NBER WORKING PAPER SERIES

THE VALUE OF SMARTER TEACHERS:
INTERNATIONAL EVIDENCE ON TEACHER COGNITIVE SKILLS AND STUDENT PERFORMANCE

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Working Paper 20727
http://www.nber.org/papers/w20727

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 2014

We would like to thank William Thorn, Veronica Borg, Vanessa Denis, and Francois Keslair for access to and help with the international PIAAC data. We further thank Lisa Leschnig, Guido Schwerdt, and Katarina Zigova for making their international data on central exit examinations available to us. We are also indebted to David Deming, Bernhard Enzi, Oliver Falck, Josh Goodman, Brian Jacob, Susanna Loeb, Daniel Münich, Paul Peterson, Jesse Rothstein, Johannes Schmieder, Guido Schwerdt, Dick Startz, Marty West, Ludger Woessmann, and participants at the CESifo Area Conference on the Economics of Education, the annual conference of the Verein für Socialpolitik, the RWI Research Network Conference on the "Economics of Education," the Applied Micro Research Seminar at CERGE-EI, the annual conference of the European Economic Association, the Third International PIAAC Conference, and seminars in Konstanz and Munich for providing valuable comments. Piopiunik is indebted to the Program on Education Policy and Governance (PEPG) at Harvard University, in particular to Paul Peterson and Antonio Wendland, for their support and hospitality during his research visit. Wiederhold is thankful for the hospitality provided by the Center for International Development at Harvard University, especially to Ricardo Hausmann, Ljubica Nedelkoska, and Frank Neffke. Wiederhold also gratefully acknowledges financial support from the Fritz Thyssen Foundation. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 20727
December 2014, Revised April 2017
JEL No. H4,I2,J2

ABSTRACT

International differences in teacher quality are commonly hypothesized to be a key determinant of the large international student performance gaps, but lack of consistent quality measures has precluded testing this. Using unique assessment data, we construct country-level measures of teacher cognitive skills. We find substantial differences in teacher cognitive skills across countries, and these are strongly related to student performance. Results are supported by fixed-effects estimation exploiting within-country between-subject variation in teacher skills. A series of robustness and placebo tests indicate a systematic influence of teacher skills as distinct from overall differences among countries in the level of cognitive skills. Moreover, observed country variations in teacher cognitive skills are significantly related to differences in women's access to high-skilled occupations outside teaching and to salary premiums for teachers.

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1. Overview

Numerous international assessment tests have shown that student achievement differs widely across developed countries, but the source of these differences is not well-understood. While prior analysis has identified the impact of overall institutional structures (Hanushek and Woessmann (2011)), the research has been much less successful at identifying systematic features of schools and teachers that enter into explaining these achievement differences – leaving many policy discussions open to anecdotal and ad hoc explanations. This paper investigates whether differences in cognitive skills of teachers – which arise both from country skill differences and from policy decisions – can help explain international differences in student performance across developed countries.

Policy discussions, building in part on within-country analyses of the importance of teachers, have emphasized the role of teacher skills in improving student achievement. For example, a widely-cited McKinsey report on international achievement concludes that "the quality of an educational system cannot exceed the quality of its teachers" and then goes on to assert that "the top-performing systems we studied recruit their teachers from the top third of each cohort graduate from their school system." (Barber and Mourshed (2007), p. 16) In a follow-on report, Auguste, Kihn, and Miller (2010) note that the school systems in Singapore, Finland, and Korea "recruit 100% of their teacher corps from the top third of the academic cohort," which stands in stark contrast to the U.S. where "23% of new teachers come from the top third." (p. 5) They then recommend a "top third+ strategy" for the U.S. educational system. We investigate the implications for student achievement of focusing policy attention on the cognitive skills of potential teachers.

Our analysis exploits unique data from the Programme for the International Assessment of Adult Competencies (PIAAC) that allow for the first time quantifying differences in teacher skills in numeracy and literacy across countries. These differences in teacher cognitive skills reflect, as we discuss below, both the overall level of cognitive skills of each country's population and where teachers are drawn from in each country's skill distribution.

Teacher cognitive skills differ widely internationally. For example, average numeracy and literacy skills of teachers in countries with the lowest measured skills (Chile and Turkey) are well below the skills of employed adults with just vocational education in Canada.[1] In contrast, the skills of teachers in countries with the highest measured skills (Japan and Finland) exceed the skills of adults with a master's or PhD degree in Canada.

The evidence from combining this information on teacher quality with student achievement indicates that differences in teacher cognitive skills are significantly associated with international differences in student performance. Specifically, we use country-level measures of subject-specific teacher skills along with rich student-level micro data from the Programme for International Student Assessment (PISA) to estimate the association of teacher cognitive skills with student performance in math and reading across 31 developed economies.

Separating the independent impact of teacher cognitive skills from other factors potentially influencing student achievement is obviously difficult in this international context. We use three different strategies to investigate the sensitivity of the estimated impact of teacher cognitive skills to potential confounding factors.

First, we estimate OLS models with extensive sets of control variables, including student and family background, general and subject-specific school inputs, institutional features of the school systems, and cross-country differences in educational inputs. Controlling for subject-specific parent cognitive skills, which can be approximated with the PIAAC data, allows us to account for the persistence of skills across generations and to distinguish between smart parents and smart teachers.

Second, we exploit differences in the performance of students and teachers across math and reading. This allows us to identify the effect of teacher cognitive skills using only variation between subjects, which directly controls for unobserved student-specific characteristics that similarly affect math and reading performance (e.g., innate ability or family background). At the same time, this within-student between-subject model also controls for all differences across countries that are not

[1] We use Canada as a benchmark for the international skill comparison because the Canadian sample is by far the largest among all countries surveyed in PIAAC, allowing for a fine disaggregation of individuals by educational degree.

subject-specific, such as general education preferences or the nature of teacher labor markets.

Third, extending the analysis of subject-specific country differences, we control for the cognitive-skill levels in other broad occupations (e.g., managers, scientists and engineers, health professionals, business professionals) and, alternatively, for the skill levels of all adults. This facet of the analysis hence exploits within-country variation in cognitive skills, placing teachers in the country-specific distribution of numeracy or literacy skills instead of exploiting variation only across countries. We also test in a placebo-type analysis whether the cognitive-skill levels in other occupations are related to student performance when the relevant skills of teachers are included.

All empirical strategies consistently indicate a robust positive relationship between teacher cognitive skills and student performance. In the OLS estimation with the full set of controls, we find that a one standard deviation (SD) increase in teacher cognitive skills is associated with about 0.15 SD higher student performance in math and 0.10 SD higher student performance in reading. To put these estimates into perspective, they imply that roughly one quarter of gaps in mean student performance across our 31 countries would be closed if each of these countries raised teacher cognitive skills to the level of Finnish teachers (the most skilled teachers by the PIAAC measures).

Between-subject estimates are similar to the OLS coefficients. When exploiting within-country variation in cognitive skills, teacher cognitive skills always show a strong association with student performance even when controlling for the cognitive-skill levels in other occupations or the cognitive skills of all adults. Importantly, while these other measures of cognitive skills are typically significantly related to student performance when not controlling for teacher skills just because of country differences in overall skills, they lose significance once teacher skills are added.

Our results are robust to adding coarse measures of teachers' pedagogical approaches, suggesting that international differences in teacher cognitive skills do not merely reflect differences in instructional style. Moreover, accounting for cross-country differences in economic development and in educational institutions such as central exit exams or controlling for continental fixed effects to address issues of divergent national cultures does not change the teacher-skill coefficients.

We also provide novel evidence about the determinants of differences in teacher cognitive skills across countries. Existing studies have shown a strong decline in teacher cognitive skills in the United States resulting from improved alternative opportunities for women in the labor market during the past decades (Bacolod (2007)). Using the PIAAC data, we generalize the U.S. evidence to a broader set of countries, exploiting within-country changes across birth cohorts in the proportion of females working in high-skilled occupations. By observing multiple countries, we can more readily assess how female labor-market opportunities interact with teacher quality.

Higher shares of women working in high-skilled occupations outside of teaching are significantly related to lower cognitive-skill levels of teachers. This suggests that international differences in women's opportunities to enter (other) high-skilled occupations provide part of the explanation for the observed variation in teacher cognitive skills across countries.

The PIAAC micro data permit looking explicitly at whether teachers in each country are paid above or below what would be expected (given their gender, work experience, and cognitive skills). We find considerable variation in the premiums paid to teachers, with Ireland paying considerably above market and the United States and Sweden paying considerably below market. These reduced form country-specific premiums are directly related to teacher cognitive skills across countries.

This paper begins to fill an important gap in the existing literature. It has not previously been possible to compare reliably the skills of teachers across countries even though both international case studies[2] and more systematic within-country evidence consistently point to the key role that teacher quality plays in student learning. While causal identification is clearly difficult to establish conclusively in a cross-country framework, the positive relationship between teacher cognitive skills and student performance holds up in the presence of plausible alternative explanations of the results and is robust to a range of analyses addressing key elements of country heterogeneity.

Finally, these findings offer a different perspective on teacher policies. The existing analyses of

[2] Elements of teacher quality play key roles in the explanation of student success of Finland (Sahlberg (2010)) and East Asia (Stevenson and Stigler (1992)) and in the lack of success in Latin America (Bruns and Luque (2014)).

teacher effectiveness fail to identify any attributes of teachers that are systematically related to effectiveness, implying that judgments on teacher effectiveness must wait until potential teachers have entered the classroom. This analysis suggests that prior, albeit incomplete, assessments of potential effectiveness can be made.

Section 2 considers relevant prior research. Section 3 introduces the datasets and describes our computation of teacher and parent cognitive skills. Section 4 presents our empirical strategies. Section 5 reports results on the association of teacher cognitive skills with student performance in math and reading and provides robustness checks and placebo tests. Section 6 analyzes possible determinants of the cross-country differences in teacher cognitive skills, focusing on women's access to alternative high-skilled occupations and on teacher salaries. Section 7 concludes.

2. Relevant Literature

Large numbers of studies investigate the determinants of student achievement within individual countries.[3] This literature consistently finds that achievement reflects a combination of family background factors, school inputs, and institutional factors. However, these studies are better suited for within-country analysis and are not structured to explain differences in achievement across countries. In particular, all of these studies consider the impacts of school characteristics within a country's overall institutional structure – such as the amount of local decision-making authority at schools, the requirements for teacher certification, and the overall salary levels for teachers – and do not necessarily give an accurate picture of their impact under differing institutional structures.[4]

A parallel literature on international differences in achievement builds on the comparative outcome data in existing international assessments (see Hanushek and Woessmann (2011)). One of the clearest explanatory factors from these international studies has been the importance of family

[3] See, for example, the reviews in Hanushek (2002) and Glewwe et al. (2013).

[4] Throughout this review, the focus is on research about performance in developed countries. This reflects the significant questions about inferences across countries with very different resources, labor markets, and institutional development. See, for example, the explicit analysis of variations in the impact of educational institutions across countries at different stages of development in Hanushek, Link, and Woessmann (2013).

background in explaining student achievement.[5] In contrast, specific conclusions about the impact of school resources have been much more limited. There has, for example, been considerable research on overall educational expenditures and on resource inputs such as class size, but the existing research has not identified these as being strong drivers of international differences in achievement.[6] The lack of findings on resources has led to a different set of international studies that focuses on the effects of institutional features of the school systems such as the degree of local decision making, the use of accountability systems, and direct rewards for personnel in the schools.[7]

The most convincing within-country studies of variations in performance across schools focus on differences in learning gains among teachers and classrooms. These studies of teacher value-added to student reading and math performance consistently find huge variations in teacher value-added that far exceed any other measured school inputs (Hanushek and Rivkin (2012)).[8] But these results have not been very useful in addressing international achievement differences. First, the studies focus almost exclusively on the experience in the United States. Second, they have not reliably described any underlying determinants of teacher value-added – and in particular any determinants that can be consistently measured across countries.

Importantly, a wide range of international within- and across-country studies have generally shown that the most common measures of teacher differences – education, experience levels, and sources and nature of teacher preparation – are not consistently related to student achievement,

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[5] For example, see the review in Björklund and Salvanes (2011) or the analysis in Woessmann et al. (2009).

[6] See Hanushek (2006) for a review of the effects of school resources and the international evidence in Hanushek and Woessmann (2011).

[7] For example, positive impacts have been estimated for school autonomy (especially in developed countries; cf. Hanushek, Link, and Woessmann (2013)) and for increased competition reflected in the share of privately operated schools (West and Woessmann (2010)). The range of institutional studies is assessed in Hanushek and Woessmann (2011).

[8] For a sample of the research into teacher effectiveness, see Rockoff (2004), Rivkin, Hanushek, and Kain (2005), Kane, Rockoff, and Staiger (2008), Chetty, Friedman, and Rockoff (2014), and the summaries in Hanushek and Rivkin (2010). As an indication of the magnitudes involved, Rivkin, Hanushek, and Kain (2005) estimate that the effect of a costly ten student reduction in class size is smaller than the benefit of moving up the teacher quality distribution by one standard deviation.

raising questions about the reliance on these as indicators of teacher quality in international studies.[9]

An interesting contrast, however, that motivates part of our subsequent analysis comes in studies of teacher salaries. While within-country studies tend to find that salaries are not a good measure of differences in teacher effectiveness,[10] the limited cross-country studies that are available have found that salary levels are more positively related to country differences in student outcomes.[11] These divergent results suggest that the salary levels of a country may be part of a country's institutional structure with important ramifications for the quality of the overall pool of potential teachers, even if the distribution of salaries within a country is not a good index of differential teacher effectiveness. Relatedly, cross-country analysis suggest that pay incentives are related to student performance even if within-country variations in pay structure are less informative.[12] The overall suggestion of the importance of salary differences across countries leads us to explore country-level teacher wage premiums and teacher cognitive skills in Section 6.

Studies of the impact of the cognitive skills of teachers on achievement are directly relevant for the main focus of this analysis. The relatively few prior studies of measured teacher cognitive skills come almost exclusively from within the United States and have relied generally on small and

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[9] For reviews of the evidence on the impact of teacher characteristics from within-country studies, see Hanushek (1995, (2003), Glewwe et al. (2013), Woessmann (2003). For cross-country evidence, see Hanushek and Woessmann (2011).

[10] Hanushek and Rivkin (2006)) provide an overview of the within-country evidence indicating that teacher salaries are a weak measure of teacher quality. However, challenging this general conclusion, Britton and Propper (2016) find positive effects of relative teacher pay on school productivity, exploiting regional variation in teachers' relative wages. Loeb and Page (2000) similarly relate regional variation in relative teacher wages to rates of educational attainment but also lack direct measures of teacher quality.

[11] In their country-level analysis, Lee and Barro (2001) find a positive association between teacher salary levels and student achievement. Similarly, Woessmann (2005) reports a significant positive coefficient on a country-level measure of teacher salary when added to an international student-level regression. Dolton and Marcenaro-Gutierrez (2010) pool country-level data from international tests in 1995-2006 to show that teacher salaries – both when measured in absolute terms and relative to wages in each country – are positively associated with student achievement, even after controlling for country fixed effects.

[12] For a review on teacher performance pay, see Leigh (2013). See also the international investigation of performance pay in Woessmann (2011).

idiosyncratic data sets (see Hanushek (2003)).[13] Teacher cognitive skills have not been uniformly significant across studies, perhaps reflecting the small samples and varied test measures. Nonetheless, compared to the various alternative measures of teacher quality commonly investigated, teacher test scores have been most consistently related to student outcomes with two-thirds of studies showing greater cognitive skills related to more student learning.[14] The within-country variations of cognitive skills may also not adequately capture the impact of moving the mean of the entire distribution – the subject of our analysis.

Other work focuses directly on the cognitive skills of teachers over time. Eide, Goldhaber, and Brewer (2004) describe various measures of changing cognitive skills of teachers over time. Bacolod (2007) documents a decrease in the academic quality (as measured by standardized test scores and undergraduate institution selectivity) of female teachers in the U.S. during the recent decades that coincided with the expansion of job opportunities for women. Corcoran, Evans, and Schwab (2004a, (2004b) show that the decline in measured teacher skills over the same period has been concentrated in the upper portion of the achievement distribution. Both suggest that women's opportunities to enter high-skilled occupations outside teaching are one determinant of the skill level of teachers in a country. The analysis of varying skill levels of teachers in these studies has, however, not been linked directly to student performance.

3. International Comparative Data

This study applies new international data on cognitive skills of teachers to assess the role of cross-country differences in teacher skills in explaining student outcomes.

3.1 Teacher Cognitive Skills

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[13] In two studies for developing countries, Metzler and Woessmann (2012) and Bietenbeck, Piopiunik, and Wiederhold (Forthcoming) show the relevance of teacher subject knowledge using individual-level teacher data. See also Harbison and Hanushek (1992) for the impact of measured teacher math skills on achievement in rural Brazil. Using a general, non-subject-specific, measure on cognitive abilities (based on a standard IQ test), Grönqvist and Vlachos (2016) find only a negligible impact of teacher cognitive skills on student achievement.

[14] See Eide, Goldhaber, and Brewer (2004); Hanushek and Rivkin (2006), and the summary in Hanushek (2003)).

Measured cognitive skills of teachers are derived from the Programme for the International Assessment of Adult Competencies (PIAAC) survey. Developed by the Organisation for Economic Co-operation and Development (OECD) and collected in 2011/2012 (Round 1) and in 2014/15 (Round 2), PIAAC tested various cognitive skill domains of more than 215,000 adults in 33 developed economies.[15] The target population of PIAAC was the non-institutionalized population aged 16-65 years, and samples included at least 5,000 participants in each country.

The survey provides rich information about demographic, educational, and occupational characteristics for each respondent. It was administered by trained interviewers either in the respondent's home or in a location agreed upon between the respondent and interviewer. The standard survey mode was to answer questions on a computer, but respondents without computer experience could opt for a pencil-and-paper interview.[16]

After providing the background information, respondents took a battery of cognitive assessments. PIAAC assessments are designed to be valid cross-culturally and cross-nationally and to provide internationally comparable measures of adult skills. The assessments measure key cognitive and workplace skills needed to advance in the job and to participate in society in three domains: numeracy, literacy, and problem solving in technology-rich environments.[17] The test

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[15] We use 31 countries in our analysis: Australia, Austria, Belgium (Flanders), Canada, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Japan, Korea, the Netherlands, Norway, Poland, the Russian Federation, the Slovak Republic, Spain, Sweden, the United Kingdom (England and Northern Ireland), and the United States (Round 1) as well as Chile, Greece, Indonesia, Israel, Lithuania, New Zealand, Singapore, Slovenia, and Turkey (Round 2). Cyprus, while participating in PIAAC, did not participate in PISA. In Indonesia, the PIAAC survey was only administered to the population in Jakarta. According to OECD (2013), data for the Russian Federation are preliminary, may still be subject to change, and are not representative of the entire Russian population because they do not include the population of the Moscow municipal area. Our results are not sensitive to dropping the Russian Federation from the sample.

