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Early childcare duration and students' later outcomes in Europe

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Abstract

The importance of investment in early childhood education (ECE) has been widely documented in the literature. Among the benefits, particularly for children from disadvantaged backgrounds, is its potential to mitigate educational inequality. However, some evidence also suggests that the positive effects of ECE on later outcomes tend to dissipate over time, leaving children who attended such programmes no better off academically than those who did not. This paper studies the relationship between students' years spent in ECE and the results of their educational assessment outcomes at age 15. Using PISA survey data for fourteen European countries from 2015 and 2018, we conduct a cross-country comparison of student performance in reading, mathematics, and science, correlating the results to early childcare and pre-primary school attendance. Our findings show that participation in early childcare is associated with better assessments at age 15, but that the benefit is nonlinear and peaks at 3-4 years of childcare attendance. Examination of gender heterogeneity patterns reveals differences in girls' and boys' performance on the assessments; however, there are no gender differences in the relationship between childcare participation and test outcomes. We also explore differences related to the type of educational system attended and find distinct results for the unitary and separate settings.

JEL: I2, J13, J16

Keywords: early childhood education, pre-primary, early investments, human capital, assessments, gender, institution, unitary, separate, PISA

1. Introduction

The early years are crucial to a child's cognitive and non-cognitive development. Early life disadvantages can lead to substantial and long-term negative effects and disparities, resulting in significant gaps in later years (Almond, et al., 2018).

Studies have pointed to the positive effects of early childhood education (ECE) in improving children's cognitive abilities and socio-emotional development, reducing inequality, and increasing social mobility. As such, early education has been one of policymakers' top priorities to achieve economic growth and reduce inequalities (OECD, 2019).

Inequalities in human capital development and outcomes are significant among certain disadvantaged groups and are largely influenced by family background (see e.g. Bjorklund and Salvanes, 2011). The lack of a rich home learning environment can be compensated for by educational programmes such as quality pre-primary education (Smidova, 2019). As some OECD countries have now reached almost universal coverage in education, policies have shifted to extending compulsory schooling and expanding pre-primary schooling to encourage earlier participation. For instance, in 2019, France lowered the school starting age to 3 years old, therby increasing the length of compulsory schooling.

The quality of education (which includes the school environment and teacher qualifications) plays a significant role in reducing inequality gaps, as it particularly benefits those from disadvantaged backgrounds. The potential benefits from investing in childhood education and childcare go well beyond education and development, as positive impacts are evident in the realms of the labour market, social cohesion and inclusion, health and well-being, and crime and justice (see Vandenbroeck, et al., 2018).

While there are several types of early childhood care (Blau and Currie, 2006), the family environment and parental investments have also been a major focus in the economic literature (Francesconi and Heckman, 2016). Cash subsidies available to families of young children and increased time dedicated to children through parental leave (see e.g. Danzer and Lavy, 2017, Del Boca et al., 2016)) are evidence of the importance attributed to the home environment in the early years.

In the absence of family-provided care and education, an alternative is a structured stimulating learning environment outside the home, such as early formal childcare and childhood education programmes. Most of the existing evidence about such programmes comes from studies of targeted initiatives in the US (e.g. Heckman, et al., 2013), whereas in Europe, universal programmes are more of the norm.

European studies of formal childcare have been conducted in Denmark (Datta Gupta et al., 2016; Rossin-Slater and Wuest, 2020), Norway (Haves and Mogstad, 2015), Spain (Felfe et al., 2015), and Italy (Brilli et al., 2016; Del Boca et al., 2021; Fort et al., 2020). Duncan et al. (2022) note that "Universal programmes […] are open for all, but children from disadvantaged families are typically prioritised or more heavily subsidised relative to advantaged families." In reviewing some key literature, they find that research on universal programmes more consistently documents positive effects persisting into adulthood than targeted programmes, where the evidence is mixed.

Dietrichson et al. (2020) provide a review of the long-term effects of universal childcare, finding that children from low socio-economic status benefit most from such programmes. Other studies, such as Magnuson et al. (2007), point to the dissipation of academic skills. These "fadeout effects", evidenced by declining impacts of short-term positive effects, may be the result of convergence of learning trajectories as children "catch up" with their peers.

