	296	273	284
Std. Dev.	21	17	19	17	17	22	19	26	14	17	20	18
Min	213	249	240	224	257	229	229	225	244	246	229	231
Max	321	305	308	302	301	303	302	296	293	313	296	308
Max-Min	65	56	68	79	44	74	73	71	49	67	67	77
		Japan	Korea	Netherl.	Norway	Poland	Russia	Slovak R.	Spain	Sweden	U.K.	U.S.
						NUMERACY						
Mean		276	265	305	275	296	295	263	272	284	294	267
Std. Dev.		23	22	16	20	19	21	20	5	19	22	31
Min		230	228	245	221	251	243	221	265	228	244	195
Max		309	287	325	297	320	321	306	278	310	322	309
Max-Min		79	58	81	76	68	78	84	13	82	78	114
						LITERACY						
Mean		282	262	302	281	293	288	267	279	278	288	277
Std. Dev.		19	17	15	18	18	18	19	8	12	21	27
Min		239	233	252	233	250	240	231	270	238	241	213
Max		309	278	321	300	314	308	302	290	292	314	311
Max-Min		70	46	68	68	64	68	71	21	55	73	98

Notes: Table reports descriptive statistics of parents' numeracy and literacy skills derived from PIAAC after matching them to the actual parents of students in PISA. See Table 2 and text for details of the construction of parent skills. *Data sources:* PIAAC, PISA 2009 and 2012.

Table 4: Summary Statistics of Student Characteristics

	Pooled	Austria	Belgium	Canada	Czech R.	Denmark	Estonia	Finland	France	Germany	Ireland	Italy
Math Score	504	500	515	522	496	513	502	484	516	530	496	493
	(93)	(94)	(103)	(88)	(94)	(97)	(84)	(89)	(81)	(85)	(100)	(91)
Reading Score	501	480	508	524	486	503	496	485	508	530	501	497
	(95)	(96)	(102)	(91)	(91)	(93)	(84)	(90)	(82)	(91)	(108)	(96)
Age (years)	15.78	15.80	15.84	15.83	15.79	15.83	15.75	15.86	15.82	15.71	15.86	15.71
Female	0.49	0.51	0.49	0.50	0.48	0.49	0.50	0.49	0.49	0.49	0.51	0.51
First-gen. migrant	0.05	0.06	0.09	0.13	0.02	0.05	0.04	0.10	0.01	0.02	0.05	0.07
Second-gen. migrant	0.05	0.11	0.08	0.15	0.01	0.11	0.06	0.01	0.07	0.01	0.10	0.05
Other language	0.08	0.11	0.22	0.16	0.02	0.09	0.05	0.18	0.04	0.04	0.08	0.07
Observations	377832	11345	17098	44751	11391	9980	13405	51200	9506	14639	8911	24838
		Japan	Korea	Netherl.	Norway	Poland	Russia	Slovak R.	Spain	Sweden	U.K.	U.S.
Math Score		494	484	533	550	524	494	506	475	489	486	484
		(86)	(93)	(94)	(94)	(90)	(88)	(90)	(86)	(99)	(93)	(90)
Reading Score		509	488	529	537	510	503	509	467	470	491	498
		(92)	(96)	(100)	(83)	(91)	(96)	(89)	(90)	(98)	(103)	(94)
Age (years)		15.70	15.74	15.78	15.71	15.71	15.80	15.72	15.80	15.76	15.74	15.81
Female		0.49	0.48	0.48	0.47	0.50	0.49	0.51	0.50	0.49	0.49	0.49
First-gen. migrant		0.12	0.06	0.00	0.00	0.04	0.05	0.00	0.05	0.01	0.06	0.07
Second-gen. migrant		0.02	0.02	0.00	0.00	0.08	0.04	0.00	0.07	0.00	0.08	0.13
Other language		0.05	0.14	0.00	0.00	0.06	0.07	0.01	0.09	0.06	0.09	0.14
Observations		8953	61978	12439	10022	9220	9346	9524	10539	9233	9303	10211

Notes: Table shows means and standard deviations (in parentheses) for student performance in math and reading in PISA 2009 and 2012 by country. Country means of student background characteristics are also shown. Except for age, values are expressed as shares. Other language indicates that a foreign language is spoken at home. Observations refer to the number of individual students in the two PISA cycles. *Data sources:* PISA 2009 and 2012.