[16] On average across countries, 70 percent of assessment participants took the computer-based assessment and 30 percent took the paper-based assessment. A field test suggests no impact of assessment mode (OECD 2013).

[17] PIAAC tests were conducted in the official language of the country of residence. In some countries, the assessment was also conducted in widely spoken minority or regional languages. Respondents could take as much time as needed to complete the assessment. *Literacy* is defined as 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," and *numeracy* is the "ability to

questions are often framed as real-world problems, such as maintaining a driver's logbook (numeracy domain) or selecting key information from a bibliographic search (literacy domain). PIAAC measures each of the skill domains on a 500-point scale.

We are particularly interested in the skills of teachers in each country. In the Public Use File, information on occupation is available only at the two-digit code in some countries (Germany, Ireland, Singapore, Sweden, and the United States), while a few other countries (Austria, Canada, Estonia, and Finland) do not publicly report any occupational code. For this study, however, we gained access through the OECD to the four-digit ISCO-08 (International Standard Classification of Occupations) codes for all countries, which allows us to identify teachers in fine categories.

We define teachers as all PIAAC respondents who report as current four-digit occupation code "primary school teacher", "secondary school teacher", or "other teacher" (which includes, for example, special education teachers and language teachers).[18] We exclude university professors and vocational school teachers since the vast majority of PISA students (15-year-olds) are still in secondary school and have therefore not been taught by these types of teachers. We also exclude pre-kindergarten teachers as the roles of this teacher group depend directly on the institutional structures of individual countries and may or may not be contributors to teaching students reading and math.[19] Because PIAAC is not a teacher survey, we benchmark the PIAAC teacher samples

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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" (see OECD (2013) for more details). Because of our focus on students' reading and math performance, we do not use the PIAAC skills in the domain "problem solving in technology-rich environments." Moreover, five countries surveyed in PIAAC (Cyprus, France, Indonesia, Italy, and Spain) did not administer tests in this optional skill domain.

[18] This includes school principals who teach, but excludes other workers at school with non-teaching occupations. Results are very similar if we drop the category "other teachers." We keep these teachers in the sample to increase sample size.

[19] For Australia and Finland we only have two-digit occupational codes and are unable to exclude pre-kindergarten teachers and university professors/vocational school teachers from our teacher sample. However, analysis of the countries where teachers are defined using the four-digit code indicates that teacher skills based on the four-digit code are very similar to those defined using the two-digit code: The correlation of both skill measures is 0.97 for numeracy and 0.95 for literacy. On average, numeracy (literacy) skills based on the two-digit code are only marginally higher (by 0.5 (0.1) PIAAC points) than the respective skills based on the four-digit codes. The average

against large administrative datasets in which detailed occupational information allows identifying teachers. Using the 2011 U.S. American Community Survey (ACS) which includes 55,000 teachers and the 2011 German Micro Census which includes about 6,400 teachers, we find similar demographic characteristics compared to the respective national PIAAC teacher samples.[20] PIAAC does not allow us to identify the subject that a teacher is teaching, so we use the numeracy and literacy skills of all teachers tested in PIAAC. We focus on the country-level median of the teacher cognitive skills because the median is more robust to outliers than the mean[21], something that is particularly relevant in smaller samples.[22] We weight individual-level observations with inverse sampling probabilities when computing country-specific teacher cognitive skills.

Table 1 reports summary statistics of the teacher cognitive skills in the 31 countries and in the pooled sample. The number of teachers in the national PIAAC samples ranges from 106 teachers in Chile to 834 teachers in Canada, with 207 teachers per country on average. (The sample size for Canada is substantially larger than for any other country surveyed in PIAAC because Canada oversampled in order to obtain regionally representative adult skills). Teachers in Finland and Japan perform best in both numeracy and literacy, while teachers in Chile and Turkey perform worst in both domains.

The mean scores in the full PIAAC sample are 259 points in numeracy and 268 points in literacy The range of teacher numeracy skills across countries is 55 points, which amounts to one international individual-level standard deviation (55 points) in the full PIAAC sample; in literacy,

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absolute value of these differences is only 2.1 points in numeracy and 1.9 points in literacy. Moreover, simultaneously excluding Australia and Finland from the analysis does not qualitatively change our results below.

[20] In the U.S. teacher samples, mean age is 41.1 years in PIAAC (44.3 years in the ACS), 67.5% (75.5%) of teachers are female, and 89.9% (88.6%) of teachers have a college degree. In the German teacher samples, mean age is 47.2 years in PIAAC (45.6 years in the Micro Census), 65.8% (74.4%) of teachers are female, and 85.2% (82.2%) of teachers have a college degree.

[21] The country-level correlation between teacher median skills and mean skills is 0.98 for both numeracy and literacy. Moreover, all results are robust to using mean teacher skills instead of median teacher skills.

[22] Due to the limited size of our teacher samples, we focus on the effect of average teacher skills and do not consider other moments like variance.

the range of teacher skills of 60 points even exceeds one international standard deviation (50 points). Teachers in the United States (284 points) perform worse than the sample-wide average teacher in numeracy (292 points) but are slightly above the international mean in literacy (301 points vs. 295 points). Interestingly, the country ranking and the cross-country variation in teacher cognitive skills are similar to those of all prime-aged workers with full-time employment (see Table 1 in Hanushek et al. (2015)).[23] Also note that teacher numeracy skills are higher than teacher literacy skills in some countries, while the reverse is true in other countries. We will exploit this variation in domain-specific teacher skills in the fixed-effects model that uses only variation within countries and between subjects (see Section 5.3). Furthermore, both numeracy and literacy skills of teachers are completely unrelated to the number of teachers in the national PIAAC samples. For the econometric analysis, we standardize the teacher cognitive skills across the 31 countries to have mean zero and standard deviation one.

Figure 1 illustrates the international variation in teacher cognitive skills. The figure arrays the median teacher numeracy and literacy skills across countries against the skills of adults in different educational groups within Canada, the country with the largest sample. The literacy skills of the lowest-performing teachers (in Turkey and Chile) are well below the literacy skills of employed Canadian adults with only a vocational degree (278 points). Teachers in Italy, Russia, and Israel perform just as well as vocationally educated Canadians. Teachers in the Netherlands and Sweden have skill levels similar to Canadian adults with a bachelor degree (306 points). The literacy skills of the best-performing teachers (in Japan and Finland) are higher than Canadian adults with a master or doctoral degree (314 points). These comparisons, which look similar for numeracy skills, underscore the vast differences in teacher cognitive skills across developed countries.

Variations in teacher cognitive skills reflect both where teachers are drawn from the country's skill distribution and where a country's overall cognitive-skill level falls in the world distribution.

[23] Younger teachers have higher skills than older teachers in almost all countries in our sample. Also, male teachers have higher skills than female teachers, especially in numeracy. These patterns, however, are not specific to teachers, but are very similar among all college graduates in a country. Detailed results are available on request.

As most teachers have obtained a college degree (89 percent across all PIAAC countries), we expect teacher cognitive skills to fall above the country's median. Across all 31 countries, median teacher skills fall at the 68th (71st) percentile of the numeracy (literacy) skill distribution of all adults, ranging from the 53rd to the 81st percentile (see Table 1).

Figure 2 compares teacher cognitive skills with the skills of all college graduates in a country. While median teacher cognitive skills fall near the middle of the 25th–75th percentile skill range of cognitive skills of college graduates in most countries, teachers come from the upper part of the college skill distribution in some (e.g., Finland, Japan, and Singapore) and from the lower part in others (e.g., Austria, Denmark, the Slovak Republic, and Poland).

From Table 1, teachers in Chile, France, Spain, and Turkey are drawn highest up in the country distributions of adult skills in numeracy and literacy. Although Finnish teachers are drawn from a somewhat lower part of the country's overall skill distribution, they have substantially greater skills than in France, Spain, Chile, and Turkey, reflecting the higher overall cognitive skill level in Finland. Or, harkening back to the argument that 100% of teachers in Korea and Singapore come from the top third of the academic cohort, the median Korean (Singaporean) teacher falls at the 72nd (72nd) percentile of the overall country distribution and at the 52nd (48th) percentile of the college graduate distribution in numeracy (see also Figure 2).[24]

Because the PIAAC tests are new and have not been fully validated, we have compared the PIAAC-based teacher cognitive skills with the numeracy and literacy skills of teachers in larger national datasets for the United States and Germany. These comparisons, described in Appendix A, support the overall validity of the estimates of teacher cognitive skills that are derived from PIAAC.

3.2 Parent Cognitive Skills

Because the parents of the PISA students (henceforth "PISA parents") are not tested, we use the PIAAC data to impute the numeracy and literacy skills of the PISA parents. We first construct a sample of adult PIAAC participants that could in principle be PISA parents. We then estimate the

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[24] This point about teacher skills was first made by Schleicher (2013).

numeracy and literacy skills of the PISA parents from the PIAAC micro data on the basis of several common observable characteristics. Specifically, separately by country, we regress the numeracy/literacy skills of PIAAC adults aged 35–59 with children[25] on three characteristics: gender[26], education (3 categories), and number of books at home (6 categories).[27] These estimated coefficients with the same three characteristics of the PISA parents are then used to obtain predicted numeracy/literacy skills of each PISA parent at the individual family level. In the student-level analysis, we use the maximum skills of mother and father as a proxy for parent cognitive skills, although results are very similar if the average skill of mother and father is used instead.

Although the PIAAC-based parent skills are only coarse proxies for the true skills of PISA parents, controlling for the estimated cognitive-skill level of parents allows us to tackle several issues. First, since originally studied in the Coleman Report (Coleman et al. (1966)), it has been clear that the family and education in the home is important. Using parental cognitive skills adds a qualitative dimension to family influences over and above the common measures of the student's family background. More generally, student performance likely persists across generations, for example, because the quality of the education system or the valuation of education changes only slowly over time. Second, adding information about parent cognitive skills provides one way of separating teacher cognitive skills from the skills of the country's overall population.

Table A-1 presents summary statistics of parent skills in numeracy and literacy by country. Similar to teacher cognitive skills, parent cognitive skills differ greatly across countries, ranging (in

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[25] Individuals in this age bracket are potential parents of the 15-year-old PISA students since they were 17–44 years old when PISA students were born.

[26] We compute skills separately for PISA mothers and fathers because numeracy/literacy skills of women and men might differ. By predicting gender-specific skills, PISA students with single mothers, for example, are assigned only the skill level of women and not the average skill level of men and women.

[27] We collapsed the original 8 categories of the PIAAC education variable into 3 categories so that the education categories in PIAAC and PISA would exactly match. The 6 categories of the number of books at home variable are identical in PIAAC and PISA, so this variable was not modified. We use number of books at home in addition to educational degree, since this variable has been shown to be the single strongest predictor of student test scores (Woessmann (2003)). Sample sizes range from 1,074 adults in the Russian Federation to 11,933 adults in Canada with an average sample size of 2,693 adults per country (see Table A-1).

numeracy) from 223 points in Chile to 308 points in Japan. Also, parent skills differ substantially within countries. On average, the difference between the minimum and maximum numeracy skill in a country is 115 points, or more than twice the international individual-level standard deviation.

3.3 Student Performance and Further Control Variables

International data on student performance come from the Programme for International Student Assessment (PISA), conducted by the OECD.[28] PISA is a triennial survey that tests math and reading competencies of nationally representative samples of 15-year-old students, an age at which students in most countries are approaching the end of compulsory schooling. PISA contains both multiple-choice and open-answer questions and provides internationally comparable test scores. The tests emphasize understanding as well as flexible and context-specific application of knowledge, and hence they do not test curriculum-specific knowledge.

We use the two PISA cycles of 2009 and 2012 because the students have largely been taught by the teacher cohorts tested between 2011 and 2015 in PIAAC. Student cohorts of earlier PISA cycles (2000, 2003, and 2006) have partially been taught by some PIAAC teachers, but teacher turnover would introduce additional error in the teacher skill measures for students in these earlier cycles. Another reason for combining PISA 2009 and 2012 is that students provide information about the instructional practices of their teachers only for the focus subject in each round of PISA testing: reading in 2009 and math in 2012. From the survey information, we can compute country-specific indicators of instructional practice for reading (based on PISA 2009) and for math (based on PISA 2012). These instructional-practice indicators capture subject-specific pedagogical skills of teachers, a potentially important confounding factor for teacher cognitive skills (see Section 5.2).

Table A-2 provides summary statistics of student performance and student characteristics. Student performance in math and reading differs widely across countries. Given that the learning

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[28] We rely on the PISA assessments instead of the alternative international test of Trends in International Mathematics and Science Study, or TIMSS (see Hanushek and Woessmann (2011)). PISA covers more PIAAC countries, and students participating in PISA were tested in both math and reading, while TIMSS only assessed math performance. Note, however, that math scores from TIMSS are strongly correlated with math scores from PISA at the country level.

progress in one school year is about 40 PISA points, the difference between the USA and Singapore is about two school years in math. The math performance gap is about three schools years between Singapore and Turkey and almost four years between Singapore and Chile. International student performance differences in reading are somewhat less pronounced, but still substantial.

For the econometric analysis, we standardize student test scores at the student level across the 31 countries and the two PISA assessments to have mean zero and standard deviation one. As we are interested in differences across countries, each country receives the same total weight in each PISA cycle. Student characteristics (e.g., gender and migration status) and information about parents (e.g., education, occupation, and number of books at home) come from student background questionnaires. We use estimated parent cognitive skills, number of books at home, parents' highest educational degree, and parental occupation to control for family background (see Table A-3).

Based on student information, we can construct measures of weekly instructional time for both language and math classes.[29] Furthermore, school principals provide information on whether the school is public or private, city size, total number of students in the school, the lack of qualified math teachers and language teachers, and different types of autonomy (see Table A-4).

Country characteristics include variables that are direct educational measures, namely, cumulative educational expenditure per student between age 6 and 15 and school starting age. We also check the robustness of our results to including further country controls, for instance, GDP per capita to capture international differences in the state of development (see Table A-5).

4. Estimation Strategy

In the baseline OLS model, we estimate an international education production function of the following form:

$$A_{iksc} = \alpha + \lambda T_{kc} + \boldsymbol{F}_{isc}\boldsymbol{\beta}_1 + \boldsymbol{S}_{sc}\boldsymbol{\beta}_2 + \boldsymbol{C}_c\boldsymbol{\beta}_3 + \gamma_1 P_{iksc} + \boldsymbol{I}_{ksc}\boldsymbol{\gamma}_2 + \epsilon_{iksc}, \quad \textbf{(1)}$$

where A_{iksc} is the test score of student *i* in subject *k* (math or reading) in school *s* in country *c*. T_{kc}

[29] Following Lavy (2015), we aggregate this information across students to the school level.

represents the median teacher cognitive skills in subject k in country c. $\boldsymbol{F}_{isc}$ is a vector of student-level variables measuring student and family background, $\boldsymbol{S}_{sc}$ is a vector of school-level characteristics, and $\boldsymbol{C}_c$ is a vector of country-level control variables. P_{iksc} contains student-level estimates of parents' numeracy and literacy skills, respectively, and $\boldsymbol{I}_{ksc}$ contains school-level variables measuring the shortage of qualified teachers and weekly instructional time in math and language classes. (See Tables A1–A5 for descriptive statistics for all control variables). ε_{iksc} is an error term, assumed to be mean zero. Throughout, we cluster standard errors at the country level because teacher skills do not vary within countries.[30]

Despite the rich set of control variables, interpreting the OLS estimate of λ as the causal effect of teacher cognitive skills on student performance is nonetheless problematic, because of the possibility of omitted variables correlated with both teacher skills and student performance. Such omitted variables could include, for example, the educational attitude in a country: Societies that emphasize the importance of good education may have both teachers with high cognitive skills and parents who strongly support their children's education. Similarly, if the quality of the education system is persistent and not perfectly captured by our measure of parent cognitive skills, student performance and teacher cognitive skills (who went through the same education system one generation earlier) might be positively correlated even if teacher cognitive skills have no real impact on student performance. Sorting of students and teachers within schools and across schools (within countries) – which often plagues micro-level analysis of educational production – is, however, no concern in our study because teacher cognitive skills are aggregated to the country level.

[30] Recent research has shown that clustered standard errors can be biased downward in samples with a small number of clusters (e.g., Donald and Lang (2007); Cameron, Gelbach, and Miller (2008); Angrist and Pischke (2009); Imbens and Kolesar (2012)). Although there is no widely accepted threshold when the number of clusters is "small," the work of Cameron, Gelbach, and Miller (2008), Angrist and Pischke (2009), and Harden (2011) suggests a cutoff of around 40 clusters. To check whether clustering in our cross-country sample with just 31 clusters produces misleading inferences, we use the wild cluster bootstrap procedure suggested by Cameron, Gelbach, and Miller (2008) for improved inference with few clusters (using Stata's *cgmwildboot* command for implementation). All results remain robust when employing the wild bootstrap procedure as an alternative to clustering.

To the extent that omitted variables are not subject-specific, we can circumvent bias by focusing on just within-student variation in teacher skills across math and reading. Within-student effects of teacher cognitive skills on student performance are estimated with the following model:[31]

$$A_{isc,math} - A_{isc,read} = \lambda(T_{c,numeracy} - T_{c,literacy}) + \gamma_1(P_{isc,numeracy} - P_{isc,literacy}) + (\boldsymbol{I}_{sc,math} - \boldsymbol{I}_{sc,read})\gamma_2 + (\varepsilon_{isc,math} - \varepsilon_{isc,read}).$$

This model – which is equivalent to pooling math and reading and including student fixed effects – holds constant all factors that do not differ between subjects, capturing subject-invariant performance differences across students (e.g., family background, innate ability, and motivation) and across countries (e.g., general educational attitude).[32]

The within-student approach, however, cannot control for unobserved differences across countries that are subject-specific. For example, if societies have both teachers with high numeracy skills and a strong preference for advancing children in math (with parents supporting their children accordingly), then fixed-effects estimates of teacher cognitive skills will still be biased. However, if a country has subject-specific preferences (e.g., for math), then the numeracy skills should be relatively high for all adults. We therefore control for the cognitive-skill levels in occupations other than teaching (e.g., managers, scientists and engineers, health professionals, business professionals) as proxies for the subject-specific preferences of countries. Alternatively, we also use as controls the average cognitive-skill level of all adults in a country and the difference in country-level adult skills between numeracy and literacy. These models exploit within-country variation in cognitive skills, placing teachers in the country-specific distribution of skills instead of relying solely on cross-country variation in teacher numeracy or literacy skills.

5. Teacher Cognitive Skills and Student Performance

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[31] Within-student across-subject variation has frequently been used in previous research (e.g., Dee (2005, (2007), Clotfelter, Ladd, and Vigdor (2010), and Lavy (2015)).

[32] In contrast to the OLS estimates, the estimated effect of teacher cognitive skills in the student fixed-effects model is "net" of teacher skill spillovers across subjects (for example, if teacher literacy skills affect student math performance). Spillover effects are completely eliminated when cross-subject spillovers are identical in math and reading.