The lasting effects of early childhood education programmes on cognitive and achievement outcomes have been investigated by Li et al. (2020), who consider starting age and programme duration in their studies. Using data published between 1960 and 2007, they find that children who started attending in infancy/toddlerhood experienced larger positive effects than those who started in preschool, and that the positive effects were greater following shorter programmes than longer ones.

Less research has been carried out on the "dosage" aspect or the intensive margin of early childcare attendance than on attendance at the extensive margin. While there is clearly a positive relation between the duration of early childcare and educational outcomes, no consensus has been reached on how many years of attendance would be optimal. Loeb et al. (2007) investigate the duration and intensity of US children's participation in childcare and their short-term effects on cognitive and social behaviours. They find positive effects of centre-based care on reading and math scores at the start of kindergarten. The greatest benefit is found among children who start at ages 2-3, with heterogeneous effects according to family income and race. Blanden et al. (2022) analyse the effect of an additional 3.5 months of preschool education at age 3 in England on children's school achievement at age 5 and find similar positive effects, as well as a "fading out effect" by age 7. Cornelissen and Dustmann (2019) instead look at the effects of additional schooling before age 5 resulting from changes in school entry rules. They find significant effects for boys at ages 5 and 7, but the positive effects on cognitive outcomes disappear by age 11. Fort et al. (2020) exploited admission thresholds in the Bologna day care system, and found that an additional month in day care at ages 0-2 is associated to a 0.5% reduction in intelligence quotient at ages 8-14. They also found that this negative effect increases with family income. These studies focus on single countries and look at short-term effects.

Our study builds on this literature. Unlike Loeb et al. (2007), we examine outcome measures at the age of 15, which is approximately when students start secondary school. It is also the age at which they start making decisions about their own education, such as what track to follow. While most of the evidence of long-term effects tends to be based on rather small samples of participants (Karoly et al., 2005; Temple and Reynolds, 2007; Reynolds et al., 2011), our evidence draws from a large international sample, as did Schuetz, 2009, for pre-primary education; Hanushek, et al., 2013, for school autonomy; Bergbauer et al., 2021, for testing; and Dolton and Marcenaro-Gutierrez, 2011, for teacher pay.

This paper focuses on the link between early childcare attendance and children's cognitive outcomes. More specifically, we first examine the role of the duration of ECE attendance in shaping long-term cognitive outcomes, observed when students are 15 years of age, exploiting PISA data across 14 countries. We then explore potential differences in the link between early childcare attendance and students' outcomes across genders and across types of ECE services.

The paper is organised as follows. The data are described in Section 2, followed by the empirical strategy in Section 3. The results are then presented in Section 4. The final section summarises the findings and provides some policy implications.

2. The data

Our analysis is based on the Organisation for Economic Cooperation and Development (OECD)'s Programme for International Student Assessment (PISA), which is a survey of 15-year-old students from different countries that is conducted every three years. The first survey was administered in 2000. The goal of PISA is "to determine the extent to which young people have acquired the wider knowledge and skills in reading, mathematical and scientific literacy that they will need in adult life," rather than mere recall of specific content knowledge.

Scientific literacy is defined as "a[n] individuals' scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how science and technology shape our material, intellectual, and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen." Mathematical literacy is defined as "a[n] individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgements and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned, and reflective citizen."

Each student is assigned a set of ten scores that are standardised across countries to have a mean of 500 and standard deviation of 100. These scores are essentially plausible values, which are used by international surveys to report student performance based on mathematically computed (posterior) distributions around the reported values. Each student is assigned a set of random values from the posterior distributions, which then represent the range of abilities that a student might reasonably possess. Plausible values are meant to prevent biased inferences from measuring an unobservable underlying ability through a test with a relatively small number of items. (OECD, 2009). Wu (2005) defines plausible values "as multiple imputations of the unobservable latent achievement for each student." Like Rivkin and Schiman (2015), we use the first plausible value in our analysis and present estimates based on them. "To estimate regression using plausible values, one must estimate separate regression with each of the five [ten] plausible values and then average across the estimates. See Adams and Wu (2002) for a detailed description of plausible values. Practically speaking, however, estimates from larger samples will be very similar regardless of which plausible value is used." (Rivkin and Schiman, 2015). Jerrim et al. (2017) replicated Lavy (2015) and showed that using one plausible value yields results similar to when using all plausible values.