Table 5: Summary Statistics of School and Country Characteristics

	Pooled	Austria	Belgium	Canada	Czech R.	Denmark	Estonia	Finland	France	Germany	Ireland	Italy
SCHOOL CHARACTERISTICS												
Private schools	0.20	0.11	0.69	0.08	0.06	0.06	0.24	0.33	0.04	0.04	0.19	0.26
Content autonomy	0.68	0.58	0.56	0.37	0.88	0.63	0.68	0.53	0.77	0.64	0.64	0.89
Personnel autonomy	0.44	0.08	0.38	0.30	0.88	0.15	0.58	0.18	0.54	0.24	0.06	0.75
Budget autonomy	0.83	0.86	0.69	0.75	0.79	0.88	0.96	0.94	0.84	0.92	0.97	0.96
Students per school	694	562	718	1032	450	702	480	701	557	429	827	1062
COUNTRY CHARACTERISTICS												
Teacher salary	42675	45088	51147	58845	23966	67877	58962	50852	15066	44982	36837	45666
Teacher perf. pay		1	0	0	1	0	1	0	1	1	0	1
Exp. per student	76884	107196	88635	80424	49640	72046	98694	78149	49279	78809	79121	91461
GDP per capita	33655	38625	36270	38266	24679	36172	38463	31521	20357	35676	33445	35128
School starting age	6	6	6	5	6	6	7	6	7	7	6	5
		Japan	Korea	Netherl.	Norway	Poland	Russia	Slovak R.	Spain	Sweden	U.K.	U.S.
SCHOOL CHARACTERISTICS												
Private schools		0.60	0.06	0.30	0.42	0.67	0.02	0.03	0.00	0.09	0.12	0.08
Content autonomy		0.69	0.72	0.92	0.89	0.93	0.49	0.75	0.59	0.59	0.63	0.48
Personnel autonomy		0.34	0.05	0.32	0.23	0.89	0.42	0.46	0.65	0.70	0.72	0.66
Budget autonomy		0.87	0.84	0.90	0.85	0.99	0.88	0.26	0.58	0.72	0.93	0.76
Students per school		593	752	750	1116	1023	340	324	566	480	420	1381
COUNTRY CHARACTERISTICS												
Teacher salary		63175	38246	50162	51340	60493	40536	19274	17875	14537	37440	46479
Teacher perf. pay		0	0	0	0	1	1	1	1	1	1	1
Exp. per student		84520	80863	83702	65071	87710	112428	48804	12074	42680	89292	110856
GDP per capita		42691	31563	34436	27701	40638	49249	18173	21109	21732	38018	46491
School starting age		4	6	6	6	6	6	7	7	6	7	6

Notes: Country means are shown. School characteristics taken from PISA, country characteristics are from OECD statistics. Teacher salary, expenditures per student, and GDP per capita are expressed as PPP-US-$. *Data sources:* PISA 2009 and 2012, OECD.

Table 6: Student Math Performance (OLS)

Dependent Variable: Student Math Scores						
	(1)	(2)	(3)	(4)	(5)	(6)
Numeracy teacher	0.088**		0.059*	0.060**	0.084***	0.075***
	(0.033)		(0.030)	(0.028)	(0.019)	(0.021)
Numeracy parents		0.051**	0.023	0.028**	0.025**	0.024***
		(0.024)	(0.015)	(0.011)	(0.009)	(0.008)
Age				0.138***	0.139***	0.150***
				(0.025)	(0.019)	(0.017)
Female				–0.156***	–0.155***	–0.152***
				(0.013)	(0.013)	(0.012)
First-generation migrant				–0.197***	–0.162***	–0.158***
				(0.054)	(0.054)	(0.052)
Second-generation migrant				–0.142***	–0.121***	–0.119***
				(0.039)	(0.041)	(0.041)
Other language at home				–0.114***	–0.104***	–0.089**
				(0.035)	(0.032)	(0.034)
Teacher salary					0.000***	0.000***
					(0.000)	(0.000)
Teacher performance pay					0.002	0.087
					(0.041)	(0.051)
Expenditures per student					0.000	–0.000
					(0.000)	(0.000)
School starting age					0.074*	0.033
					(0.036)	(0.036)
GDP per capita					–0.000**	–0.000**
					(0.000)	(0.000)
Instruction quality math						–0.277**
						(0.108)
Shortage math teacher						–0.032**
						(0.012)
Weekly hours math						0.067**
						(0.025)
Parent characteristics	No	Yes	Yes	Yes	Yes	Yes
School characteristics	No	No	No	Yes	Yes	Yes
Imputation indicators	No	Yes	Yes	Yes	Yes	Yes
N	377832	377832	377832	373534	373534	373534
Countries	22	22	22	22	22	22
Adj. R2	0.01	0.21	0.21	0.25	0.26	0.27