It is easiest to motivate the analysis with simple visual evidence showing that teacher cognitive skills are positively associated with student performance aggregated to the country level. The two upper graphs in Figure 3 show the unconditional cross-country relationship between teacher numeracy skills and student math performance (left panel) and between teacher literacy skills and student reading performance (right panel). Both numeracy and literacy skills of teachers are clearly positively associated with aggregate student performance. The two middle graphs control for the country-specific skills of all adults aged 25–65 to net out the skill persistence across generations.[33] The coefficient on teacher numeracy skills is reduced only modestly, while the coefficient on teacher literacy skills even increases. In the two bottom graphs, we control for all covariates of the baseline OLS specifications (see Table 2 below). While this reduces the teacher-skill estimates, they are still strongly positively associated with student performance. As expected, the skill level of all adults (aged 25–65) is also strongly positively related to student performance (Figure A-1). However, when controlling for teacher cognitive skills, the estimates for adult skills substantially decrease in size and lose statistical significance. This suggests that student performance is positively related to adult skills because countries with high adult skills also have teachers with high skills.

5.1 Ordinary Least Squares Results

We now investigate the relationship between teacher cognitive skills and student performance using student-level test-score data (Table 2). Of course, the unconditional relationship between teacher numeracy skills and individual-level student math performance (Column 1) is identical to the country-level estimate in Figure 3. The coefficient on teacher numeracy skills remains significant when adding a large set of background factors at the individual, family, school, and country level (Column 2) and when including the numeracy skills of parents of PISA students (Column 3). The estimate in Column 3 implies that a one SD increase in teacher numeracy skills increases student math performance by almost 0.15 SD. Even though various parent characteristics,

[33] The country-level correlations between teacher skills and adult skills are 0.77 for numeracy and 0.86 for literacy. Skills of teachers and adults are substantially correlated since both have been educated in the same education system at about the same time.

such as education level and number of books at home, are included, parent numeracy skills are significantly related to student performance, but the coefficient is rather modest in size compared to teacher cognitive skills. Columns 4–6 report results for reading. Teacher literacy skills are highly statistically significant across specifications, although the coefficient is somewhat smaller than the coefficient on teacher numeracy skills in the specification with all controls (0.09; see Column 6).[34]

When accounting for student characteristics and family influences (Columns 2 and 5), the impact of teacher skills decreases considerably more in reading than in math, suggesting that parents are more important for improving their children's reading abilities than their math performance. These results, and the smaller impact of teacher literacy skills compared to teacher numeracy skills, are consistent with the common finding that students' reading performance is more difficult to improve by teachers than their math performance.[35]

We find some evidence for heterogeneity of the teacher-skill effect across student subgroups (Table A-7). The impact is somewhat larger for girls than for boys, for low-SES students compared to high-SES students[36] (particularly in reading), and for natives relative to migrants (particularly in math).[37] Parent cognitive skills are considerably more important for high-SES students, but there are no differences by student gender or migration status.

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[34] Using average teacher skills instead of median teacher skills leads to very similar results, with a coefficient on numeracy (literacy) skills of 0.138 (0.093). Both coefficients are statistically significant at the 1 percent level.

[35] Coefficients on the other control variables are reported in Appendix Table A-6. All coefficients have the expected signs. Regarding the country-level characteristics, we observe a zero coefficient on educational expenditure per student, while school starting age is positively related to student performance.

[36] Socioeconomic status (SES) is measured by the PISA index of economic, social, and cultural status (ESCS).[37] Because first-generation migrants might have migrated to the PISA test country shortly before the PISA test, we cannot ascribe their math and reading performance to the skill level of teachers in the test country. Therefore, we use only second-generation migrants in this analysis, since these students were born in the PISA test country and have spent their school career in the education system of that country.

[37] Because first-generation migrants might have migrated to the PISA test country shortly before the PISA test, we cannot ascribe their math and reading performance to the skill level of teachers in the test country. Therefore, we use only second-generation migrants in this analysis, since these students were born in the PISA test country and have spent their school career in the education system of that country.

To gauge the magnitude of our estimates, we use the OLS coefficients to simulate the improved student performance if each country brought its teachers up to the level of Finnish teachers, the highest skilled in our sample (Table 3). For Japan, this is not a huge change, but even Japanese students would improve somewhat (0.06 SD in math and 0.02 SD in reading). But for others, the improvements in student performance would be substantial. The U.S. would be expected to improve by roughly 0.33 SD in math; Turkey and Chile, being at the bottom of the international league table, would be expected to improve by about 0.54 SD and 0.57 SD, respectively, in math.

Returning to our original question, we can provide some indication of how much impact our measured teacher dimension of teacher quality could have on variations in student achievement across countries. For our 31 countries, the country-level SD of mean PISA scores is 29.3 for math and 21.9 for reading. The simulations in Table 3 imply that bringing teachers in each country to the Finnish level would reduce the country dispersion to 22.1 in math and 15.9 in reading – roughly a one-quarter reduction in each domain.

The teacher-skill estimates do not capture the effect of just one school year but rather reflect the cumulative effect of teacher cognitive skills on student performance over all school years. Thus, these are long-run impacts that presume that the quality of students' teachers in the first ten grades would improve to the level of Finland.

5.2 Robustness Checks

One worry is that our subject-specific teacher-skill measures are confounded by correlated differences in pedagogical skills. To investigate this, we use information from the PISA students about their teachers' activities in language and math classes to construct indicators of subject-specific instructional activities as proxies for teachers' pedagogical skills. We follow the OECD (2010) approach of measuring specific instructional practices through survey responses of students (e.g., how often does a teacher ask questions that make students reflect on a problem), while we aggregate these instructional practices to the school level.[38] As noted in Section 3, instructional practices are asked only for the subject that was the focus in the respective PISA cycle (reading in 2009 and math in 2012). For the PISA cycle when a subject was not the focus, we impute the subject-specific instructional-practice indicator by using the country-level measure from the other PISA survey, assuming that the instructional practices in a subject have not noticeably changed within a country over the three-year period between 2009 and 2012.[39]

Table 4 reports the results when we augment the baseline model by controls for the instructional practices in math and language classes (the baseline estimates are reported in Column 1 for math and in Column 3 for reading). The instructional-practice indicators are positively related to student performance, but are statistically insignificant. Importantly, however, when instructional practices are added, the teacher-skill estimates change very little, suggesting that teacher cognitive skills have an independent impact on student performance.

Supporting this, we construct another indicator using information on instructional practices reported by teachers.[40] In line with the results in Table 4, all teacher-reported instructional practices

[38] For *reading*, we use the following items (each measured on a 4-point scale ranging from "never or hardly ever" to "in all lessons") to construct the instructional-practice indicator: asking students to explain the meaning of a text; asking questions that challenge students to get a better understanding 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. For *math*, we use the following items (each measured on a very similar 4-point scale ranging from "never or rarely" to "almost or almost always"): 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; and presenting problems that require students to apply what they have learnt to new contexts.

[39] To some extent, the country-level instructional-practice indicators just reflect cultural differences in how actively teachers communicate with their students. Therefore, it is understandable that the instructional-practice measure is largest in Anglo-Saxon countries and smallest in Asian countries.

[40] Data come from TALIS 2013 (see OECD (2014) for details). Instructional practices assessed in TALIS include: present a summary of recently learned content; students work in small groups to come up with a joint solution to a problem or task; give different work to the students who have difficulties learning and/or to those who can advance faster; refer to a problem from everyday life or work to demonstrate why new knowledge is useful; let students practice similar tasks until teacher

are negatively correlated with teacher cognitive skills, suggesting that, if anything, the impacts of cognitive skills are understated by omitting the pedagogical skills of teachers.[41]

Another worry is that teacher cognitive skills are correlated with other country-level factors. For example, both teacher cognitive skills and student performance might be higher in more developed countries, or countries with higher teacher skills might also have educational institutions that are more supportive of student learning. To rule out these potential confounds, we additionally control for a series of institutional factors at the country level: GDP per capita (as a measure of a country's state of development), teacher gross hourly wage (as a proxy for general teacher quality), the existence of teacher performance pay (to capture teacher-incentive and teacher-sorting mechanisms), and central exit exams (reflecting other achievement-enhancing institutions). Adding these country-level factors does not change the impact of teacher cognitive skills (Table A-8).

Finally, we show that the teacher-skill effect holds in several country subsamples (Table A-9). To address divergent national cultures (in particular, differing educational attitudes), we show that our results are robust to specifications that include continental fixed effects and that restrict the analysis to just European countries, which makes the sample culturally more homogeneous (Columns 2 and 3). Furthermore, excluding the ex-communist countries (the Czech Republic, Estonia, Lithuania, Poland, Russia, the Slovak Republic, and Slovenia) and Turkey, where occupational choices were less driven by market incentives but also depended on political attitudes, yields similar results (Column 4). Using only countries with larger teacher PIAAC samples, where measurement error in country-level teacher cognitive skills is likely smaller, leads to somewhat larger teacher-skill coefficients (Column 5). Importantly, the teacher-skill coefficient is very similar in all subsamples, lying within the 95% confidence interval of the full-sample estimate.

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knows that every student has understood the subject matter; check students' exercise books or homework; students work on projects that require at least one week to complete; students use ICT for projects or class work.

[41] We do not use instructional practices from TALIS in the student-level regressions because nine of the 31 countries in our sample (Austria, Germany, Greece, Ireland, Lithuania, New Zealand, the Russian Federation, Slovenia, and Turkey) did not participate in TALIS 2013, which would substantially reduce our sample.

Moreover, any analysis that exploits international variation with limited degrees of freedom might have results driven by a few outliers. Therefore, we replicated the baseline OLS specification with all control variables, but sequentially excluded each country from the sample. The estimated teacher-skill effects are always very close to the baseline coefficients, confirming that the results are not driven by any individual country (results available upon request).

In summary, the estimated impact of teacher cognitive skills on student performance proves highly robust to additional controls and to using different samples.

5.3 Student Fixed-Effects Results

While the previous section has shown that our teacher-skill estimates are remarkably robust to additional controls and various subgroups, the possibility of omitted variables that vary at the country level remains. Thus, we turn to estimation with student fixed effects. We exploit only within-country variation to identify the effect of teacher cognitive skills on student performance, eliminating any non-subject-specific bias.[42]

Table 5 presents the results of the student fixed-effects specifications that match the OLS specifications except that now the difference in student performance between math and reading is regressed on the difference in teacher skills between numeracy and literacy. Also, all control variables that differ across subjects are included in first differences. Across specifications, the student fixed-effects estimates for teacher cognitive skills remain sizeable and close to the OLS coefficients on teacher numeracy and literacy skills.

While neither parent cognitive skills nor teacher shortages are significantly related to student performance, the effect of instructional time on student performance is significant and similar to the effect size in Lavy (2015).[43]

5.4 Overall Country-Level Skill Differences

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[42] An assumption embodied in the student fixed effects model is that the effect of teacher cognitive skills is similar across subjects. Supporting this assumption, a cross-equation test indicates that one cannot reject the equality of OLS coefficients in math and reading (in the full-control models in Column 3 and 6 in Table 2, the respective p-value is 0.11).

[43] Lavy (2015) exploits within-student between-subject variation using PISA data from 2006.

While the within-student approach captures any differences across countries that are not subject-specific, it does not control for subject-specific differences. If some countries systematically do better in math or reading – because of strong preferences for one particular subject, curricular differences, or other reasons – the estimated impacts of teacher cognitive skills may simply be a reflection of subject-specific country differences. In Table 6, we therefore additionally control for the country's cognitive-skill level of all adults and all parents to account for countries' potential subject preference or other subject-related differences.[44] Adding the cognitive-skill levels of these broad groups does not change the impact of teachers' cognitive skills on student performance (Columns 1 and 2 for math and Columns 5 and 6 reading).

Another way to proxy for the subject-specific preferences of a country is to consider the difference between numeracy and literacy of the adult population. If the country has a strong preference for math, then it should have students with high math performance and adults whose numeracy skills are high relative to their literacy skills (vice versa for reading). However, controlling for the cognitive-skill differences of parents or adults does not affect the impact of teacher skills (Columns 3 and 4 for math and Columns 7 and 8 for reading). Interestingly, these controls are statistically insignificant, and even have counterintuitive positive signs in reading.

5.5 A Simple Placebo Test

Our estimates emphasize the relationship between teacher cognitive skills and student performance, which in turn reflects the allocation of overall country talent to teaching. But, is it the skills of the teachers themselves that is affecting student performance? If the estimates do not reflect the impact of teachers per se but instead just reflect the overall skills of the society, it would be the case that relating the cognitive-skill levels of workers in occupations other than teaching could also equally explain the pattern of student achievement. To investigate this possibility, we consider a simple placebo test where we replace teacher cognitive skills with the cognitive skills of

[44] The country-specific adult skills are measured by the median skill level of all adults aged 25–65. The country-level parent cognitive skills are measured by the median skills of all PIAAC respondents aged 35–59 with children (i.e., the same PIAAC respondents used to construct the individual-level parent skills).

workers in 14 different occupational groups that cover the full range of a country's occupational distribution (e.g., managers, scientists and engineers, health professionals, business professionals, clerks, sales workers, service workers). Of course, since all adults went through the same education system and reflect to some extent the overall skill level of the country, the cognitive skills of workers in these occupations should be positively correlated with the cognitive skills of teachers. Thus, it is hardly surprising that student performance is positively related to the cognitive-skill levels in some of these occupations (Panel A in Tables 7 and 8). Yet, especially for literacy skills, this is true only for remarkably few occupations.

Most importantly, controlling for the cognitive-skill levels of workers in other occupations does not change the estimated impact of teacher cognitive skills (see Panel B in Tables 7 and 8). In contrast, the cognitive-skill levels of only few occupations are still significantly positively related to student performance when teacher skills are included; in fact, this is true for just 3 out of 14 occupations in numeracy and not a single occupation in literacy. The impact of teacher cognitive skills remains highly significant even after controling for the cognitive-skill levels of *all* other occupations simultaneously (not shown). In this specification, almost none of the cognitive-skill levels of other occupations are significantly related to student performance (except numeracy skills of craft workers and literacy skills of elementary workers). Thus, it is the allocation of skills to teaching and not a country's overall skill level that appears to matter for student performance.[45]

6. Determinants of Teacher Cognitive Skills

International differences in teacher cognitive skills reflect both where teachers are drawn from each country's skill distribution and the overall skill level of each country's population – and policies to improve the skills of teachers could conceptually focus on either of these dimensions. Increasing the overall achievement of a country's population would of course be both desirable and

[45] Alternatively, we have estimated the placebo tests in the within-student model by adding the numeracy-literacy differences in other occupations to the model in Equation (2). In this specification, identification is based only on within-student variation in the cognitive skills of teachers conditional on the within-student variation in other occupations. Even in these demanding models, the teacher-skill impacts are similar to the baseline fixed effects estimate.

self-reinforcing through improving the pool of potential teachers. Nonetheless, potential overall improvement policies, while widely discussed elsewhere, are beyond the scope of this analysis.

We instead focus on the determinants of where teachers are drawn from the overall skill distribution of the population, which as noted above has received relatively little and narrow attention. Our international data permit a much broader investigation of how external forces and policy choices affect the skills of the teaching force.

One general strand of research, largely focused on entry and exit from teaching, investigates the importance of alternative job opportunities for teacher quality.[46] Although these studies look just within the U.S., they suggest feasible approaches to international comparisons. Nagler, Piopiunik, and West (2015) exploit business cycle conditions at career start as a source of exogenous variation in the outside options of potential teachers, finding that teachers entering the profession during recessions are significantly more effective in raising student test scores than teachers who entered the profession during non-recessionary periods.

We are, however, interested in more structural issues of teacher labor markets. We focus on females because teaching remains a female-dominated profession across our sample of countries. On average, 69 percent of teachers in the 23 countries for this analysis are female, ranging from 59 percent in Japan to 79 percent in Austria. We explore international experience in how improvements in alternative job opportunities for women over time and differences in relative teacher pay have altered the skill levels of teachers.

6.1 Alternative Professional Opportunities for Women

Changes in the cognitive skills of teachers have been studied in the U.S., where there is general agreement of a decline over time in measured achievement and in other quality indicators (Murnane

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[46] Early estimation of outside opportunities on teacher transitions is found in Dolton and van der Klaauw (1999), although the key issues were suggested long before in Kershaw and McKean (1962). An early investigation of how preparation for and entry into teaching are related to cognitive skills is found in Hanushek and Pace (1995).

et al. (1991), Corcoran, Evans, and Schwab (2004a, (2004b), Bacolod (2007)).[47] A common hypothesis is that this decline in teacher cognitive skills in the U.S. during the past decades was the result of improving alternative labor-market opportunities for women, who constitute the majority in the teacher workforce. As more women have access to high-skill, high-wage occupations, fewer high-skilled women choose to become teachers, thus leading to declining average teacher skills.[48] Testing this hypothesis has been difficult, however, because the underlying data on teachers have come from piecing together a limited number of snapshots of skill differences from U.S. surveys conducted at different points in time. The limited observations plus incomplete measures of skill demands or rewards in alternative occupations present serious challenges to any analysis.[49]

Using different indicators of teacher quality, such as standardized test scores, Bacolod (2007) documents a clear decline in the quality of young women entering the teaching profession between 1960 and 1990 that is related to falling relative teacher wages. While we also relate within-country changes in labor-market choices of females to changes in teacher cognitive skills across birth cohorts, our analysis differs from Bacolod (2007) in two key ways. First, we explicitly consider the human capital intensity of alternative employment opportunities (instead of simply relying on relative average wages in teaching and elsewhere). Second, we observe multiple countries, which not only dramatically expands the range of observations but also allows us to account for any general (i.e., non-country-specific) time trends that affect both the nature of female labor-market participation and teacher skills. For example, the teaching profession might have become less attractive relative to other high-skilled occupations over time, explaining both an increasing share of

[47] There is a longer investigation of the teaching profession, largely from a sociological perspective, that focuses on the well-being of teachers in terms of their relative status and earnings, as opposed to any aspect of teacher quality or teacher effectiveness. See, for example, Bergmann (1974), Reskin (1984), and Tienda, Smith, and Ortiz (1987). Such analyses have also had an international comparative component as in Charles (1992), Blackburn, Jarman, and Brooks (2000), and Kelleher (2011), but again lacking any attention to the impact on students.

[48] As Bacolod (2007) points out, the opening of alternative high-wage jobs does not necessarily imply declining teacher quality; in a Roy model, it would depend on comparative advantage in different occupations and the correlation of a worker's skills in different occupations.

[49] Bacolod (2007) expands on the data by using observations for the separate U.S. states.

females in other high-skilled occupations and a decline in average teacher skills.