The survey also includes a rich set of information about the student, family background, school, and home environment. For waves 2003, 2009, 2012, 2015, and 2018, the survey asked student respondents to provide some retrospective information about their participation

in ISCED level 0 programmes. The ISCED classification (International Standard Classification of Education) was developed by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) to make education systems comparable across countries. Since its initial development in the mid-1970s, it was revised in 1997 and then again in 2011 after a further review between 2009 and 2011. The 2011 ISCED incorporated changes that occurred over the last decade, including those relating to the Bologna process in tertiary education and the expansion of education programmes for very young children. The correspondence between the 2011 ISCED and 1997 ISCED can be found in the manual. [1] The 1997 ISCED-0 definition was disaggregated into ISCED-01 and ISCED-02 in the 2011 definition. "ISCED level 0 programmes are usually school-based or otherwise institutionalised for a group of children (e.g. centre-based, community-based, home-based). ISCED level 0 excludes purely family-based arrangements that may be purposeful but are not organised in a 'programme' (e.g. informal learning by children from their parents, other relatives or friends is not included under ISCED 0). Within ISCED-0, early childhood educational development programmes are targeted at children aged 0 to 2 years; and pre-primary education programmes are targeted at children aged 3 years until the age to start ISCED-1. The upper age limit for the pre-primary education category depends in each case on the theoretical age of entry into ISCED level 1." (OECD, 2015)

The 2015 and 2018 PISA waves used the ISCED 2011 definition. We use this definition to investigate the relationship of the years of ECE attendance (corresponding to ISCED-0 level) with student assessment outcomes in reading, mathematics, and science at 15 years of age. We limit our analysis to the following EU countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and the United Kingdom.

Our sample consists of 109,012 observations from the 2015 (45,346; 11 countries)[2] and 2018 (63,666, 12 countries) waves of PISA. Table 1 reports the descriptive statistics for the variables used in our analyses. A little more than half of the sample are girls, 88% are natives, 6% are first-generation migrants, and 7% are second-generation migrants. The parents' education is given as ISCED levels. Like Dustmann et al. (2012), we classified ISCED levels 0 to 2 (up to lower-secondary education) as low education, and ISCED levels 5 and 6 (tertiary education) as high education. Around half of the student sample have high-educated parents, at 51% and 48% for maternal and paternal education, respectively. Comparing the two, mothers are generally more educated than fathers, with 24% of the fathers being low educated, as opposed to 20% of the mothers. As regards the number of books at home, there is an inverted U-shaped pattern, wherein 30% of the sample have 26-100 books, followed by 20% with 101-200 books. Approximately 85% of the sample speak the language used on the test at home. In terms of school characteristics, 80% are public schools, with an average of 79% of the funding coming from the government, and 87% average having fully certified

[1] ISCED 2011 http://uis.unesco.org/en/glossary-term/isced-0-early-childhood-education-includes-isced-01-and-isced-02

[2] We do not observe the following countries: Austria, Denmark, and the Netherlands in 2015, and Belgium and Ireland in 2018.

teachers. The schools are mostly in towns (64%), with some in cities (30%) and a few in villages (6%).