* p<0.10, ** p<0.05, *** p<0.01

Notes: Least squares regressions weighted by students' sampling probability. Dependent variable: student PISA test score in math. Student test score standardized to std. dev. 1 across countries within each PISA cycle. Country-level teacher numeracy standardized to std. dev. 1 across all countries. Numeracy parents is maximum of mother's and father's numeracy skills. Parent skills standardized using teacher skills as numeraire, such that teacher and parent skills are measured on the same scale. Parent characteristics include parents' educational degree, number of books at home, and type of occupation. School characteristics include school location, number of students per school, and three autonomy measures. See Table A1 for the results of parent and school characteristics. All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Specifications give same weight to each country. Robust standard errors (adjusted for clustering at country level) in parentheses. *Data sources:* PIAAC, PISA 2009 and 2012.

Table 7: Student Reading Performance (OLS)

Dependent Variable: Student Reading Scores						
	(1)	(2)	(3)	(4)	(5)	(6)
Literacy teacher	0.132***		0.102***	0.091***	0.091***	0.093***
	(0.023)		(0.029)	(0.020)	(0.017)	(0.020)
Literacy parents		0.043*	–0.003	–0.009	–0.002	0.000
		(0.024)	(0.015)	(0.013)	(0.011)	(0.012)
Age				0.129***	0.128***	0.128***
				(0.016)	(0.013)	(0.014)
Female				0.351***	0.352***	0.350***
				(0.017)	(0.017)	(0.017)
First-generation migrant				–0.158***	–0.143**	–0.142**
				(0.053)	(0.051)	(0.050)
Second-generation migrant				–0.065	–0.050	–0.051
				(0.041)	(0.042)	(0.041)
Other language at home				–0.189***	–0.192***	–0.187***
				(0.037)	(0.035)	(0.036)
Teacher salary					0.000	0.000
					(0.000)	(0.000)
Teacher performance pay					–0.061	–0.070
					(0.046)	(0.050)
Expenditures per student					0.000*	0.000
					(0.000)	(0.000)
School starting age					0.039	0.045
					(0.042)	(0.040)
GDP per capita					–0.000*	–0.000
					(0.000)	(0.000)
Instruction quality reading						0.047
						(0.124)
Shortage language teacher						–0.046**
						(0.018)
Weekly hours lang						0.006
						(0.023)
Parent characteristics	No	Yes	Yes	Yes	Yes	Yes
School characteristics	No	No	No	Yes	Yes	Yes
Imputation indicators	No	Yes	Yes	Yes	Yes	Yes
N	377832	377832	377832	373534	373534	373534
Countries	22	22	22	22	22	22
Adj. R2	0.02	0.22	0.23	0.29	0.29	0.30

* p<0.10, ** p<0.05, *** p<0.01

Notes: Least squares regressions weighted by students' sampling probability. Dependent variable: student PISA test score in reading. Student test score standardized to std. dev. 1 across countries within each PISA cycle. Country-level teacher literacy standardized to std. dev. 1 across all countries. Literacy parents is maximum of mother's and father's literacy skills. Parent skills standardized using teacher skills as numeraire, such that teacher and parent skills are measured on the same scale. Parent characteristics include parents' educational degree, number of books at home, and type of occupation. School characteristics include school location, number of students per school, and three autonomy measures. See Table A2 for the results of parent and school characteristics. All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Specifications give same weight to each country. Robust standard errors (adjusted for clustering at country level) in parentheses. *Data sources:* PIAAC, PISA 2009 and 2012.