As a direct indicator of women's access to high-skilled occupations in a country's labor market, we compute the proportion of female teachers relative to females in high-skilled occupations, separately for each country-cohort cell. We use the PIAAC micro data to classify occupations as "high-skilled" by identifying country-specific occupations that employ the most educated workers. For two-digit occupations in each country, we calculate the average years of schooling of employees currently working in each occupation at the time of the PIAAC assessment (i.e., in 2011/2012 for Round 1 and 2014/2015 for Round 2).[50] Second, ranking occupations in each country by average schooling level and starting with the occupation with the highest level, we define all occupations as "high-skilled" until males working in these occupations comprise 25 percent of all working males in the country.[51] The 25-percent rule ensures that a similar share of workers is employed in high-skilled occupations in each country; other variants of defining high-skilled occupations led to very uneven shares of males working in high-skilled occupations across countries. To obtain cohorts with sufficient numbers of teachers, we merge 15 adjacent age cohorts. As the PIAAC data cover 45 birth years (excluding very young workers who mainly have not completed their university degree), we obtain three age cohorts per country.

Consistent with the notion that teacher skills are directly affected by competition from other occupations that demand high skills, we expect that higher concentrations of females in teaching lead to higher cognitive skills of teachers. The test of this exploits changes in the share of female teachers relative to women in all high-skilled occupations over three age cohorts in 23 countries.[52]

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[50] There are no internationally comparable data that would allow computing these country-by-cohort-specific shares on the basis of historical labor-market records.

[51] Note that teaching is a high-skilled occupation in every country in our sample. Applying an alternative categorization that classifies all occupations contained in the one-digit ISCO codes 1 (Managers) and 2 (Professionals) as high-skilled leads to qualitatively similar results.

[52] For this analysis, we exclude all ex-communist countries and Turkey since occupational choices in these countries were less driven by market incentives but rather depended on political attitudes. While our results indicate that females' labor-market opportunities affect the level of teacher cognitive skills, the analysis uses only pseudo cohorts based on the cross-sectional PIAAC data. Thus, the validity of our results depends on the assumption that women do not change the type

Our estimation always includes cohort fixed effects to control for general time trends in women's labor-market opportunities and for skill depreciation across cohorts. Moreover, country fixed effects account for cross-country differences in women's labor-market participation and in average skill levels that are constant across birth cohorts.

Table 9 reports the results of estimating the effect of alternative job opportunities on the skill level of teachers.[53] For both numeracy and literacy, we find that a higher share of high-skilled female workers in teaching is positively and statistically significantly related to teacher cognitive skills. The coefficients barely change when we add the average skill level of university graduates in the respective country-cohort cell to account for country-specific skill depreciation.[54]

The estimates are also economically meaningful. An increase in the share of high-skilled female workers in teaching by 10 percentage points leads to a 0.36 SD increase in the numeracy skills of teachers. (The results are slightly weaker for literacy.) The share of high-skilled female workers in teaching varies between 17 percent in Chile (18 percent in the U.S.) and 38 percent in Singapore (across all three cohorts). Thus, if females in the U.S. had similar employment opportunities as in Singapore, average teacher numeracy skills in the U.S. would increase by about 0.72 SD, bringing U.S. teachers to just above the international average in teacher numeracy skills. Across all 23 countries in the sample, the share of high-skilled female workers in teaching decreases from 29 percent in the oldest age cohort (born 1946–1960) to 22 percent in the youngest cohort (born 1976–1990), reflecting an international improvement of alternative job opportunities for women across cohorts. This is associated with a decline of 0.25 SD in teacher numeracy skills.[55]

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of their occupation (high-skilled vs. low-skilled; teacher vs. nonteacher) in a systematic way over their careers. Furthermore, our approach assumes that the country-specific pattern of skill depreciation across cohorts is similar for teachers and university graduates.

[53] Results are qualitatively similar when we use the skill level of female teachers as dependent variable.

[54] Several studies suggest that losses of skills over the life cycle occur, underlining the importance of controlling for skill depreciation (e.g., Cascio, Clark, and Gordon (2008); Edin and Gustavsson (2008)).

[55] Note that skill depreciation over the lifecycle is accounted for by including both cohort fixed effects and the cohort-specific skill level of nonteacher college graduates.

6.2 Teacher Pay

An obvious consideration in looking at the pattern of teacher skills is the pay of teachers. The argument that teacher pay is significantly related to teacher quality has been in the heart of much of the debate about educational policy for many years (see, e.g., Dolton and Marcenaro-Gutierrez (2011)). The idea is that countries that pay teachers relatively better are able to recruit teachers from higher up in the skill distribution and also are able to retain teachers in their profession.[56] If this link is present, there would be leverage for policymakers to raise the skills of teachers in the country by paying them higher wages, with commensurate positive effects on student performance.[57]

To investigate the salary-skills relationship across countries, we first estimate whether *ceteris paribus* teachers are paid a premium in the labor market. Using the individual-level PIAAC data, we estimate a Mincer-like earnings equation with log earnings ($\ln y$) regressed on gender (G), potential experience (E), achievement in numeracy and literacy (A), and a teacher indicator (T).[58]

$$\ln y = a_0 + a_1 G + a_2 E + a_3 E^2 + \boldsymbol{A a}_4 + \delta T + \varepsilon \qquad (2)$$

The coefficient δ is the premium for teachers given their characteristics. We estimate a separate premium for each country, and we find a wide dispersion. Figure 4 shows the estimated

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[56] Raising pay might also provide already-recruited teachers with more incentives to exert higher effort to improve the educational outcomes of the children they teach. The evidence on effort is, however, not very encouraging; see Springer et al. (2010). While much of the policy discussion of performance pay does not distinguish between the effort margin and the selection-retention margin, it is the latter that seems more important. The international studies effectively look at selection and retention, while within-country analyses almost always look at effort; see Woessmann (2011). For developing countries, the evidence on effort is stronger (see Muralidharan and Sundararaman (2011)), but this might not generalize to the developed countries we analyze. Among other things, the very high rates of teacher absenteeism in many developing countries indicates more room for improvement on the effort margin.

[57] Another channel through which a positive association between teacher pay and teacher skills may materialize (at least in the long run) is that higher salaries for teachers may improve the status of the teaching profession. As a result, more children might want to become teachers in the future, facilitating the recruitment of more able individuals.

[58] This approach follows Hanushek et al. (2015, (2017) in estimating an earnings function without years of schooling, which is one of several inputs into cognitive skills. We use the sample of all university graduates surveyed in PIAAC in each country, which are the relevant comparison group for teachers (88 percent of teachers have obtained a college degree). However, results are qualitatively similar when we add years of schooling as an additional control or estimate the Mincer earnings function on the whole population.

teacher premiums across countries, ranging from +45 percent in Ireland to -22 percent in the United States and Sweden.[59] (Table A-10 presents the detailed regression output for each country). While there have been many discussions of the relative pay of teachers in the United States (see Hanushek (2016)), most have ignored the possibility that teachers are systematically different from college graduates working in other occupations (e.g., in terms of cognitive skills and gender composition). The estimates here indicate that teachers are paid some 20 percent less than comparable college graduates elsewhere in the U.S. economy after adjusting for observable characteristics.

Table 10 puts teacher pay and teacher skills together by regressing cognitive skills of teachers on teacher wage premiums (δ). Estimates are conditioned on the cognitive skills of nonteacher college graduates to account for overall country skill levels and to allow us to assess how pay relates to the position of teachers in the distribution of the country's skills.[60]

The results, shown graphically in Figure 5, indicate that higher relative teacher pay is systematically related to higher teacher skills. The clear conclusion is that countries that pay teachers more for their skills also draw their teachers from higher parts of the skill distribution. In terms of magnitude, a 10 percentage points higher teacher wage premium is associated with an increase in teacher skills of about 0.10 SD.[61] The coefficient on college graduates' skills is close to 1, again suggesting the powerful influence of a country's overall skill level.

These results are also consistent with previous work in the U.S. on pay-skill relationships. Corcoran, Evans, and Schwab (2004b) argue that, while average cognitive skills of teachers have

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[59] It is remarkable that teacher wage premiums are similarly low in the United States and Sweden, since both countries are at opposite extremes of wage inequality (see Table 1 in Hanushek et al. (2015)). In the United States, the ratio of 90 to 10 percentile wages is 4.5 times compared to 2 in Sweden.

[60] An alternative approach is to run country-level regressions of teacher skills on relative teacher wages, measured as the percentile rank of country-specific mean teacher wages in the wage distribution of all nonteacher college graduates. This approach yields similar salary-teacher skill results, but it does not allow for any differences in the distribution of earnings characteristics between teachers and nonteachers.

[61] These estimates are likely downward biased because the teacher wage premiums are estimated coefficients and therefore contain error. Assuming that the errors are heteroscedastic (as they come from separate regressions), the true coefficients are slightly larger by 5 percent.

not changed much, there has been a sharper decline in the top deciles of skills. Bacolod (2007) finds larger declines in teacher cognitive skills. Both see the importance of teacher salaries and alternative opportunities for women in the labor market.

The interpretation of these results is, however, important for policy. These estimates are reduced-form estimates that reflect the labor-market equilibrium. They do not, however, indicate what the supply function for higher quality teachers looks like. In other words, they are not causal estimates of how the quality of teachers would change if teacher salaries were raised.[62] Moreover, the estimated relationship relates to the long run after many cohorts of teachers have been recruited. In other words, while making it clear that a more skilled teaching force will require higher salaries, the evidence says nothing about either how salaries should be structured or the responsiveness of teachers to higher salary offers.[63]

7. Conclusions

Cross-country comparisons of student achievement potentially provide unique information about the educational process and about the impact of alternative policies. In particular, all countries have distinctive institutional features that bound and facilitate the operations of their schools and that influence how specific policies will affect student outcomes. But because the

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[62] These issues have been part of the policy discussion in the U.S., where questions have arisen about how to attract more effective teachers as measured by teacher value-added. Higher teacher salaries would undoubtedly expand the pool of potential teachers and would also help to cut down on teacher turnover. This evidence does not, however, indicate that more effective teachers will be hired out of the enlarged pool; nor does it indicate that the teachers who are induced to stay in teaching are the more effective teachers. The same holds for changing the cognitive skills of the teaching force.

[63] In a separate analysis, we have investigated whether relative public-sector wages (i.e., mean public-sector wages over mean private-sector wages) affects an individual's decision to enter the teaching profession. Using annual OECD data on public-sector and private-sector wages for multiple countries, we aggregated the data to the same three birth cohorts as in Section 6.1. Controlling for country and birth-cohort fixed effects, we fail to find a robust relationship between teacher cognitive skills and the relative public-sector wages in the years before college graduation. There are several potential reasons for this result. Most importantly, we do not observe teacher wages, but rather rely on coarse measures of average public and private wages. Furthermore, it is unclear at which point in their educational career individuals decide to become teachers. We also made a preliminary investigation of considering economic conditions at the beginning of careers on teacher skills (following Nagler, Piopiunik, and West (2015)), but the small samples when finely disaggregated by age could not support this estimation.

institutions are constant across the country's schools, they are themselves impossible to analyze with within-country data. The international student achievement data currently available open up the possibility of delving into the role of such international institutions, but such analysis comes with a trade-off. It is frequently difficult to observe exogenous variation in major institutions that would allow clear identification of the impact of international institutions that are embedded within the cultures, governments, and historical development of countries. An alternative, pursued here, is to eliminate major threats to identification of causal impacts, while admitting to the possibility that other remaining factors may potentially confound the estimates.

We focus on what can be learned about the impact of teachers on international differences in student achievement. Within-country evidence has highlighted the importance of teacher quality for student achievement with the most convincing evidence coming from value-added analysis. Such analysis provides information about the relative learning gains across a set of teachers, but it does not indicate what might be possible if there were a different pool of potential teachers from which the teacher corps could be drawn. Moreover, it has previously not been possible to describe reliably any aspects of teachers that could be used to index quality differences across countries.

Based on suggestive prior evidence on the role of cognitive skills of teachers, we systematically address how cross-country differences in teacher skills enter into educational production. We use newly available data from the Programme for the International Assessment of Adult Competencies (PIAAC) to provide the first description of the skills of teachers in numeracy and literacy in 31 developed economies. These teacher cognitive skills differ substantially across countries, reflecting both country-wide differences in cognitive skills and policy choices about where teachers are drawn from the country's skill distribution. We then combine the country-level measures of teacher cognitive skills with micro data on student performance from PISA to estimate international education production functions with rich controls for student, school, and country background factors, including coarse measures of the cognitive skills of the parents of PISA students and a variety of institutional features of the schools in each country. In addition to OLS models, we estimate the impact of teacher cognitive skills using student fixed-effects models, which exploit between-subject variation and account for constant individual factors (e.g., ability and parental influences) along with non-subject-specific country-level factors.

With both approaches, we consistently find that differences in teacher cognitive skills across countries are strongly associated with international differences in student performance. In terms of magnitude, a one SD increase in teacher cognitive skills is associated with an increase in student performance of about 0.15 SD in math and 0.09 SD in reading. Since PISA scores represent the cumulative learning of 15-year-olds, this suggests an average learning gain of about 0.01-0.015 SD per year. Alternative specifications that control for the cognitive skills of all adults in a country or of workers in occupations other than teaching indicate that the teacher-skill effects are not simply reflecting overall differences in skills among countries but instead are directly related to where teachers are drawn from in the country's skill distribution.

The magnitude of the estimated relationship is important. These results suggest that the dispersion in average PISA scores across our 31 country sample would be reduced by roughly one-quarter if each country brought its average teacher skills up to the average in Finland, the country with the highest measured skills of teachers.

We then consider possible determinants of teacher cognitive skills. Exploiting within-country changes in the share of women working in high-skilled occupations outside teaching, we find that a larger share of women in high-skilled jobs other than teaching is significantly related to a lower cognitive-skill level of teachers. Differences in women's access to high-skilled occupations represent one determinant of the observed international differences in teacher cognitive skills and of the time pattern of changing teacher skills. We also show that wage premiums paid to teachers (given their gender, work experience, and cognitive skills) are directly related to teacher cognitive skills in a country.

Again, while causal identification is clearly difficult in this cross-country analysis, the consistency of our estimated teacher-skill effects across different model specifications and different country subsamples suggests a causal interpretation. And even if there is some additional but unmeasured influence on student outcomes, it is unlikely that it would eliminate or reverse the estimated effect of teacher skills.

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Appendix A. Validation of PIAAC Cognitive Skills Data with External Sources

The PIAAC data on teacher cognitive skills raise two potential concerns. First, the teacher skill measures are derived from relatively small samples.Second, they rely on a new battery of achievement tests. In order to validate these measures, we compare them with estimates from larger national surveys in the United States and Germany.

We first look at the U.S. National Longitudinal Survey of Youth (NLSY79 and NLSY97). The NLSY79 is a nationally representative sample of 6,111 young men and women who were born between 1957 and 1964. The NLSY97 is a nationally representative sample of 6,748 individuals born between 1980 and 1984. (Note that these age cohorts partly overlap with the age range of the PIAAC participants.) We measure NLSY79 respondents' occupation (using four-digit Census codes) in 2010 (last available year) and NLSY97 respondents' occupation in 2011 to make this sample as comparable as possible to the PIAAC survey in 2011.[64]

We take the mathematics and language skills tested in the four AFQT subtests which are part of the Armed Services Vocational Aptitude Battery (ASVAB). The ASVAB was administered to 94 percent of NLSY79 respondents in 1980 and to 81 percent of NLYS97 respondents in 1997. We combine the scores from the mathematical knowledge and arithmetic reasoning tests into a numeracy skills measure and the scores from the word knowledge and paragraph comprehension tests into a literacy skills measure.[65] Based on these measures, teacher skills fall at the 67th (64th) percentile in the adult skill distribution in numeracy (literacy). This is quite close to the position of teacher skills in the PIAAC data for the USA (see Table 1): 70th (71st) percentile in numeracy

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[64] Teachers are defined as in PIAAC (i.e., excluding pre-kindergarten teachers and university professors/vocational education teachers). We weight individual-level observations with the cross-sectional weights taken from the year in which the occupation is measured, giving each NLSY survey the same total weight.

[65] As respondents were born in different years, we take out age effects by regressing test scores on year of birth dummies first (separately for NLSY79 and NYS97). We control for age effects in the NLSY data because participants were still children or adolescents at the time of testing. In contrast, we do not take out age effects in the PIAAC data because most PIAAC participants have already completed their education when tested.

(literacy).

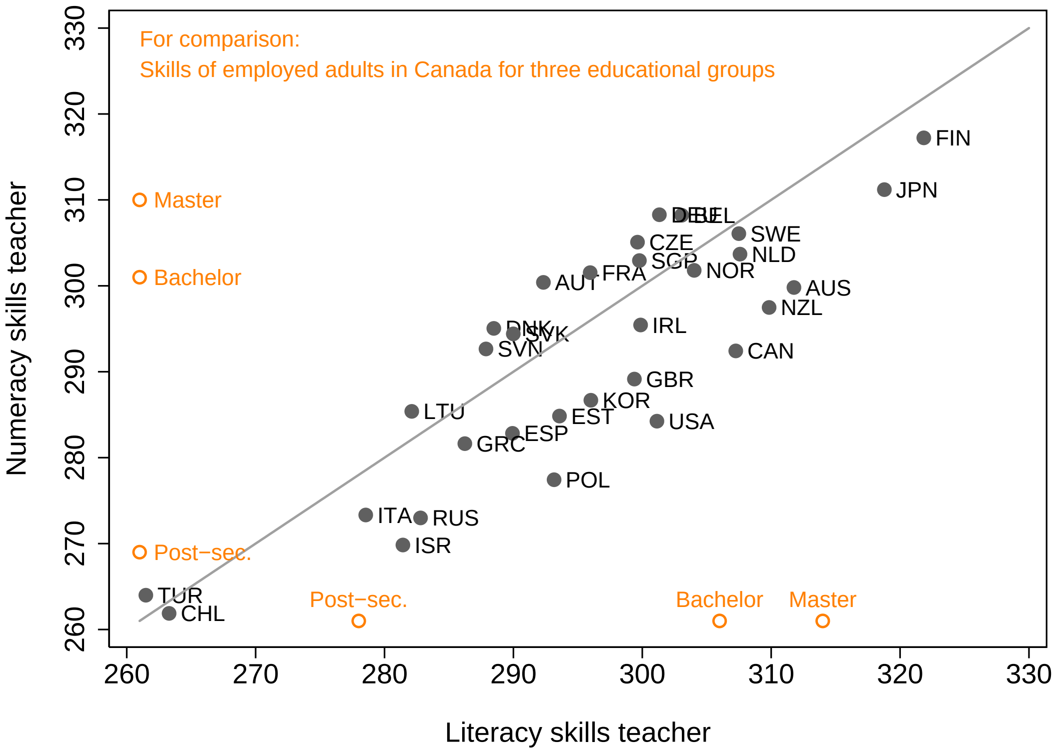
We also compare teacher cognitive skills from PIAAC with those from Germany's adult cohort of the National Educational Panel Study (NEPS).[66] This dataset is a nationally representative dataset of 9,352 adults born between 1944 and 1986. NEPS has several advantages for our purpose. First, similar to PIAAC, the competency tests in NEPS aim at measuring numeracy and literacy skills in real-life situations which are relevant for labor market success and participation in society. Second, NEPS tested skills at about the same time (in 2010/2011) as PIAAC did. Third, almost the same age cohorts were tested in NEPS and PIAAC. Similar to PIAAC, we keep all adults aged 25–65 and identify teachers based on the four-digit ISCO-88 occupation codes, where occupation is measured in 2010/2011. Teacher skills in NEPS fall at the 68th (76th) percentile among the adult skill distribution in numeracy (literacy). Again, this is similar to the respective positions of teachers in the PIAAC sample for Germany: 72th (74th) percentile in numeracy (literacy).