Table 1. Descriptive Statistics

Variable	Mean	Std. dev.
Test assessment outcomes		
Reading	501.9995	93.8482
Mathematics	501.8812	87.9109
Science	501.8570	91.7809
Test assessment outcomes, girls		
Girls' Reading	513.0412	89.8551
Girls' Mathematics	496.1776	84.8784
Girls' Science	499.8112	88.6125
Test assessment outcomes, boys		
Boys' Reading	489.8332	96.6103
Boys' Mathematics	508.1656	90.7221
Boys' Science	504.1111	95.0997
ECE attendance		
ECE: 0 to <1 year	0.0333	0.1795
ECE: 1 to <2 years	0.1157	0.3199
ECE: 2 to <3 years	0.2413	0.4279
ECE: 3 to <4 years	0.4360	0.4959
ECE: 4 to <5 years	0.1244	0.3300
ECE: at least 5 years	0.0493	0.2164
Student characteristics		
Age	15.7931	0.2916
Female	0.5242	0.4994
Native background	0.8785	0.3268
First-generation migrant	0.0556	0.2292
Second-generation migrant	0.0659	0.2482
Parents' characteristics		
Mother's education: Low	0.1956	0.3967
Mother's education: Middle	0.2955	0.4563
Mother's education: High	0.5089	0.4999
Father's education: Low	0.2376	0.4256
Father's education: Middle	0.2837	0.4508
Father's education: High	0.4788	0.4996
Highest parental occupational status (ISEI index)	51.7878	22.2097
Home environment		
Books at home: 0-10 books	0.1102	0.3131
Books at home: 11-25 books	0.1501	0.3572
Books at home: 26-100 books	0.2994	0.4580
Books at home: 101-200 books	0.1950	0.3962
Books at home: 201-500 books	0.1592	0.3659
Books at home: more than 500 books	0.0861	0.2804
Language at home is same as test	0.8442	0.3627
School characteristics		
School Size	803.5093	586.4779
Public School	0.7903	0.4071
Share of total funding for school year from government	85.0683	24.1181
Index proportion of all fully certified teachers	0.8728	0.2559
School is in a village	0.0583	0.2344
School is in a small town	0.2600	0.4386
School is in a town	0.3830	0.4861
School is in a city	0.2319	0.4221
School is in a large city	0.0667	0.2496

The students in our sample are born in years 1999/2000 and 2002/2003. Most of them attended ECE for 3-4 years (43.6%) or for 2-3 years (24.13%). That would roughly coincide with students entering ISCED-0 at ages 3 or 2 years old. We are interested in how the duration of ECE attendance during the early years correlates with assessment scores at age 15. Table 2 shows the average test scores by years of ECE attendance. The test averages increase with additional years of ECE attendance reaching the highest value in correspondence to 3 to 4 years of ECE: 506.33, 508.10, and 506.74 for reading, mathematics, and science, respectively. Attendance of 4 years or more corresponds to lower test scores, but not as low as 0 to <2 years of ECE attendance. This pattern may be the result of ECE settings and the ages at which children experience the learning environment. Shorter ECE participation means children have had less time to acquire skills, while longer ECE participation implies that they started attending when they were younger. For children aged 0-2, the ECE environments may not be sufficiently stimulating to promote development for all young children.

Table 2. Average Test Scores and Years of ECE Attendance

	Reading		Mathematics		Science	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
ECE: 0 to <1 year	459.2643	97.4059	463.6643	88.9795	463.1721	92.7122
ECE: 1 to <2 years	499.4202	95.3320	491.5810	87.6927	497.1002	94.7087
ECE: 2 to <3 years	500.8664	93.7456	501.5377	88.7425	500.9178	92.5763
ECE: 3 to <4 years	506.3326	91.4962	508.0961	86.2236	506.7422	88.9895
ECE: 4 to <5 years	503.3862	95.1681	503.3094	87.4485	502.4845	92.4205
ECE: at least 5 years	500.6616	97.9246	494.9955	90.2849	498.9752	95.8790
Overall mean	501.9995	93.8482	501.8812	87.9109	501.8570	91.7809

3.Empirical Model

To estimate the correlational link between ECE and later student achievement – net of a rich set of observables and unobservable covariates, we use an education production function framework, where student outcome is conceived as a function of family and school inputs (e.g. Lazear, 2001; Todd and Wolpin, 2007). A simple linear formulation of the education production function yields the following empirical model,

$$T_{isct} = \alpha \boldsymbol{E}_{ict_0} + \beta_F \boldsymbol{F}_{ict} + \beta_S \boldsymbol{S}_{sct} + \mu_c + \mu_t + \mu_{ct} + \varepsilon_{isct}$$