Table 8: Correlated Random Effects Models

Dependent Variable: Student Performance					
	(1)	(2)	(3)	(4)	(5)
Implied $\beta_{Numeracy}$	0.063^{**}	0.059^{**}	0.068^{***}	0.069^{***}	0.073^{***}
$\chi^2(\beta_{Numeracy} = 0)$	6.012	6.300	9.017	8.133	11.546
Prob> χ^2	[0.014]	[0.012]	[0.003]	[0.004]	[0.001]
Implied $\beta_{Literacy}$	0.046^{**}	0.044^{**}	0.046^{**}	0.044^{*}	0.058^{**}
$\chi^2(\beta_{Literacy} = 0)$	3.922	4.289	4.600	3.390	5.836
Prob> χ^2	[0.048]	[0.038]	[0.032]	[0.066]	[0.016]
$\chi^2(\eta_{Num} = \eta_{Lit})$	11.581	3.116	0.615	1.339	0.142
Prob> χ^2	[0.001]	[0.078]	[0.433]	[0.247]	[0.706]
$\chi^2(\beta_{Num} = \beta_{Lit})$	2.676	2.124	4.051	7.267	1.773
Prob> χ^2	[0.102]	[0.145]	[0.044]	[0.007]	[0.183]
Parent skills and characteristics	No	Yes	Yes	Yes	Yes
Student characteristics	No	No	Yes	Yes	Yes
School and country characteristics	No	No	No	Yes	Yes
Instruction indicators	No	No	No	No	Yes
N	377832	377832	373534	373534	373534
Countries	22	22	22	22	22

* 0.10, ** 0.05, *** 0.01

Notes: Dependent variable: student test score in math and reading, respectively. Regressions in the two subjects estimated by seemingly unrelated regressions (SUR). Implied β represents the effect of the teacher skills, given by the difference between the estimate on the teacher skills in the respective subject between the equation of the student test score in the respective subject and the equation of the student test score in the other subject (see Eqs. (4a) and (4b)). All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Specifications give same weight to each country. Clustered standard errors in the SUR models are estimated by maximum likelihood. Robust standard errors (adjusted for clustering at country level) in parentheses. *Data sources:* PIAAC, PISA 2009 and 2012.

Table 9: First-Differenced (Fixed-Effects) Models

Dependent Variable: Student Math-Reading Scores					
	(1)	(2)	(3)	(4)	(5)
Teacher skills: numeracy-literacy	0.071**	0.051*	0.062**	0.067**	0.070***
	(0.026)	(0.027)	(0.026)	(0.024)	(0.016)
Parent skills: numeracy-literacy		0.024	0.022	0.013	0.012*
		(0.025)	(0.024)	(0.011)	(0.007)
Age			0.006	0.010	0.016
			(0.015)	(0.011)	(0.010)
Female			–0.507***	–0.507***	–0.503***
			(0.014)	(0.014)	(0.013)
First-generation migrant			–0.041**	–0.022	–0.015
			(0.019)	(0.016)	(0.015)
Second-generation migrant			–0.085***	–0.076***	–0.070***
			(0.018)	(0.012)	(0.011)
Other language at home			0.077***	0.088***	0.093***
			(0.022)	(0.020)	(0.020)
Teacher salary				0.000**	0.000***
				(0.000)	(0.000)
Teacher performance pay				0.066	0.109***
				(0.041)	(0.029)
Expenditures per student				–0.000	–0.000**
				(0.000)	(0.000)
School starting age				0.039	0.012
				(0.030)	(0.027)
GDP per capita				–0.000**	–0.000***
				(0.000)	(0.000)
Shortage math teacher					0.004
					(0.004)
Weekly hours math					0.051***
					(0.012)
Instruction quality math					–0.113
					(0.074)
Shortage language teacher					0.008
					(0.008)
Weekly hours lang					–0.025
					(0.015)
Instruction quality reading					–0.138**
					(0.056)
Parent characteristics	No	Yes	Yes	Yes	Yes
School characteristics	No	No	Yes	Yes	Yes
Imputation indicators	No	Yes	Yes	Yes	Yes
N	377832	377832	373534	373534	373534
Countries	22	22	22	22	22
Adj. R2	0.01	0.01	0.22	0.23	0.23

* p<0.10, ** p<0.05, *** p<0.01

Notes: Dependent variable: difference in student test score between math and reading. All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Specifications give same weight to each country. Robust standard errors (adjusted for clustering at country level) in parentheses. *Data sources:* PIAAC, PISA 2009 and 2012.