The similarity of teacher cognitive skills in the adult skill distribution found in PIAAC and in these nationally representative datasets with larger sample sizes supports using the PIAAC scores as measures of the teacher cognitive skills in each country.

[66] This paper uses data from the National Educational Panel Study (NEPS): Starting Cohort 6 – Adults, doi:10.5157/NEPS:SC6:3.0.1. From 2008 to 2013, NEPS data were collected as part of the Framework Programme for the Promotion of Empirical Educational Research funded by the German Federal Ministry of Education and Research (BMBF). As of 2014, the NEPS survey is carried out by the Leibniz Institute for Educational Trajectories (LIfBi) at the University of Bamberg in cooperation with a nationwide network. See Blossfeld, Roßbach, and Maurice (2011).

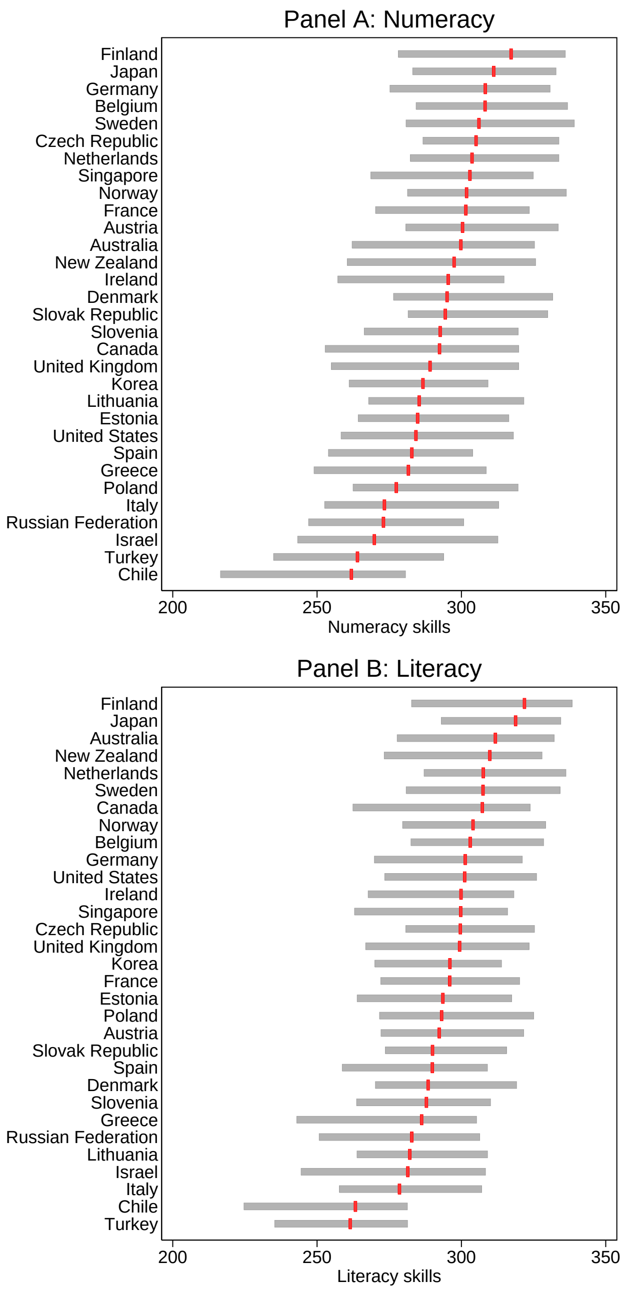
Figures and Tables

Figure 1: Teacher Cognitive Skills
Compared to Canadian Workers with Varying Education Levels



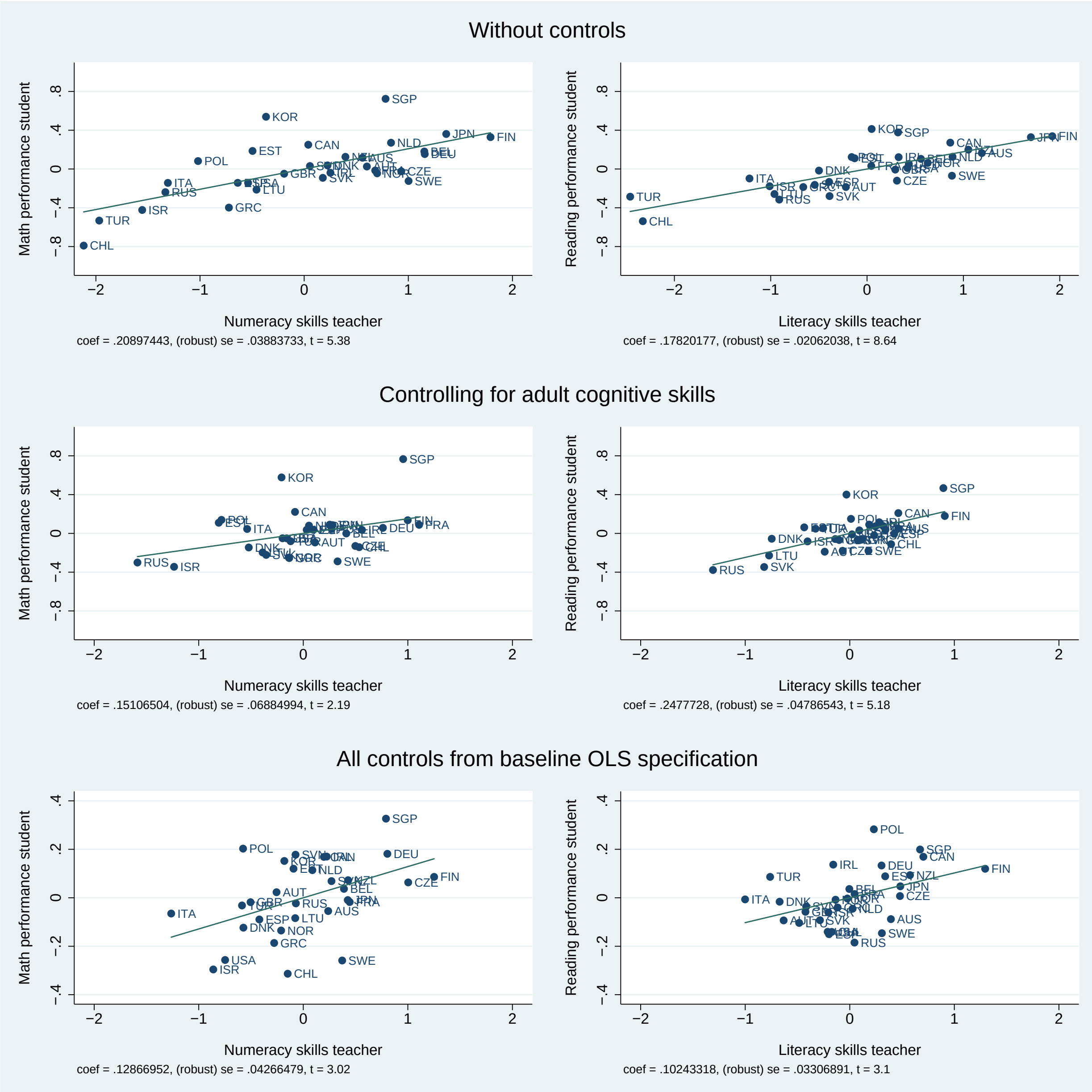
Note: The blue dots indicate country-specific teacher skills in numeracy and literacy (see text for construction of teacher cognitive skills). The orange circles indicate the median cognitive skills for three educational groups of employed adults aged 25–65 years in Canada (the largest national sample in PIAAC). *Post-sec.* includes individuals with vocational education (post-secondary, non-tertiary) as highest degree (2,434 observations); *Bachelor* includes individuals with bachelor degree (3,671 observations); *Master* includes individuals with a master or doctoral degree (1,052 observations). *Data sources*: PIAAC 2011/12 and 2014/15.

Figure 2: Position of Teacher Cognitive Skills in the Skill Distribution of College Graduates



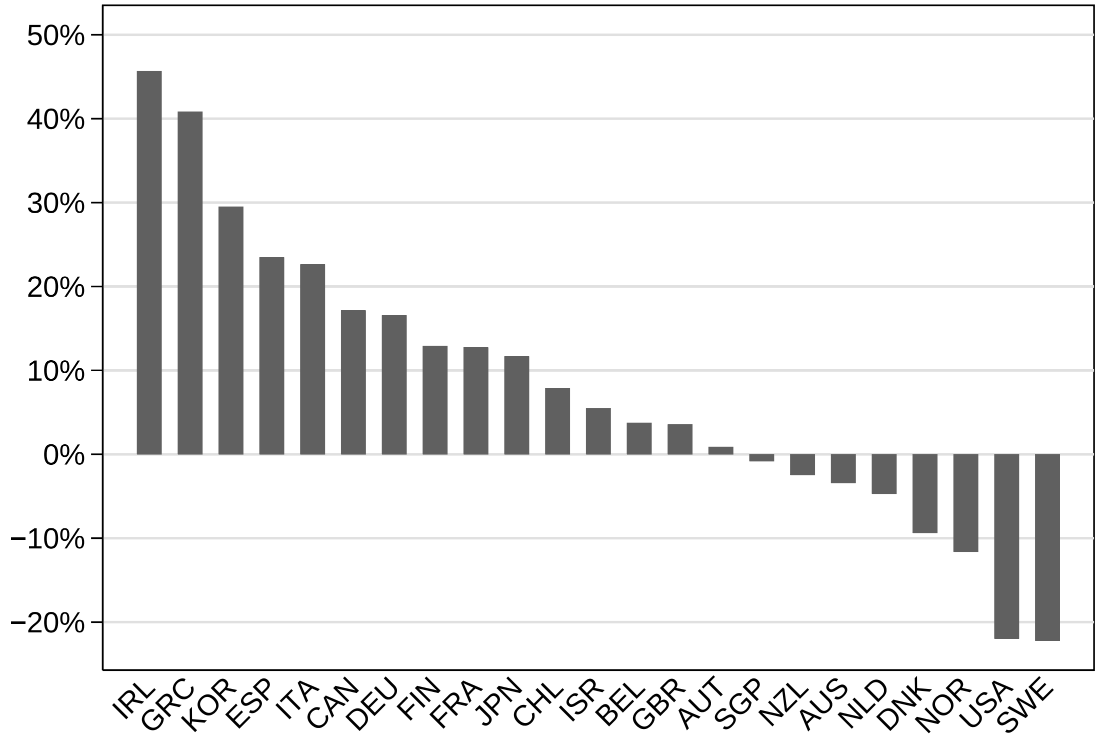
Note: Modified figure from Schleicher (2013). Vertical bars indicate median cognitive skills of teachers in a country. Horizontal bars show the interval of cognitive skill levels of all college graduates (including teachers) between the 25th and 75th percentile. Countries are ranked by the median teacher skills in numeracy and literacy, respectively. *Data sources*: PIAAC 2011/12 and 2014/15.

Figure 3: Student Performance and Teacher Cognitive Skills



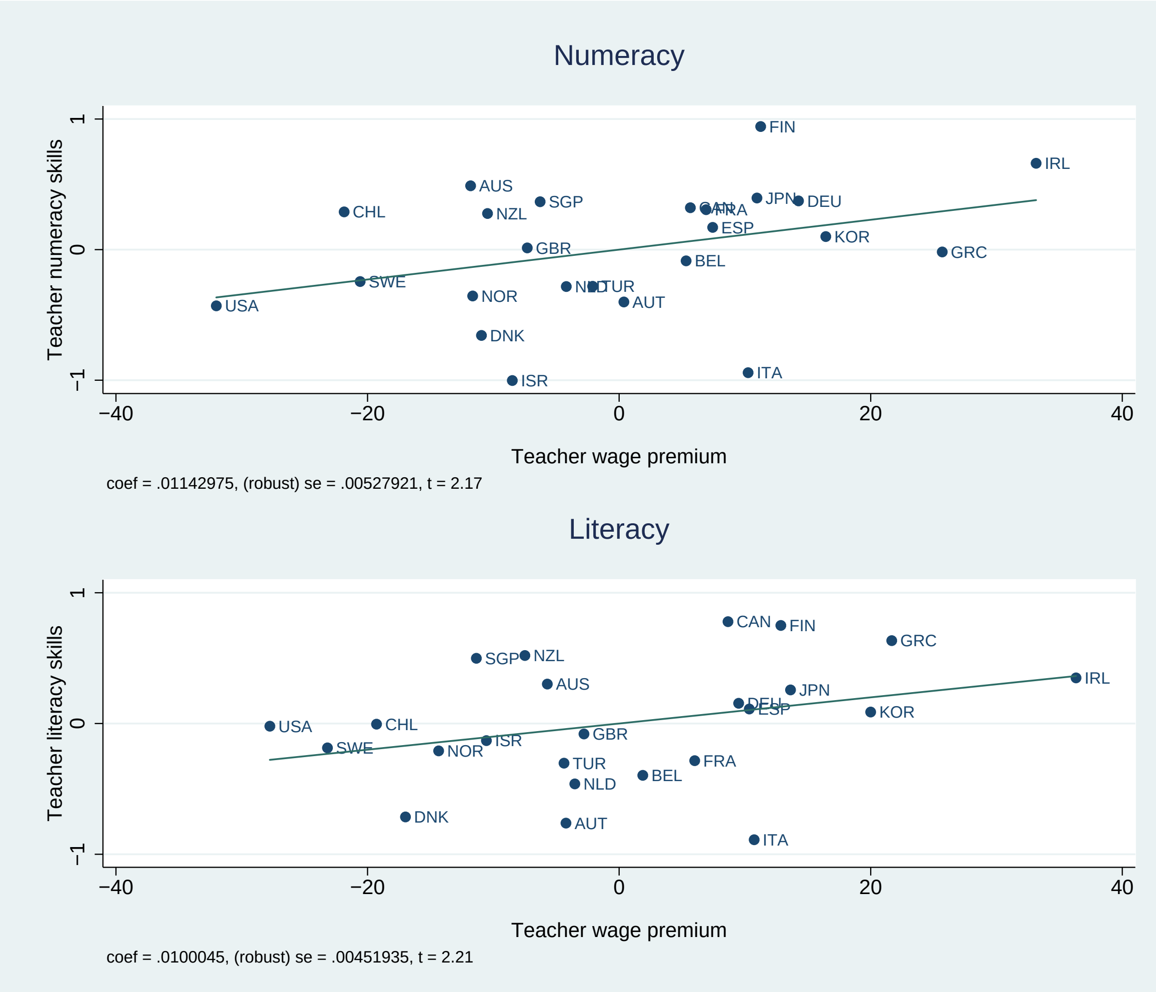
Note: The two graphs in the top panel do not include any controls. The two graphs in the middle panel are added-variable plots that control for country-specific average skills in numeracy and literacy, respectively, of all adults aged 25–65. The two plots in the bottom panel are added-variable plots that control for all variables included in the baseline OLS specification in Columns 3 and 6 of Table 2. *Data sources*: OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Figure 4: Teacher Wage Premiums around the World



Notes: Bars indicate the percentage difference in gross hourly earnings of teachers with a college degree relative to all nonteacher college graduates in a country. Estimates condition on gender, a quadratic polynomial in potential work experience (age − years of schooling − 6), and numeracy and literacy skills. Post-communist countries and Turkey are excluded (explanations see text). *Data sources:* PIAAC 2011/12 and 2014/15.

Figure 5: Teacher Wage Premiums and Teacher Cognitive Skills



Notes: Graphs show added-variable plots that control for country-specific numeracy skills (upper panel) and literacy skills (lower panel) of all college graduates (without teachers). Teacher wage premiums are the percentage difference in gross hourly earnings of teachers with a college degree relative to all nonteacher college graduates in a country, conditional on gender, quadratic polynomial in potential work experience, and numeracy and literacy skills (see also Figure 4 and Table A-10). Post-communist countries and Turkey are excluded (explanations see text). See Table 10 for regression output. *Data sources:* PIAAC 2011/12 and 2014/15.

Table 1: Teacher Cognitive Skills by Country

	Pooled	Australia	Austria	Belgium	Canada	Chile	Czech R.	Denmark	Estonia	Finland	France
Numeracy	292	300	300	308	292	262	305	295	285	317	302
Literacy	295	312	292	303	307	263	300	288	294	322	296
Domain difference	-3	-12	8	5	-15	-1	5	7	-9	-5	6
Numeracy percentile	68	71	69	68	67	81	73	56	60	73	80
Literacy percentile	71	75	70	71	72	79	77	60	69	74	77
Observations	6,402	248	188	215	834	106	141	413	188	221	163

	Germany	Greece	Ireland	Israel	Italy	Japan	Korea	Lithuania	Netherl.	New Zealand	Norway
Numeracy	308	282	295	270	273	311	287	285	304	297	302
Literacy	301	286	300	281	279	319	296	282	308	310	304
Domain difference	7	-5	-4	-12	-5	-8	-9	3	-4	-12	-2
Numeracy percentile	72	74	75	57	67	70	72	66	63	64	65
Literacy percentile	74	75	74	62	73	67	74	64	67	71	68
Observations	127	150	180	250	124	147	217	133	197	198	279

	Poland	Russia	Singapore	Slovak R.	Slovenia	Spain	Sweden	Turkey	U.K.	U.S.
Numeracy	277	273	303	294	293	283	306	264	289	284
Literacy	293	283	300	290	288	290	307	261	299	301
Domain difference	-16	-10	3	4	5	-7	-1	3	-10	-17
Numeracy percentile	64	53	72	66	70	75	62	80	65	70
Literacy percentile	73	54	76	60	69	80	65	78	67	71
Observations	199	137	193	133	121	183	147	128	310	132

Notes: Teacher cognitive skills are country-specific median cognitive skills of primary school teachers, secondary school teachers, and "other" teachers (including, e.g., special education teachers and language teachers). Because occupation in Australia and Finland is reported only at the two-digit level, teachers in these countries include all "teaching professionals" (ISCO-08 code 23), i.e., additionally include pre-kindergarten teachers and university professors. All skill measures are rounded to the nearest integer. Percentile refers to the position of median cognitive skills of teachers in the cognitive skill distribution of all adults aged 25–65 excluding teachers. Individuals are weighted with PIAAC final sample weights. Observations refer to the number of teachers used to construct country-specific teacher skills. *Data sources:* PIAAC 2011/12 and 2014/15.