where reading, mathematics, and science assessment T of student i in school s of country c at time t is a function of the student's attendance of ISCED-0 programmes in the early years (E) before entering compulsory (primary) schooling t_0, and inputs from family (F) and school (S). The parameters μ_c, μ_t, and μ_{ct} are country, year, and country-by-year fixed effects, respectively, and ε_{ict} is an individual-specific time-varying error term. The model allows for non-constant partial effects of ECE attendance, since E is a vector composed of dummy variables indicating the years of ECE attended (0 to <1, 1 to <2, 2 to <3, 3 to <4, 4 to <5, and 5 or more years). The vector of student and family characteristics includes: age (in years), gender, migration background (native, first-generation, second-generation), mother's

education (ISCED levels), father's education (ISCED levels), highest parental occupation status (ISEI index),[3] books at home (0-10, 11-25, 26-100, 101-200, 201-500, more than 500), and language at home (if the same as test). School-level variables include: public school (vs. private), school size (number of students), share of funding received from the government, proportion of fully certified teachers, school community (whether located in a village, small town, town, city, or large city).

Our parameters of interest are the six parameters contained in α, which are the partial effects of each level of ECE attendance on achievement, holding other inputs and covariates constant.

We use panel data from PISA with student-level data on T, F, and S. We implement a fixed effects estimation approach, similar to Hanushek, et al. (2013) and Bergbauer, et al. (2021). Country fixed effects μ_c account for country-specific time-invarying factors, such as the state of social and economic institutions, or families' attitudes to children's education. Time fixed effects μ_t account for common shocks affecting PISA tests in a wave or changes in testing instruments across waves, as well as for cohort-specific characteristics. Country-by-year fixed effects μ_{ct} account for country-specific time-varying characteristics, such as changes in spending levels.

In a further specification, we include school fixed effects, like Lavy (2015) and Freeman and Viarengo (2014). Because the schools are not observed panel-wise, we are essentially removing school-specific covariates that are time-constant. Since schools are nested within a country, school fixed effects also effectively capture country fixed effects. Basically, this approach allows us to estimate school effects through the similarity of outcomes among students in the same school without measures of school policies.

Our estimation is therefore based on variations in students' attendance of early education, exploiting within-country (and within-school) variation in individual ECE participation and eliminating any time influences on the estimates.

4.The Empirical Results

This section presents our main results, as well as heterogeneity analysis based on student gender and on the institutional characteristics of the ECE provision. Tables 3, 4, and 5 show the estimated coefficients of ECE attendance on reading, mathematics, and science in international education production functions, with various sets of controls and country, year, country-by-year, and school fixed effects. The sets of controls in our specifications include student, family, and school characteristics as explanatory variables. The full models are reported in Tables A1, A2, and A3 in the Appendix for reading, mathematics, and science, respectively.

The results show that the years of attendance of ECE has a positive and statistically significant partial correlation with all three test outcomes. The magnitudes of the estimated

[3] The ISEI index captures occupational attributes convertible to income, wherein higher values correspond to occupations with higher returns to education. Lower values, instead, correspond to occupations with lower rewards to education. (Ganzeboom et al., 1992)

coefficients indicate a nonlinear relationship, with the maximum "benefit" observable at 3 to <4 years of ECE attendance.

Column 1 shows results from estimation with country, year, and country-by-year fixed effects. Attendance of 3 to <4 years of ECE is associated with 53.76 more standard deviation points in reading, 46.46 more in mathematics, and 47.46 more in science. These magnitudes are significantly higher than the estimated magnitudes for 1 to <2 years of ECE attendance - 32.75 for reading, 24.38 for mathematics, and 27.26 for science, respectively.