Table A-1: Student Math Performance (OLS): Parent and School Characteristics

Dependent Variable: Student Math Scores					
	(2)	(3)	(4)	(5)	(6)
HH ISCED 1	0.170**	0.177**	0.070	0.091*	0.090*
	(0.070)	(0.068)	(0.057)	(0.046)	(0.049)
HH ISCED 2	0.278***	0.286***	0.169***	0.182***	0.179***
	(0.070)	(0.070)	(0.057)	(0.062)	(0.061)
HH ISCED 3B,C	0.322***	0.375***	0.263***	0.256***	0.248***
	(0.101)	(0.091)	(0.064)	(0.061)	(0.059)
HH ISCED 3A, 4	0.357***	0.414***	0.275***	0.302***	0.284***
	(0.103)	(0.092)	(0.070)	(0.062)	(0.061)
HH ISCED 5B	0.232	0.339***	0.203**	0.248***	0.231***
	(0.138)	(0.108)	(0.084)	(0.072)	(0.066)
HH ISCED 5A, 6	0.339**	0.454***	0.292***	0.325***	0.304***
	(0.137)	(0.108)	(0.081)	(0.066)	(0.060)
11-25 books	0.264***	0.268***	0.261***	0.249***	0.245***
	(0.020)	(0.020)	(0.018)	(0.017)	(0.018)
26-100 books	0.531***	0.546***	0.524***	0.509***	0.501***
	(0.032)	(0.032)	(0.028)	(0.025)	(0.025)
101-200 books	0.690***	0.735***	0.699***	0.687***	0.678***
	(0.056)	(0.050)	(0.038)	(0.034)	(0.033)
201-500 books	0.917***	0.963***	0.916***	0.902***	0.893***
	(0.065)	(0.057)	(0.044)	(0.039)	(0.038)
More than 500 books	0.931***	0.980***	0.938***	0.926***	0.920***
	(0.075)	(0.065)	(0.051)	(0.044)	(0.042)
Blue collar-high skilled	0.114***	0.119***	0.127***	0.112***	0.113***
	(0.018)	(0.018)	(0.015)	(0.012)	(0.012)
White collar-low skilled	0.212***	0.208***	0.176***	0.174***	0.172***
	(0.021)	(0.021)	(0.018)	(0.017)	(0.016)
White collar-high skilled	0.447***	0.443***	0.395***	0.408***	0.404***
	(0.035)	(0.034)	(0.025)	(0.022)	(0.021)
Small Town			–0.009	–0.017	–0.008
			(0.027)	(0.026)	(0.026)
Town			0.016	–0.010	0.006
			(0.034)	(0.029)	(0.029)
City			0.024	–0.014	–0.018
			(0.033)	(0.030)	(0.031)
Large City			0.042	–0.012	–0.025
			(0.046)	(0.043)	(0.046)
Content autonomy			0.091*	0.024	0.021
			(0.051)	(0.034)	(0.033)
Personnel autonomy			–0.160***	–0.123***	–0.138***
			(0.044)	(0.033)	(0.037)
Budget autonomy			–0.005	0.021	0.026
			(0.054)	(0.040)	(0.038)
Private school			0.152***	0.144***	0.152***
			(0.041)	(0.027)	(0.031)
No. students per school			0.268***	0.293***	0.280***
			(0.075)	(0.056)	(0.055)
Student characteristics	No	No	Yes	Yes	Yes
Country characteristics	No	No	No	Yes	Yes
Imputation indicators	Yes	Yes	Yes	Yes	Yes
N	377832	377832	377832	377832	377832
Countries	22	22	22	22	22
Adj. R2	0.21	0.21	0.25	0.26	0.27

* p<0.10, ** p<0.05, *** p<0.01

Notes: Table reports parent and school characteristics included in the regressions shown in Table 6 but omitted there for brevity. Column names similar to those in Table 6. For parents' education, the omitted category is ISCED 0 (below primary education). For books at home, the omitted category is less than 10 books at home. For occupational type, the omitted category is blue collar-low skilled. *Data sources:* PIAAC, PISA 2009 and 2012.