Table 2: Student Performance and Teacher Cognitive Skills (OLS)

	Student Math Performance			Student Reading Performance		
	(1)	(2)	(3)	(4)	(5)	(6)
Teacher cognitive skills	0.209***	0.173***	0.145***	0.178***	0.102***	0.092***
	(0.038)	(0.031)	(0.032)	(0.020)	(0.020)	(0.022)
Parent cognitive skills			0.044**			0.015
			(0.017)			(0.016)
Student characteristics		X	X		X	X
Parent characteristics		X	X		X	X
School characteristics		X	X		X	X
Country characteristics		X	X		X	X
Students	490,818	490,818	490,818	490,818	490,818	490,818
Countries	31	31	31	31	31	31
Adj. R2	0.04	0.29	0.29	0.03	0.30	0.30

Notes: Least squares regressions weighted by students' inverse sampling probability, giving each country the same weight. Dependent variable: student PISA test score in math (Columns 1–3) and in reading (Columns 4–6), respectively. Student test scores are z-standardized at the individual level across countries. Country-level teacher cognitive skills refer to numeracy in Columns 1–3 and to literacy in Columns 4–6. Teacher skills are z-standardized across countries. Parent cognitive skills are computed as the maximum of mother's and father's skills in numeracy (Columns 1–3) or literacy (Columns 4–6). Parent cognitive skills are standardized using teacher cognitive skills as "numeraire" scale. Student characteristics are age, gender, migrant status (first-generation or second-generation), and language spoken at home. Parent characteristics include parents' educational degree, number of books at home, and occupation. School characteristics include school location, number of students per school, and three autonomy measures. Country characteristics are expenditures per student and school starting age (Table A-6 reports results for all control variables). All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table 3: Simulation Analysis: Raising Teacher Cognitive Skills to Finnish Level

	Teacher Numeracy Skills		Teacher Literacy Skills	
	Difference from Finnish teachers (in PIAAC points)	Student perf. increase (in % of internat. SD)	Difference from Finnish teachers (in PIAAC points)	Student perf. increase (in % of internat. SD)
	(1)	(2)	(3)	(4)
Australia	17	17.8	10	6.7
Austria	17	17.2	30	19.6
Belgium	9	9.2	19	12.5
Canada	25	25.3	15	9.7
Chile	55	56.6	59	38.9
Czech R.	12	12.4	22	14.8
Denmark	22	22.7	33	22.2
Estonia	32	33.1	28	18.8
France	16	16.0	26	17.2
Germany	9	9.1	21	13.6
Greece	36	36.4	36	23.7
Ireland	22	22.3	22	14.6
Israel	47	48.4	40	26.9
Italy	44	44.8	43	28.8
Japan	6	6.2	3	2.0
Korea	31	31.2	26	17.2
Lithuania	32	32.5	40	26.4
Netherlands	14	13.8	14	9.5
New Zealand	20	20.2	12	8.0
Norway	15	15.8	18	11.8
Poland	40	40.7	29	19.1
Russia	44	45.2	39	26.0
Singapore	14	14.6	22	14.7
Slovak R.	23	23.3	32	21.2
Slovenia	25	25.1	34	22.6
Spain	34	35.1	32	21.2
Sweden	11	11.4	14	9.5
Turkey	53	54.4	60	40.1
U.K.	28	28.7	22	14.9
U.S.	33	33.7	21	13.8

Notes: This table shows by how much student performance would increase if teacher skills in numeracy and literacy, respectively, were at the levels in Finland (i.e., the country with highest teacher skills in both numeracy and literacy). Estimations are based on Columns 3 and 6 of Table 2. Columns 1 and 3 show difference in teacher skills to Finland. *Data sources:* PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table 4: Student Performance and Teacher Cognitive Skills with Instructional Practices (OLS)

	Student Math Performance		Student Reading Performance	
	(1)	(2)	(3)	(4)
Teacher cognitive skills	0.145***	0.147***	0.092***	0.101***
	(0.032)	(0.032)	(0.022)	(0.023)
Parent cognitive skills	0.044**	0.045**	0.015	0.012
	(0.017)	(0.017)	(0.016)	(0.014)
Instructional practices		0.190		0.289
		(0.190)		(0.211)
Student characteristics	X	X	X	X
Parent characteristics	X	X	X	X
School characteristics	X	X	X	X
Country characteristics	X	X	X	X
Students	490,818	490,818	490,818	490,818
Countries	31	31	31	31
Adj. R2	0.29	0.29	0.30	0.30

Notes: Dependent variable: standardized student PISA test score in math (Columns 1–2) and reading (Columns 3–4), respectively. All cognitive skill measures in Columns 1–2 (3–4) refer to numeracy (literacy). Indicator for teacher instructional practices is based on the PISA data. See text for details on the construction of the instructional practices indicator. Control variables are the same as in the baseline least squares models (see Table 2). Specifications give equal weight to each country. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table 5: Student Performance and Teacher Cognitive Skills (Student Fixed Effects)

Dependent Variable: Student Performance Difference: Math – Reading			
	(1)	(2)	(3)
Teacher skills: numeracy – literacy	0.105***	0.117***	0.106**
	(0.037)	(0.035)	(0.049)
Parent skills: numeracy – literacy			0.016
			(0.035)
Instruction time: math – reading		0.058**	0.058**
		(0.026)	(0.026)
Shortage teachers: math – reading		–0.012	–0.012
		(0.012)	(0.012)
Students	490,818	490,818	490,818
Countries	31	31	31
Adj. R2	0.01	0.02	0.02

Notes: Dependent variable: difference in standardized student test scores between math and reading. All regressions include controls for respective imputation dummies and for the PISA wave. Specifications give equal weight to each country. Robust standard errors, adjusted for clustering at country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table 6: Impact of Country-Level Adult Cognitive Skills on Student Performance (OLS)

	Student Math Performance				Student Reading Performance			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Teacher cognitive skills	0.134***	0.117**	0.143***	0.143***	0.144***	0.148***	0.096***	0.101***
	(0.048)	(0.051)	(0.032)	(0.031)	(0.039)	(0.044)	(0.023)	(0.023)
Parent cognitive skills	0.039***	0.033**	0.042**	0.039**	0.038**	0.035**	0.015	0.014
	(0.012)	(0.012)	(0.018)	(0.018)	(0.015)	(0.015)	(0.016)	(0.016)
Parent cognitive skills (country level)	0.014				–0.061*			
	(0.035)				(0.035)			
Adult cognitive skills (country level)		0.036				–0.064		
		(0.040)				(0.041)		
Parent cognitive skills (country level): num – lit			0.042				0.039	
			(0.074)				(0.054)	
Adult cognitive skills (country level): num – lit				0.074				0.063
				(0.071)				(0.049)
Student characteristics	X	X	X	X	X	X	X	X
Parent characteristics	X	X	X	X	X	X	X	X
School characteristics	X	X	X	X	X	X	X	X
Country characteristics	X	X	X	X	X	X	X	X
Students	490,818	490,818	490,818	490,818	490,818	490,818	490,818	490,818
Countries	31	31	31	31	31	31	31	31
Adj. R2	0.29	0.29	0.29	0.29	0.30	0.30	0.30	0.30

Notes: Dependent variable: standardized student PISA test score in math (Columns 1–4) and reading (Columns 5–8), respectively. All cognitive skill measures in Columns 1–4 (5–8) refer to numeracy (literacy) unless noted otherwise. In Columns 1 and 5, we add the country-specific median cognitive skill level of PIAAC respondents aged 35–59 with children. In Columns 2 and 6, we add the median cognitive skill level of all PIAAC respondents aged 25–65. In Columns 3 and 7 (4 and 8), we add the difference between numeracy and literacy skills of parents (adults). Student, parent, school, and country characteristics are the same as in the baseline least squares models (see Table 2). All regressions include controls for imputation dummies and the PISA wave. Specifications give equal weight to each country. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table 7: Placebo Tests of Numeracy Skills in Other Occupations (OLS)

Dependent Variable: Student Math Performance														
Occupation:	Managers	S&E	Health	Busin. I	Busin. II	Legal	Clerk	Service	Sales	Care	Agric.	Craft	Operator	Elem.
	Panel A: Without Teacher Skills													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Skills in occupation	0.096***	0.004	0.053	0.112***	0.156***	0.070*	0.133***	0.048	0.068	0.121***	0.072*	0.047	0.046	–0.007
	(0.025)	(0.038)	(0.033)	(0.030)	(0.027)	(0.038)	(0.031)	(0.039)	(0.043)	(0.039)	(0.036)	(0.049)	(0.045)	(0.046)
Parent skills	0.060***	0.095***	0.078***	0.052***	0.029**	0.079***	0.039***	0.078***	0.070***	0.057***	0.078***	0.077***	0.079***	0.099***
	(0.017)	(0.018)	(0.013)	(0.017)	(0.011)	(0.020)	(0.012)	(0.017)	(0.014)	(0.018)	(0.017)	(0.014)	(0.014)	(0.014)
Adj. R2	0.28	0.28	0.28	0.29	0.29	0.28	0.29	0.28	0.28	0.29	0.28	0.28	0.28	0.28
	Panel B: With Teacher Skills													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Skills in occupation	–0.037	–0.105**	–0.009	0.024	0.093**	–0.009	0.074*	–0.018	0.005	0.075*	0.035	–0.006	–0.023	–0.018
	(0.062)	(0.049)	(0.038)	(0.042)	(0.044)	(0.039)	(0.043)	(0.046)	(0.048)	(0.039)	(0.044)	(0.044)	(0.040)	(0.037)
Parent skills	0.048***	0.063***	0.045***	0.041**	0.023**	0.044**	0.023**	0.048***	0.042***	0.033**	0.051***	0.045***	0.049***	0.049***
	(0.016)	(0.016)	(0.013)	(0.016)	(0.011)	(0.017)	(0.011)	(0.012)	(0.012)	(0.015)	(0.011)	(0.012)	(0.014)	(0.012)
Teacher skills	0.172**	0.199***	0.148***	0.126**	0.091**	0.149***	0.112**	0.152***	0.143***	0.107***	0.103**	0.147***	0.155***	0.147***
	(0.069)	(0.043)	(0.039)	(0.049)	(0.042)	(0.043)	(0.041)	(0.043)	(0.043)	(0.038)	(0.038)	(0.040)	(0.039)	(0.033)
Adj. R2	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.28	0.29	0.29	0.29
	Additional controls													
Student char.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Parent char.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
School char.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Country char.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Students	490,818	490,818	490,818	490,818	490,818	490,818	490,818	490,818	490,818	490,818	479,989	490,818	490,818	490,818
Countries	31	31	31	31	31	31	31	31	31	31	30	31	31	31

Notes: Dependent variable: student PISA test score in math. Occupations indicated in the column header: "Manager": administrative and commercial managers, production and specialised services managers, and hospitality, retail and other services managers; "S&E": science and engineering professionals and associate professionals; "Health": health professionals and associate professional; "Busin. I": business and administration professionals; "Busin. II": business and administration associate professionals; "Legal": legal, social and cultural professionals and associate professionals; "Clerk": general and keyboard clerks, customer services clerks,and numerical and material recording clerks; "Service": personal service workers; "Sales": sales workers; "Care": personal care workers; "Agric.": skilled agricultural, forestry and fishery workers (no agricultural workers in Singapore); "Craft": craft and related trades workers; "Operator": plant and machine operators, and assemblers; "Elem.": elementary occupations. Skills in occupation, parent skills, and teacher skills refer to numeracy. Skills in occupation and teacher skills are z-standardized across countries; skills in occupation and parent skills use teacher skills as "numeraire" scale. Control variables are the same as in the baseline least squares models (see Table 2). All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table 8: Placebo Tests of Literacy Skills in Other Occupations (OLS)

Dependent variable: Student Reading Performance														
Occupation:	Managers	S&E	Health	Busin. I	Busin. II	Legal	Clerk	Service	Sales	Care	Agric.	Craft	Operator	Elem.
							Panel A: Without Teacher Skills							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Skills in occupation	0.081***	0.034	0.013	0.025	0.082***	0.029	0.021	–0.003	–0.003	0.013	0.007	–0.020	–0.042	–0.024
	(0.026)	(0.025)	(0.033)	(0.030)	(0.025)	(0.029)	(0.028)	(0.029)	(0.032)	(0.027)	(0.028)	(0.029)	(0.028)	(0.028)
Parent skills	0.017	0.041***	0.051***	0.048**	0.015	0.049**	0.045***	0.059***	0.059***	0.050***	0.070***	0.069***	0.082***	0.072***
	(0.017)	(0.014)	(0.016)	(0.020)	(0.017)	(0.018)	(0.014)	(0.013)	(0.015)	(0.017)	(0.016)	(0.015)	(0.017)	(0.015)
Adj. R2	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
							Panel B: With Teacher Skills							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Skills in occupation	0.020	–0.042	–0.079*	–0.065	0.020	–0.040	–0.044	–0.070**	–0.066**	–0.051	–0.036	–0.065**	–0.092***	–0.057**
	(0.053)	(0.032)	(0.040)	(0.042)	(0.039)	(0.035)	(0.035)	(0.034)	(0.029)	(0.032)	(0.035)	(0.024)	(0.026)	(0.023)
Parent skills	0.013	0.024*	0.033**	0.015	0.011	0.015	0.032**	0.037***	0.038**	0.030*	0.040**	0.040**	0.054***	0.040**
	(0.016)	(0.013)	(0.014)	(0.014)	(0.017)	(0.015)	(0.014)	(0.012)	(0.014)	(0.016)	(0.016)	(0.015)	(0.016)	(0.015)
Teacher skills	0.075	0.118***	0.141***	0.147***	0.078**	0.118***	0.113***	0.129***	0.125***	0.120***	0.098***	0.117***	0.128***	0.112***
	(0.046)	(0.030)	(0.035)	(0.044)	(0.034)	(0.031)	(0.032)	(0.029)	(0.028)	(0.028)	(0.028)	(0.023)	(0.024)	(0.025)
Adj. R2	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
							Additional controls							
Student char.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Parent char.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
School char.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Country char.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Students	490,818	490,818	490,818	490,818	490,818	490,818	490,818	490,818	490,818	490,818	479,989	490,818	490,818	490,818
Countries	31	31	31	31	31	31	31	31	31	31	30	31	31	31

Notes: Dependent variable: student PISA test score in reading. Student test scores are z-standardized at the individual level across countries. Skills in occupation (see Table 7 for definition of the occupations), parent skills, and teacher skills refer to literacy. Skills in occupation and teacher skills are z-standardized across countries; skills in occupation and parent skills use teacher skills as "numeraire" scale. Control variables are the same as in the baseline least squares models (see Table 2). All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table 9: Impact of Female Share in High-Skilled Occupations on Teacher Cognitive Skills

Dependent Variable: Teacher Cognitive Skills	Numeracy		Literacy	
	(1)	(2)	(3)	(4)
Share: female teachers/females in high-skilled occ. (×10)	0.371***	0.361***	0.243**	0.238*
	(0.120)	(0.123)	(0.124)	(0.126)
Numeracy skills of college graduates (w/o teachers)		0.271		
		(0.253)		
Literacy skills of college graduates (w/o teachers)				0.405*
				(0.224)
Country fixed effects	X	X	X	X
Cohort fixed effects	X	X	X	X
Observations	69	69	69	69
Countries	23	23	23	23

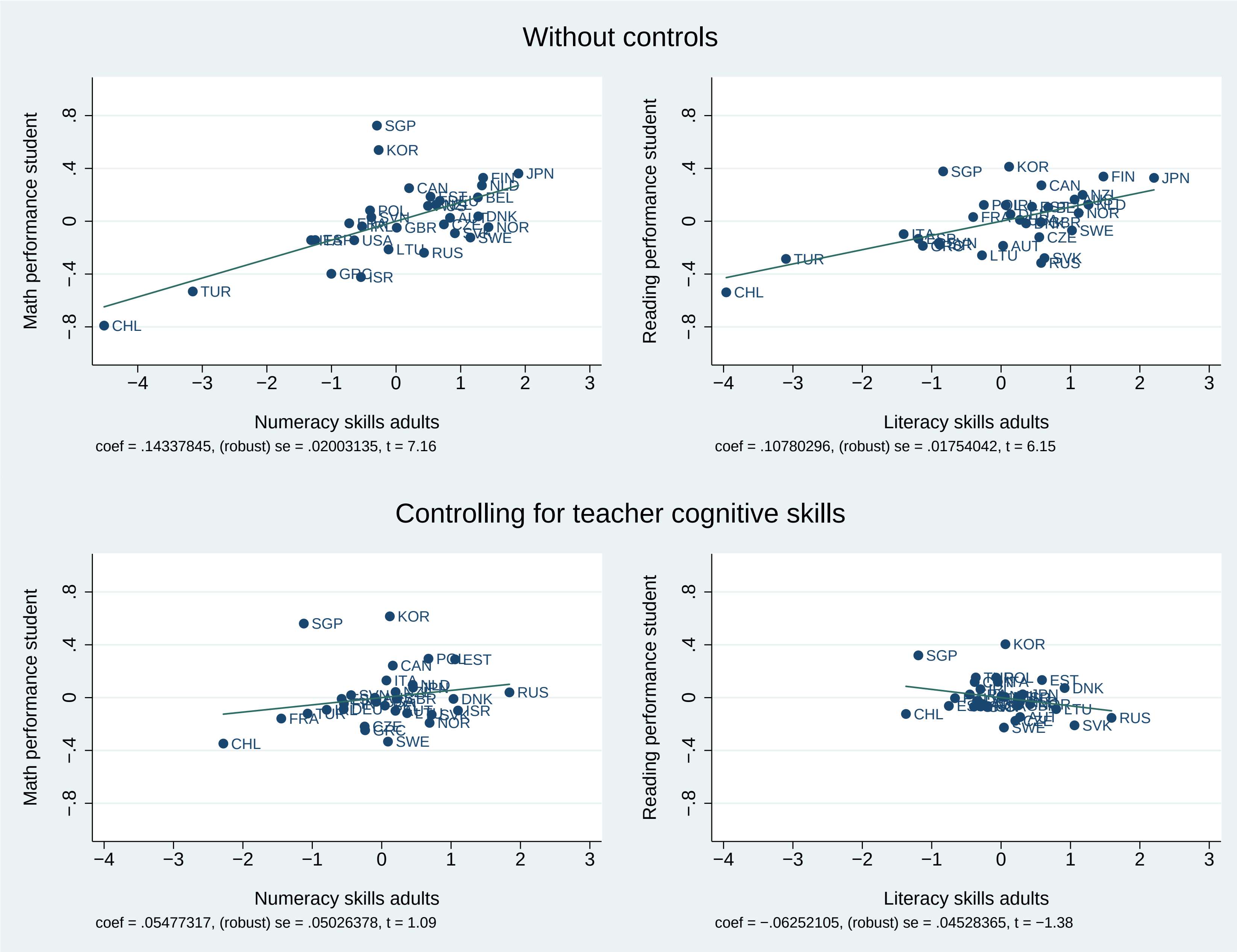
Notes: Dependent variable: teacher skills in numeracy (Columns 1–2) and literacy (Columns 3–4). Teacher cognitive skills are standardized using the standard deviation from the full sample (31 countries) as "numeraire" scale, such that magnitudes are comparable to the main analysis; cognitive skills of college graduates are standardized similarly. *Share: female teachers/females in high-skilled occ.* is the share of female teachers in a country-cohort cell over all females working in high-skilled occupations. Each cohort covers 15 adjacent birth years. Occupations are classified as high-skilled applying the following procedure in PIAAC: First, for each two-digit occupation in each country, we calculate average years of schooling of persons currently working in these occupations. Second, ranking occupations by average schooling level and starting from the occupation with the highest level, we define occupations as high-skilled until males working in these occupations comprise 25 percent of all males currently working in that country. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. Post-communist countries and Turkey are excluded (explanations see text). *Data sources:* PIAAC 2011/12 and 2014/15.