Table 3. Regression Results for Reading

	Reading					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
ECE 1 to <2 years	32.7460***	27.0150***	21.9838***	19.0699***	19.1764***	16.0845***
	(3.169)	(2.343)	(2.472)	(2.120)	(2.143)	(1.581)
ECE 2 to <3 years	44.5562***	37.4520***	29.3182***	24.9384***	24.7410***	20.5190***
	(4.794)	(3.881)	(3.652)	(3.520)	(3.532)	(1.523)
ECE 3 to <4 years	53.7561***	44.3520***	33.8633***	27.9495***	27.6128***	23.8181***
	(4.698)	(3.791)	(4.013)	(3.735)	(3.801)	(1.499)
ECE 4 to <5 years	46.0424***	37.1050***	24.9883***	19.7497***	18.9480***	17.1046***
	(4.074)	(3.480)	(3.353)	(3.105)	(3.169)	(1.603)
ECE 5 or more years	39.4685***	30.2652***	18.1509***	14.2004**	13.2266**	12.7800***
	(6.400)	(6.015)	(5.046)	(4.856)	(4.775)	(1.869)
Student characteristics		Y	Y	Y	Y	Y
Parents' characteristics			Y	Y	Y	Y
Home environment				Y	Y	Y
School characteristics					Y	
Country, Year FE	Y	Y	Y	Y	Y	Y
Country-by-year FE	Y	Y	Y	Y	Y	Y
School FE						Y
Observations	109,012	109,012	109,012	109,012	109,012	109,012
R-squared	0.017	0.049	0.136	0.212	0.220	0.112
Number of countries	14	14	14	14	14	
Number of schools						4,983

Note: This table reports the estimated coefficients for regressions on the reading test (pv1read) as the dependent variable. Student characteristics include age, gender, and migration background. Parents' characteristics include mother's education, father's education, and highest parental ISEI. Home environment includes the number of books and the language spoken at home. School characteristics include school size, public/private school, share of funding from the government, proportion of fully certified teachers, and school location.
Robust standard errors are clustered (Columns 1-5 by country, Column 6 by school) in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Table 4. Regression Results for Mathematics

	Math					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
ECE 1 to <2 years	24.3786***	20.0803***	15.0247***	12.6447***	12.7006***	10.4652***
	(1.890)	(1.353)	(1.451)	(1.215)	(1.095)	(1.454)
ECE 2 to <3 years	37.6151***	32.4114***	24.2876***	20.4854***	20.3830***	16.6917***
	(3.508)	(3.106)	(2.929)	(2.896)	(2.849)	(1.374)
ECE 3 to <4 years	46.4589***	40.3638***	29.9036***	24.7308***	24.4193***	20.6811***

	(3.485)	(2.761)	(2.867)	(2.738)	(2.769)	(1.367)
ECE 4 to <5 years	39.3643***	33.7839***	21.6658***	17.0621***	16.3189***	13.7533***
	(3.673)	(3.044)	(2.698)	(2.494)	(2.512)	(1.475)
ECE 5 or more years	30.1437***	24.8270***	12.6908**	9.2120**	8.4772*	7.6279***
	(5.499)	(5.584)	(4.314)	(4.161)	(4.118)	(1.720)
Student characteristics		Y	Y	Y	Y	Y
Parents' characteristics			Y	Y	Y	Y
Home environment				Y	Y	Y
School characteristics					Y	
Country, Year FE	Y	Y	Y	Y	Y	Y
Country-by-year FE	Y	Y	Y	Y	Y	Y
School FE						Y
Observations	109,012	109,012	109,012	109,012	109,012	109,012
R-squared	0.014	0.038	0.135	0.208	0.215	0.107
Number of countries	14	14	14	14	14	
Number of schools						4,983

Note: This table reports the estimated coefficients for regressions on the mathematics test (pv1math) as the dependent variable. Student characteristics include age, gender, and migration background. Parents' characteristics include mother's education, father's education, and highest parental ISEI. Home environment includes the number of books and language spoken at home. School characteristics include school size, public/private school, share of funding from the government, proportion of fully certified teachers, and school location.
Robust standard errors are clustered (Columns 1-5 by country, Column 6 by school) in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Table 5. Regression Results for Science