Table A-2: Student Reading Performance (OLS): Parent and School Characteristics

Dependent Variable: Student Reading Scores					
	(2)	(3)	(4)	(5)	(6)
HH ISCED 1	0.267***	0.264***	0.158*	0.165**	0.158**
	(0.085)	(0.081)	(0.077)	(0.071)	(0.073)
HH ISCED 2	0.321***	0.342***	0.237***	0.239***	0.230***
	(0.089)	(0.086)	(0.073)	(0.075)	(0.076)
HH ISCED 3B,C	0.339***	0.448***	0.384***	0.369***	0.349***
	(0.108)	(0.094)	(0.070)	(0.065)	(0.064)
HH ISCED 3A, 4	0.365***	0.475***	0.402***	0.402***	0.382***
	(0.104)	(0.090)	(0.066)	(0.065)	(0.064)
HH ISCED 5B	0.263*	0.467***	0.415***	0.415***	0.390***
	(0.145)	(0.097)	(0.066)	(0.064)	(0.061)
HH ISCED 5A, 6	0.339**	0.544***	0.487***	0.475***	0.447***
	(0.132)	(0.089)	(0.063)	(0.058)	(0.053)
11-25 books	0.302***	0.304***	0.269***	0.265***	0.260***
	(0.023)	(0.022)	(0.018)	(0.018)	(0.018)
26-100 books	0.576***	0.594***	0.539***	0.530***	0.523***
	(0.033)	(0.033)	(0.028)	(0.026)	(0.026)
101-200 books	0.751***	0.825***	0.753***	0.734***	0.722***
	(0.062)	(0.050)	(0.041)	(0.037)	(0.037)
201-500 books	0.953***	1.029***	0.940***	0.920***	0.908***
	(0.069)	(0.055)	(0.048)	(0.043)	(0.042)
More than 500 books	0.934***	1.017***	0.943***	0.923***	0.912***
	(0.074)	(0.060)	(0.051)	(0.047)	(0.047)
Blue collar-high skilled	0.093***	0.092***	0.100***	0.094***	0.092***
	(0.021)	(0.020)	(0.018)	(0.015)	(0.014)
White collar-low skilled	0.224***	0.216***	0.174***	0.174***	0.171***
	(0.025)	(0.022)	(0.018)	(0.018)	(0.016)
White collar-high skilled	0.469***	0.456***	0.404***	0.410***	0.405***
	(0.037)	(0.031)	(0.023)	(0.022)	(0.020)
Small Town			0.014	0.009	0.012
			(0.025)	(0.023)	(0.023)
Town			0.057*	0.042	0.047
			(0.030)	(0.030)	(0.030)
City			0.071**	0.052	0.051
			(0.031)	(0.032)	(0.032)
Large City			0.096**	0.068	0.068
			(0.041)	(0.049)	(0.048)
Content autonomy			0.038	0.004	0.011
			(0.039)	(0.033)	(0.034)
Personnel autonomy			–0.161***	–0.092**	–0.097**
			(0.037)	(0.039)	(0.038)
Budget autonomy			0.019	0.019	0.024
			(0.060)	(0.044)	(0.038)
Private school			0.152***	0.122***	0.127***
			(0.037)	(0.031)	(0.032)
No. students per school			0.242***	0.241***	0.240***
			(0.056)	(0.053)	(0.055)
Student characteristics	No	No	Yes	Yes	Yes
Country characteristics	No	No	No	Yes	Yes
Imputation indicators	Yes	Yes	Yes	Yes	Yes
N	377832	377832	377832	377832	377832
Countries	22	22	22	22	22
Adj. R2	0.22	0.23	0.29	0.29	0.30

* p<0.10, ** p<0.05, *** p<0.01

Notes: Table reports parent and school characteristics included in the regressions shown in Table 7 but omitted there for brevity. Column names similar to those in Table 7. For parents' education, the omitted category is ISCED 0 (below primary education). For books at home, the omitted category is less than 10 books at home. For occupational type, the omitted category is blue collar-low skilled. *Data sources:* PIAAC, PISA 2009 and 2012.