Table 10: Relationship of Teacher Wage Premiums to Teacher Cognitive Skills

Dependent Variable: Teacher Cognitive Skills	Numeracy	Literacy
	(1)	(2)
Teacher wage premium (/10)	0.113**	0.097**
	(0.052)	(0.044)
Numeracy skills of college graduates (w/o teachers)	0.943***	
	(0.112)	
Literacy skills of college graduates (w/o teachers)		0.918***
		(0.070)
Countries	23	23
Adj. R2	0.77	0.78

Notes: Dependent variable: teacher skills in numeracy (Column 1) and literacy (Column 2). *Teacher wage premium (/10)* is the percentage difference in gross hourly earnings of teachers with a college degree relative to all college graduates in a country, conditional on gender, quadratic polynomial in potential work experience, and numeracy and literacy skills; divided by 10. Robust standard errors in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. Post-communist countries and Turkey are excluded (explanations see text). *Data sources:* PIAAC 2011/12 and 2014/15.

Figure A-1: Student Performance and Adult Cognitive Skills



Note: The two graphs in the top panel do not include any controls. The two graphs in the bottom panel are added-variable plots that control for country-level teacher skills in numeracy and literacy, respectively. *Data sources*: PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table A-1: Summary Statistics for Parent Cognitive Skills

	Pooled	Australia	Austria	Belgium	Canada	Chile	Czech R.	Denmark	Estonia	Finland	France
						Numeracy					
Mean	278	287	291	301	282	223	276	293	276	299	275
Std. Dev.	29	21	22	22	20	30	27	21	16	18	26
Max – Min	115	128	140	108	120	139	109	141	87	102	132
						Literacy					
Mean	275	293	279	289	284	226	270	278	272	297	272
Std. Dev.	26	19	20	20	18	23	24	20	16	17	21
Max – Min	101	113	111	96	116	105	98	148	95	101	106
Observations	83,492	3,137	2,231	2,251	11,933	2,165	2,105	3,352	3,463	2,252	3,086

	Germany	Greece	Ireland	Israel	Italy	Japan	Korea	Lithuania	Netherl.	New Zealand	Norway
						Numeracy					
Mean	289	273	275	267	267	308	276	277	295	284	297
Std. Dev.	21	19	22	25	19	14	17	20	22	22	23
Max – Min	126	77	96	132	104	50	85	65	120	134	192
						Literacy					
Mean	279	268	280	260	264	307	281	271	293	288	290
Std. Dev.	19	16	18	23	16	12	15	13	21	19	19
Max – Min	109	75	86	117	86	44	76	46	109	109	162
Observations	2,293	2,128	2,371	1,882	1,789	2,103	3,361	2,364	2,276	2,504	2,228

		Poland	Russia	Singapore	Slovak R.	Slovenia	Spain	Sweden	Turkey	U.K.	U.S.
						Numeracy					
Mean		264	271	261	281	268	265	295	240	281	267
Std. Dev.		19	8	39	23	24	22	25	27	20	32
Max – Min		103	32	149	139	149	94	174	100	109	135
						Literacy					
Mean		267	277	253	275	261	266	290	237	285	277
Std. Dev.		19	9	31	17	22	21	23	19	18	27
Max – Min		92	35	116	129	120	87	156	69	95	122
Observations		1,793	1,074	2,119	2,442	2,435	2,614	1,864	2,319	3,578	1,980

Notes: Summary statistics of parents' cognitive skills (average skill of mother and father) based on actual parents of PISA students. See text for computation of parent cognitive skills. *Max-Min* indicates the difference between the maximum and minimum parent cognitive skills within a country. *Observations* refer to the number of adults in the PIAAC samples used for computing parents' skills. *Data sources:* PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table A-2: Summary Statistics for Student Performance and Student Characteristics

	Pooled	Australia	Austria	Belgium	Canada	Chile	Czech R.	Denmark	Estonia	Finland	France
Math performance	498	509	500	515	522	422	496	502	516	530	496
	(97)	(95)	(94)	(103)	(88)	(80)	(94)	(84)	(81)	(85)	(100)
Reading performance	497	513	480	508	524	445	486	496	508	530	501
	(97)	(98)	(96)	(102)	(91)	(81)	(91)	(84)	(82)	(91)	(108)
Age (in years)	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.7	15.8	15.7	15.9
Female	0.49	0.50	0.51	0.49	0.50	0.50	0.48	0.50	0.49	0.49	0.51
First-gen. migrant	0.06	0.12	0.06	0.09	0.13	0.01	0.02	0.04	0.01	0.02	0.05
Second-gen. migrant	0.05	0.12	0.11	0.08	0.15	0.00	0.01	0.06	0.07	0.01	0.10
Other language	0.09	0.09	0.11	0.22	0.16	0.01	0.02	0.05	0.04	0.04	0.08
Observations	490,818	28,732	11,345	17,098	44,751	12,525	11,391	13,405	9,506	14,639	8,911

	Germany	Greece	Ireland	Israel	Italy	Japan	Korea	Lithuania	Netherl.	New Zealand	Norway
Math performance	513	459	494	457	484	533	550	477	524	510	494
	(97)	(89)	(86)	(105)	(93)	(94)	(94)	(88)	(90)	(99)	(88)
Reading performance	503	479	509	480	488	529	537	473	510	517	503
	(93)	(97)	(92)	(113)	(96)	(100)	(83)	(87)	(91)	(104)	(96)
Age (in years)	15.8	15.7	15.7	15.7	15.7	15.8	15.7	15.8	15.7	15.8	15.8
Female	0.49	0.51	0.49	0.51	0.48	0.48	0.47	0.49	0.50	0.49	0.49
First-gen. migrant	0.05	0.07	0.12	0.07	0.06	0.00	0.00	0.01	0.04	0.19	0.05
Second-gen. migrant	0.11	0.04	0.02	0.12	0.02	0.00	0.00	0.01	0.08	0.09	0.04
Other language	0.09	0.05	0.05	0.11	0.14	0.00	0.00	0.04	0.06	0.15	0.07
Observations	9,980	10,094	8,953	10,816	61,978	12,439	10,022	9,146	9,220	8,934	9,346

		Poland	Russia	Singapore	Slovak R.	Slovenia	Spain	Sweden	Turkey	U.K.	U.S.
Math performance		506	475	568	489	501	484	486	447	493	484
		(90	(86)	(105)	(99)	(93)	(89)	(93)	(92)	(91)	(90)
Reading performance		509	467	534	470	482	485	491	470	497	498
		(89)	(90)	(100)	(98)	(91)	(90)	(103)	(84)	(96)	(94)
Age (in years)		15.7	15.8	15.8	15.8	15.7	15.9	15.7	15.8	15.7	15.8
Female		0.51	0.50	0.49	0.49	0.49	0.49	0.49	0.49	0.51	0.49
First-gen. migrant		0.00	0.05	0.12	0.01	0.03	0.10	0.06	0.00	0.07	0.07
Second-gen. migrant		0.00	0.07	0.05	0.00	0.06	0.01	0.08	0.01	0.05	0.13
Other language		0.01	0.09	0.57	0.06	0.06	0.18	0.09	0.05	0.07	0.14
Observations		9,524	10,539	10,829	9,233	12,066	51,200	9,303	9,844	24,838	10,211

Notes: Means and standard deviations (in parentheses) reported. *Other language* indicates a student who speaks a foreign language at home. *Observations* refer to the number of students in both PISA cycles. Statistics are based on student-level observations weighted with inverse sampling probabilities, giving each PISA cycle the same total weight. *Data sources:* PISA 2009 and 2012.

Table A-3: Summary Statistics for Parent Characteristics

	Pooled	Australia	Austria	Belgium	Canada	Chile	Czech R.	Denmark	Estonia	Finland	France
Number of books at home											
0-10 books	0.13	0.09	0.13	0.16	0.10	0.23	0.10	0.13	0.07	0.07	0.16
11-25 books	0.16	0.12	0.16	0.17	0.14	0.29	0.14	0.16	0.14	0.12	0.17
26-100 books	0.32	0.30	0.31	0.29	0.31	0.31	0.35	0.32	0.31	0.34	0.29
101-200 books	0.18	0.21	0.17	0.17	0.21	0.10	0.19	0.18	0.21	0.22	0.17
201-500 books	0.14	0.18	0.14	0.13	0.16	0.05	0.15	0.14	0.17	0.18	0.13
More than 500 books	0.08	0.10	0.09	0.08	0.08	0.02	0.07	0.07	0.09	0.06	0.07
Highest educational degree											
ISCED 0	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01
ISCED 1	0.02	0.01	0.01	0.02	0.01	0.03	0.00	0.01	0.00	0.01	0.01
ISCED 2	0.06	0.05	0.04	0.03	0.02	0.18	0.01	0.05	0.03	0.02	0.09
ISCED 3B,C	0.09	0.07	0.29	0.05	0.00	0.00	0.18	0.13	0.02	0.08	0.19
ISCED 3A,4	0.29	0.32	0.18	0.28	0.25	0.43	0.49	0.15	0.38	0.09	0.19
ISCED 5B	0.19	0.13	0.28	0.22	0.24	0.12	0.09	0.41	0.22	0.27	0.22
ISCED 5A,6	0.34	0.42	0.20	0.40	0.48	0.22	0.23	0.24	0.35	0.53	0.30
Highest occupational status											
Blue collar-low skilled	0.07	0.05	0.05	0.09	0.06	0.16	0.07	0.05	0.06	0.03	0.07
Blue collar-high skilled	0.11	0.08	0.14	0.10	0.07	0.17	0.13	0.07	0.14	0.07	0.11
White collar-low skilled	0.24	0.17	0.26	0.23	0.21	0.28	0.27	0.25	0.23	0.20	0.26
White collar-high skilled	0.56	0.68	0.53	0.56	0.64	0.34	0.52	0.62	0.55	0.69	0.54

Table A-3: Summary Statistics for Parent Characteristics (continued)

	Germany	Greece	Ireland	Israel	Italy	Japan	Korea	Lithuania	Netherl.	New Zealand	Norway
Number of books at home											
0-10 books	0.11	0.11	0.14	0.12	0.12	0.09	0.05	0.16	0.16	0.10	0.08
11-25 books	0.13	0.20	0.15	0.17	0.19	0.13	0.09	0.20	0.18	0.13	0.11
26-100 books	0.10	0.08	0.07	0.12	0.08	0.09	0.10	0.05	0.07	0.09	0.11
101-200 books	0.29	0.32	0.30	0.30	0.30	0.35	0.29	0.33	0.30	0.31	0.30
201-500 books	0.20	0.17	0.19	0.17	0.18	0.19	0.23	0.15	0.15	0.21	0.22
More than 500 books	0.17	0.12	0.15	0.13	0.13	0.15	0.24	0.10	0.13	0.17	0.19
Highest educational degree											
ISCED 0	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
ISCED 1	0.00	0.03	0.02	0.01	0.01	0.00	0.01	0.00	0.02	0.01	0.00
ISCED 2	0.15	0.09	0.07	0.03	0.21	0.02	0.04	0.01	0.04	0.06	0.02
ISCED 3B,C	0.12	0.02	0.02	0.09	0.06	0.06	0.07	0.01	0.00	0.16	0.03
ISCED 3A,4	0.23	0.34	0.35	0.26	0.37	0.30	0.34	0.37	0.32	0.25	0.25
ISCED 5B	0.18	0.14	0.18	0.16	0.07	0.15	0.06	0.19	0.39	0.15	0.39
ISCED 5A,6	0.30	0.37	0.35	0.44	0.28	0.47	0.48	0.41	0.21	0.37	0.30
Highest occupational status											
Blue collar-low skilled	0.06	0.08	0.05	0.07	0.07	0.07	0.04	0.08	0.04	0.07	0.03
Blue collar-high skilled	0.10	0.14	0.09	0.06	0.17	0.08	0.06	0.18	0.06	0.07	0.04
White collar-low skilled	0.29	0.24	0.26	0.15	0.28	0.36	0.29	0.22	0.20	0.18	0.16
White collar-high skilled	0.53	0.51	0.58	0.68	0.45	0.48	0.59	0.49	0.68	0.66	0.75

Table A-3: Summary Statistics for Parent Characteristics (continued)

	Poland	Russia	Singapore	Slovak R.	Slovenia	Spain	Sweden	Turkey	U.K.	U.S.
Number of books at home										
0-10 books	0.11	0.09	0.11	0.15	0.14	0.09	0.09	0.26	0.14	0.21
11-25 books	0.20	0.19	0.19	0.17	0.20	0.15	0.11	0.26	0.16	0.18
26-100 books	0.07	0.08	0.05	0.05	0.06	0.09	0.11	0.03	0.08	0.05
101-300 books	0.34	0.34	0.36	0.37	0.35	0.32	0.30	0.28	0.29	0.29
301-500 books	0.17	0.17	0.17	0.17	0.15	0.21	0.20	0.11	0.18	0.15
More than 500 books	0.11	0.13	0.12	0.10	0.10	0.15	0.19	0.06	0.15	0.11
Highest educational degree										
ISCED 0	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.04	0.00	0.01
ISCED 1	0.00	0.00	0.05	0.00	0.00	0.07	0.01	0.32	0.00	0.02
ISCED 2	0.01	0.05	0.02	0.04	0.18	0.04	0.24	0.03	0.05	
ISCED 3B,C	0.39	0.01	0.00	0.14	0.35	0.02	0.07	0.02	0.20	0.00
ISCED 3A,4	0.33	0.08	0.44	0.54	0.19	0.25	0.18	0.17	0.18	0.34
ISCED 5B	0.00	0.44	0.19	0.06	0.16	0.14	0.21	0.08	0.23	0.15
ISCED 5A,6	0.24	0.46	0.27	0.23	0.25	0.33	0.48	0.14	0.36	0.43
Highest occupational status										
Blue collar-low skilled	0.07	0.06	0.06	0.11	0.07	0.09	0.05	0.14	0.05	0.07
Blue collar-high skilled	0.27	0.11	0.04	0.16	0.14	0.18	0.05	0.25	0.05	0.06
White collar-low skilled	0.23	0.26	0.21	0.31	0.24	0.29	0.24	0.25	0.26	0.21
White collar-high skilled	0.43	0.54	0.67	0.40	0.53	0.43	0.65	0.28	0.62	0.64

Notes: Shares reported. Statistics are based on student-level observations weighted with inverse sampling probabilities, giving each PISA cycle the same total weight. *Highest educational degree* includes the following categories: *ISCED 0:* no educational degree; *ISCED 1:* primary education; *ISCED 2:* lower secondary; *ISCED 3B,C:* vocational/pre-vocational upper secondary; *ISCED 3A,4:* upper secondary or non-tertiary post-secondary; *ISCED 5B:* vocational tertiary; and *ISCED 5A,6:* theoretically oriented tertiary and post-graduate. *Data sources:* PISA 2009 and 2012.

Table A-4: Summary Statistics for School Characteristics

	Pooled	Australia	Austria	Belgium	Canada	Chile	Czech R.	Denmark	Estonia	Finland	France
Instructional time math	3.6	4.0	2.6	3.5	5.3	5.8	3.1	3.7	3.7	2.9	3.5
Instructional time reading	3.6	3.9	2.4	3.6	5.4	5.7	3.0	5.2	3.3	2.5	3.7
Shortage math teachers	1.52	1.89	1.33	1.92	1.44	2.05	1.25	1.23	1.45	1.16	1.35
Shortage language teachers	1.42	1.53	1.36	1.54	1.26	1.82	1.12	1.17	1.30	1.10	1.36
Private school	0.19	0.41	0.11	0.69	0.08	0.61	0.06	0.24	0.04	0.04	0.20
Students per school	735	981	559	718	1032	1013	450	480	557	429	821
Content autonomy	0.64	0.71	0.58	0.56	0.37	0.67	0.88	0.68	0.77	0.64	0.64
Personnel autonomy	0.42	0.39	0.08	0.38	0.30	0.63	0.88	0.58	0.54	0.24	0.06
Budget autonomy	0.82	0.93	0.86	0.69	0.75	0.78	0.79	0.96	0.84	0.92	0.97

	Germany	Greece	Ireland	Israel	Italy	Japan	Korea	Lithuania	Netherl.	New Zealand	Norway
Instructional time math	3.3	3.4	3.1	4.3	3.8	3.9	3.6	2.9	2.8	4.0	3.2
Instructional time reading	3.1	3.0	3.0	3.4	4.7	3.5	3.5	3.4	2.8	4.1	3.8
Shortage math teachers	1.78	1.13	1.40	1.90	1.69	1.27	1.57	1.14	2.10	1.72	1.73
Shortage language teachers	1.46	1.20	1.16	1.96	1.64	1.21	1.57	1.14	1.74	1.40	1.70
Private school	0.06	0.06	0.60	0.09	0.06	0.30	0.42	0.01	0.67	0.06	0.02
Students per school	702	283	593	770	752	750	1116	593	1023	1178	340
Content autonomy	0.63	0.04	0.69	0.53	0.72	0.92	0.89	0.80	0.93	0.88	0.49
Personnel autonomy	0.15	0.03	0.34	0.39	0.05	0.32	0.23	0.65	0.89	0.55	0.42
Budget autonomy	0.88	0.84	0.87	0.69	0.84	0.90	0.85	0.59	0.99	0.99	0.88

		Poland	Russia	Singapore	Slovak R.	Slovenia	Spain	Sweden	Turkey	U.K.	U.S.
Instructional time math		3.4	3.6	5.4	3.0	2.7	3.5	3.1	2.9	3.7	4.3
Instructional time reading		3.7	3.1	4.3	3.0	2.9	3.4	3.0	3.6	3.8	4.4
Shortage math teachers		1.03	1.71	1.35	1.13	1.12	1.09	1.35	2.73	1.64	1.37
Shortage language teachers		1.01	1.63	1.95	1.10	1.06	1.08	1.19	2.64	1.38	1.20
Private school		0.03	0.00	0.02	0.09	0.03	0.33	0.12	0.01	0.26	0.08
Students per school		324	566	1367	480	462	701	420	890	1062	1381
Content autonomy		0.75	0.59	0.63	0.59	0.45	0.53	0.63	0.20	0.89	0.48
Personnel autonomy		0.46	0.65	0.10	0.70	0.51	0.18	0.72	0.02	0.75	0.66
Budget autonomy		0.26	0.58	0.89	0.72	0.79	0.94	0.93	0.77	0.96	0.76

Notes: Country means reported. Student-level information on *instructional time* (hours per week) is aggregated to the school level for both math and reading (see also Lavy (2015)). *Shortage math/language teachers* is based on the following school principal question: "Is your school's capacity to provide instruction hindered by any of the following issues? A lack of qualified mathematics/test language teachers" Possible answer categories are: not at all (1), very little (2), to some extent (3), a lot (4). School autonomy measures are binary. *Data sources:* PISA 2009 and 2012.

Table A-5: Summary Statistics for Country Characteristics

	Pooled	Australia	Austria	Belgium	Canada	Chile	Czech R.	Denmark	Estonia	Finland	France
Expenditure per student	70.79	85.21	107.20	88.64	80.42	27.92	49.64	98.69	49.28	78.81	79.12
School starting age	6.12	5	6	6	5	6	6	7	7	7	6
Instruction practice math	0.61	0.66	0.57	0.56	0.70	0.67	0.62	0.64	0.59	0.58	0.59
Instruction practice reading	0.50	0.53	0.41	0.43	0.56	0.53	0.44	0.57	0.50	0.37	0.52
GDP per capita	35.34	41.43	43.24	39.78	40.45	18.80	27.87	41.93	23.06	38.99	36.13
Teacher gross hourly wage	18.9	21.4	19.6	23.6	26.6	14.2	9.4	22.9	9.1	22.6	21.1
Teacher performance pay	0.59	0	1	0	0	1	1	1	1	1	0
Central exit exams	0.70	1.0	0.0	0.0	0.7	0.0	0.5	1.0	1.0	1.0	1.0

	Germany	Greece	Ireland	Israel	Italy	Japan	Korea	Lithuania	Netherl.	New Zealand	Norway
Expenditure per student	72.05	53.29	84.52	55.17	80.86	83.70	65.07	41.20	87.71	59.64	112.43
School starting age	6	6	4	6	6	6	6	7	6	5	6
Instruction practice math	0.64	0.62	0.69	0.69	0.59	0.46	0.38	0.63	0.57	0.66	0.52
Instruction practice reading	0.44	0.49	0.51	0.40	0.49	0.44	0.34	0.58	0.37	0.53	0.37
GDP per capita	40.36	28.32	43.96	29.78	35.02	33.80	30.31	21.38	45.42	31.89	60.78
Teacher gross hourly wage	26.7	18.8	35.7	14.7	23.0	18.4	25.0	11.0	22.3	19.8	23.6
Teacher performance pay	0	0	0	0	0	0	0	.	1	1	1
Central exit exams	0.9	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

		Poland	Russia	Singapore	Slovak R.	Slovenia	Spain	Sweden	Turkey	U.K.	U.S.
Expenditure per student		48.80	13.29	78.15	42.68	84.84	78.15	89.29	16.26	91.46	110.86
School starting age		7	7	7	6	6	6	7	7	5	6
Instruction practice math		0.60	0.69	0.70	0.54	0.56	0.64	0.51	0.59	0.73	0.72
Instruction practice reading		0.59	0.80	0.47	0.47	0.56	0.44	0.42	0.64	0.54	0.61
GDP per capita		21.37	22.35	69.37	24.63	27.99	32.52	42.05	16.55	36.97	49.22
Teacher gross hourly wage		12.8	4.7	22.4	8.6	11.7	19.8	16.4	19.7	21.2	20.0
Teacher performance pay		1	1	.	1	1	0	1	1	1	1
Central exit exams		1.0	.	.	1.0	1.0	0.0	0.0	0.0	1.0	0.1

Notes: Expenditure per student and GDP per capita are expressed in 1,000 PPP-US-$. The *instruction practice* indicators are based on student information provided in PISA; in 2009 for language teachers and in 2012 for math teachers. See text for details on the construction of the instruction practice indicators. *Teacher performance pay* is a binary variable, taking the value 1 if salary adjustments are awarded to teachers with outstanding performance in teaching in a country; not available for Lithuania and Singapore. *Central exit exams* equals 1 if central exam examinations exist on the upper secondary level (ISCED 3) in a country, 0 otherwise; data are taken from Leschnig, Schwerdt, and Zigova (2016). Information on central exit exams is not available for the Russian Federation and Singapore. The remaining country characteristics come from OECD statistics. *Data sources:* Leschnig, Schwerdt, and Zigova (2016), OECD, PISA 2009 and 2012.

Table A-6: Student Performance and Teacher Cognitive Skills from OLS Estimation: Results on Covariates not Reported in Table 2

Dependent variable: student performance	Math	Reading
Student characteristics		
Age	0.137***	0.137***
	(0.018)	(0.012)
Female	–0.145***	0.358***
	(0.011)	(0.015)
First-generation migrant	–0.107***	–0.103**
	(0.038)	(0.038)
Second-generation migrant	–0.086**	–0.021
	(0.035)	(0.034)
Other language at home	–0.056*	–0.179***
	(0.029)	(0.031)
Family background		
Books at home		
11-25 books	0.186***	0.226***
	(0.021)	(0.021)
26-100 books	0.420***	0.467***
	(0.033)	(0.034)
101-200 books	0.588***	0.647***
	(0.043)	(0.044)
201-500 books	0.776***	0.822***
	(0.049)	(0.053)
More than 500 books	0.775***	0.801***
	(0.053)	(0.059)
Parental education		
ISCED 1	0.175***	0.219***
	(0.042)	(0.042)
ISCED 2	0.090	0.137**
	(0.065)	(0.054)
ISCED 3B,C	0.254***	0.242***
	(0.069)	(0.060)
ISCED 3A, 4	0.249***	0.270***
	(0.062)	(0.055)
ISCED 5B	0.169*	0.244***
	(0.089)	(0.074)
ISCED 5A, 6	0.261***	0.330***
	(0.085)	(0.067)
Parental occupation		
Blue collar-high skilled	0.119***	0.097***
	(0.015)	(0.018)
White collar-low skilled	0.190***	0.184***
	(0.016)	(0.019)
White collar-high skilled	0.403***	0.405***
	(0.018)	(0.020)

(continued on next page)

Table A-6 (continued)

Dependent variable: student performance	Math	Reading
School characteristics		
School location		
Small Town	–0.008	0.019
	(0.032)	(0.028)
Town	0.014	0.057
	(0.042)	(0.035)
City	0.014	0.079**
	(0.040)	(0.034)
Large City	0.080*	0.129***
	(0.045)	(0.043)
Private school	0.140***	0.159***
	(0.038)	(0.031)
No. students per school (in 1000)	0.281***	0.255***
	(0.062)	(0.052)
School autonomy		
Content autonomy	0.069	0.002
	(0.051)	(0.032)
Personnel autonomy	–0.148***	–0.167***
	(0.048)	(0.031)
Budget autonomy	0.020	0.048
	(0.039)	(0.036)
Shortage math teacher	–0.048***	
	(0.012)	
Shortage language teacher		–0.032**
		(0.013)
Weekly hours math classes	0.057**	
	(0.027)	
Weekly hours language classes		–0.001
		(0.018)
Country-level measures		
Educational expenditure per student	–0.000	0.000
	(0.001)	(0.001)
School starting age	0.139***	0.080*
	(0.049)	(0.041)
Students	490,818	490,818
Countries	31	31
Adj. R2	0.29	0.30

Notes: The table reports results on all further covariates of the ordinary least squares estimations with the full set of control variables, corresponding to Column 3 (math) and Column 6 (reading) in Table 2. Omitted categories of family background and school characteristics: *0-10 books*; *parents have no educational degree*; *blue collar-low skilled*; and *village*. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table A-7: Student Performance and Teacher Cognitive Skills (Heterogeneity)

	Gender		Parental background		Migration background	
	Boys	Girls	High SES	Low SES	Natives	Migrants
Panel A: Student Math Performance						
Teacher cognitive skills	0.135***	0.155***	0.137***	0.144***	0.140***	0.107**
	(0.032)	(0.032)	(0.032)	(0.033)	(0.034)	(0.045)
Parent cognitive skills	0.046***	0.040**	0.079***	0.025	0.049**	0.061**
	(0.016)	(0.019)	(0.020)	(0.019)	(0.018)	(0.026)
Panel B: Student Reading Performance						
Teacher cognitive skills	0.081***	0.103***	0.068***	0.112***	0.082***	0.070*
	(0.021)	(0.025)	(0.024)	(0.024)	(0.023)	(0.038)
Parent cognitive skills	0.016	0.013	0.052**	0.004	0.022	0.017
	(0.015)	(0.018)	(0.025)	(0.015)	(0.018)	(0.023)
Students	246,649	244,169	250,954	239,864	424,419	24,232
Countries	31	31	31	31	31	30
Additional controls in Panels A + B						
Student characteristics	X	X	X	X	X	X
Parent characteristics	X	X	X	X	X	X
School characteristics	X	X	X	X	X	X
Country characteristics	X	X	X	X	X	X

Notes: Dependent variable: standardized student PISA test score in math (Panel A) and reading (Panel B), respectively. Parental background is measured by the PISA index of economic, social and cultural status (ESCS). This index captures a range of aspects of a student's family and home background that combines information on parents' education, occupations, and home possessions. Migrants refer to second-generation migrants. To account for the unequal distribution of migrants across countries, we re-weight regressions based on the sample of natives and migrants, respectively, giving equal weight to each country within each subsample. Korea has no second-generation migrants in the PISA sample and is therefore excluded. All cognitive skill measures in Panel A (Panel B) refer to numeracy (literacy). Student, parent, school, and country characteristics are the same as in the least squares models (see Table 2). All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Specifications give equal weight to each country. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table A-8: Student Performance and Teacher Cognitive Skills: Including Additional Country Controls

	Student Math Performance						Student Reading Performance					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Teacher cognitive skills	0.145***	0.134***	0.138***	0.115***	0.108***	0.123***	0.092***	0.080***	0.084***	0.072***	0.070***	0.068***
	(0.032)	(0.030)	(0.031)	(0.028)	(0.029)	(0.027)	(0.022)	(0.024)	(0.019)	(0.023)	(0.021)	(0.018)
Parent cognitive skills	0.044**	0.047**	0.044**	0.061***	0.052***	0.056***	0.015	0.022	0.015	0.033*	0.032*	0.031**
	(0.017)	(0.017)	(0.017)	(0.016)	(0.014)	(0.013)	(0.016)	(0.015)	(0.013)	(0.017)	(0.017)	(0.013)
GDP per capita (1,000 PPP-$)		0.003				–0.016***		0.003				–0.007**
		(0.004)				(0.004)		(0.003)				(0.003)
Teacher gross hourly wage			0.011**			0.016***			0.018***			0.018***
			(0.005)			(0.006)			(0.003)			(0.004)
Teacher performance pay				–0.028		0.029				–0.049		0.003
				(0.060)		(0.056)				(0.036)		(0.028)
Central exit exams					0.167***	0.162***					0.095**	0.092***
					(0.056)	(0.047)					(0.036)	(0.029)
Student characteristics	X	X	X	X	X	X	X	X	X	X	X	X
Parent characteristics	X	X	X	X	X	X	X	X	X	X	X	X
School characteristics	X	X	X	X	X	X	X	X	X	X	X	X
Country characteristics	X	X	X	X	X	X	X	X	X	X	X	X
Students	490,818	490,818	490,818	470,843	469,450	460,304	490,818	490,818	490,818	470,843	469,450	460,304
Countries	31	31	31	29	29	28	31	31	31	29	29	28
Adj. R2	0.29	0.29	0.29	0.28	0.29	0.29	0.30	0.30	0.31	0.30	0.30	0.31

Notes: Dependent variable: standardized student PISA test score in math (Columns 1–6) and reading (Columns 7–12), respectively. Teacher and parent cognitive skills in Columns 1–6 (7–12) refer to numeracy (literacy). Columns 1 and 7 replicate the baseline models from Columns 3 and 6 in Table 2. Teacher wages are taken from the PIAAC microdata and are expressed in PPP-$. *Teacher performance pay* is a binary variable, taking the value 1 if salary adjustments are awarded to teachers with outstanding performance in teaching in a country (see also Woessmann, 2011). Information on teacher performance pay is not available for Lithuania and Singapore. *Central exit exams* takes the value 1 if central exam examinations exist on the upper secondary level (ISCED 3) in a country; data are taken from Leschnig, Schwerdt, and Zigova (2016). Information on central exit exams is not available for the Russian Federation and Singapore. Student, parent, school, and country characteristics are the same as in the baseline least squares models (see Table 2). All regressions include controls for imputation dummies and the PISA wave. Specifications give equal weight to each country. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* OECD, Leschnig, Schwerdt, and Zigova (2016), PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table A-9: Student Performance and Teacher Cognitive Skills with Continental Fixed Effects and in Country Subsamples (OLS)

Panel A: Student Math Performance					
		Continent		w/o ex-communist	Large
	Baseline	Fixed effects	Europe only	& Turkey	teacher sample
	(1)	(2)	(3)	(4)	(5)
Teacher cognitive skills	0.145***	0.127***	0.104***	0.178***	0.171***
	(0.032)	(0.030)	(0.030)	(0.032)	(0.045)
Parent cognitive skills	0.044**	0.024**	0.038**	0.034**	0.004
	(0.017)	(0.012)	(0.014)	(0.014)	(0.010)
Panel B: Student Reading Performance					
Teacher cognitive skills	0.092***	0.088***	0.072**	0.102***	0.118***
	(0.022)	(0.025)	(0.029)	(0.028)	(0.020)
Parent cognitive skills	0.015	0.003	0.016	0.003	–0.019
	(0.016)	(0.012)	(0.015)	(0.018)	(0.018)
Students	490,818	490,818	352,375	409,569	312,163
Countries	31	31	23	23	19
			Additional controls in Panels A + B		
Student characteristics	X	X	X	X	X
Parent characteristics	X	X	X	X	X
School characteristics	X	X	X	X	X
Country characteristics	X	X	X	X	X

Notes: Dependent variable: standardized student PISA test score in math (Panel A) and reading (Panel B). All skill measures in Panel A (Panel B) refer to numeracy (literacy). Column 1 replicates the baseline least squares models from Columns 3 and 6 in Table 2. In Column 2, we add continental fixed effects and in Column 3, the sample is restricted to only European countries. In Column 4, we exclude countries with a communist heritage and Turkey, while we keep only countries with at least 150 teacher observations in PIAAC in Column 5. Student, parent, school, and country characteristics are the same as in the baseline least squares models (see Table 2). All regressions include controls for imputation dummies and the PISA wave. Specifications give equal weight to each country. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* OECD, PIAAC 2011/12 and 2014/15, PISA 2009 and 2012.

Table A-10: Teacher Wage Premiums around the World: Regression Output

	Australia	Austria	Belgium	Canada	Chile	Denmark	Finland	France	Germany	Greece	Ireland	Israel
Teacher	–0.034	0.009	0.037	0.171***	0.079	–0.094***	0.129***	0.127***	0.165***	0.408***	0.457***	0.055
	(0.027)	(0.034)	(0.025)	(0.025)	(0.091)	(0.016)	(0.021)	(0.032)	(0.042)	(0.064)	(0.040)	(0.052)
Numeracy	0.124***	0.015	0.058***	0.082***	0.174***	0.046***	0.103***	0.076***	0.062**	0.027	0.095***	0.133***
	(0.019)	(0.027)	(0.017)	(0.013)	(0.049)	(0.014)	(0.014)	(0.017)	(0.026)	(0.042)	(0.025)	(0.022)
Literacy	–0.013	0.105***	0.016	0.073***	–0.007	0.040***	–0.009	0.013	0.073 ***	0.014	0.037	0.050**
	(0.020)	(0.026)	(0.017)	(0.013)	(0.054)	(0.014)	(0.015)	(0.018)	(0.026)	(0.037)	(0.026)	(0.023)
Female	–0.120***	–0.113***	–0.036*	–0.113***	–0.210***	–0.116***	–0.162***	–0.061***	–0.168***	–0.071	0.004	–0.102***
	(0.021)	(0.030)	(0.019)	(0.016)	(0.060)	(0.016)	(0.017)	(0.020)	(0.029)	(0.048)	(0.029)	(0.035)
Pot. experience	0.036***	0.026***	0.026***	0.039***	0.035***	0.026***	0.024***	0.031***	0.046***	0.042***	0.052***	0.051***
	(0.003)	(0.005)	(0.003)	(0.003)	(0.009)	(0.003)	(0.003)	(0.003)	(0.006)	(0.009)	(0.005)	(0.006)
Pot. experience^2	–0.001***	–0.000**	–0.000***	–0.001***	–0.001***	–0.000***	–0.000***	–0.000***	–0.001***	–0.000*	–0.001***	–0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

	Italy	Japan	Korea	Netherl.	New Zeal.	Norway	Singapore	Spain	Sweden	U.K.	U.S.
Teacher	0.226***	0.116**	0.295***	–0.047	–0.025	–0.116***	–0.008	0.234***	–0.222***	0.035	–0.220***
	(0.055)	(0.049)	(0.052)	(0.030)	(0.033)	(0.016)	(0.043)	(0.035)	(0.021)	(0.039)	(0.039)
Numeracy	0.106***	0.245***	0.099***	0.025	0.096***	0.055***	0.224***	0.094***	0.028*	0.134***	0.112***
	(0.035)	(0.025)	(0.036)	(0.022)	(0.018)	(0.015)	(0.023)	(0.031)	(0.016)	(0.025)	(0.030)
Literacy	–0.017	–0.091***	0.056	0.081***	0.047**	0.021	–0.016	0.035	0.034**	0.043	0.061**
	(0.034)	(0.027)	(0.036)	(0.021)	(0.020)	(0.016)	(0.023)	(0.026)	(0.015)	(0.026)	(0.031)
Female	–0.133***	–0.334***	–0.203***	–0.078***	–0.092***	–0.117***	–0.048*	–0.111***	–0.110***	–0.131***	–0.108***
	(0.045)	(0.025)	(0.035)	(0.022)	(0.022)	(0.015)	(0.025)	(0.029)	(0.017)	(0.028)	(0.033)
Pot. experience	0.041***	0.037***	0.024***	0.042***	0.035***	0.030***	0.076***	0.036***	0.024***	0.042***	0.046***
	(0.007)	(0.004)	(0.006)	(0.003)	(0.003)	(0.002)	(0.004)	(0.006)	(0.003)	(0.004)	(0.005)
Pot. experience^2	–0.000**	–0.001***	–0.000	–0.001***	–0.001***	–0.001***	–0.001***	–0.001***	–0.000***	–0.001***	–0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes: Least squares regressions (weighted by sampling weights). Dependent variable: log gross hourly wage. All country samples include workers with a college degree. Numeracy and literacy scores are standardized with standard deviation 1 across countries. *Pot. experience* is age − years of schooling − 6. Robust standard errors in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* PIAAC 2011/12 and 2014/15.