	Science					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
ECE 1 to <2 years	27.2598***	22.5279***	17.4567***	14.7843***	14.7934***	11.9882***
	(2.689)	(2.220)	(2.304)	(1.960)	(1.967)	(1.531)
ECE 2 to <3 years	38.9436***	33.1959***	25.0093***	20.8177***	20.6831***	16.5897***
	(4.613)	(3.964)	(3.748)	(3.549)	(3.550)	(1.445)
ECE 3 to <4 years	47.4618***	40.5041***	29.9513***	24.2279***	23.9290***	19.9076***
	(4.746)	(4.177)	(4.208)	(3.747)	(3.822)	(1.426)
ECE 4 to <5 years	38.9505***	32.5017***	20.2659***	15.1834***	14.5553***	12.3942***
	(3.972)	(3.518)	(3.229)	(2.935)	(3.034)	(1.535)
ECE 5 or more years	30.8994***	24.6630***	12.3977**	8.5737*	7.9090	6.9284***
	(5.871)	(5.857)	(4.781)	(4.603)	(4.597)	(1.829)
Student characteristics		Y	Y	Y	Y	Y
Parents' characteristics			Y	Y	Y	Y
Home environment				Y	Y	Y
School characteristics					Y	
Country, Year FE	Y	Y	Y	Y	Y	Y
Country-by-year FE	Y	Y	Y	Y	Y	Y
School FE						Y
Observations	109,012	109,012	109,012	109,012	109,012	109,012
R-squared	0.014	0.034	0.126	0.207	0.212	0.106
Number of countries	14	14	14	14	14	
Number of schools						4,983

Note: This table reports the estimated coefficients for regressions on the science test (pv1scie) as the dependent variable. Student characteristics include age, gender, and migration background. Parents' characteristics include mother's education, father's education, and highest parental ISEI. Home environment includes the number of books and language spoken at home. School characteristics include school size, public/private school, share of funding from the government, proportion of fully certified teachers, and school location.

Robust standard errors are clustered (Columns 1-5 by country, Column 6 by school) in parentheses. *** p<0.01, ** p<0.05, * p<0.10

The general results hold true even after introducing other covariates. Column 2 includes student characteristics, namely: age, gender, and migrant background; column 3 includes the education of both parents and the highest parental ISEI. The magnitudes of our estimated coefficients for duration of ECE attendance decrease by about 20% when we include student-level covariates (column 2) and decrease by 30-50% (compared to column 1) when we also include parent characteristics. A drastic drop (70%-90%) in the estimated coefficients occurs when we further include home environment variables, such as the number of books and the language spoken at home, shown in column 4. The estimated coefficients are similar to those shown in column 5, which additionally includes school-level covariates such as school size, an indicator for public (vs. private) school, share of funding from government, proportion of fully certified teachers, and school location. In column 6, we include school fixed effects. We find that adding school fixed effects in the estimation substantially decreases the estimated impacts of ECE attendance (and student and family background) on test scores, but the impact of ECE attendance remains positive and statistically significant in explaining reading, mathematics, and science assessments at 15 years old. Having participated in ECE is associated with 12.78 to 23.82 more standard deviation points in reading. This is equivalent to 14% to 25% of the standard deviation of reading at 93.85. Results for mathematics are between 7.63 and 20.68, which is equivalent to 9% to 24% of the standard deviation at 87.91; and science results are between 6.93 and 19.91, equivalent to 8% to 22% of the standard deviation of 91.78. We note that while the results for our ECE variables are still positive and statistically significant, the magnitudes in column 6 have dropped by at least 50% of the results in column 1. This gives an indication of the possible relation of ECE participation with student, family, and school-specific covariates that may confound its impact on the assessment outcomes. As a result, the initial minimum benefit shown at 1 to <2 years of ECE participation changes. Once we control for parental characteristics, the minimum has changed instead to 5 or more years of ECE participation, while the peak remains at 3 to <4 years. This is true for all three outcomes.

Looking at the estimated coefficients of the other explanatory variables provides additional information. Parental education and occupation are positively related to student outcomes, as is commonly reported in the literature (e.g. Martins and Veiga, 2010). We find that together with parental characteristics, variables indicating the home learning environment are strong predictors of student performance. Taking the test in the same language as that spoken at home is particularly significant for the reading test. Similar to Brunello et al. (2015), the number of books at home is a similarly strong predictor of test outcomes, with the magnitudes of the contribution to the test scores increasing with the number of additional books at home. By looking at column 5, we can also see the contribution of school inputs to student performance (e.g. Das et al., 2013). We find schools with more students and more fully certified teachers are positively associated with student assessment scores. School location in towns and (big) cities are likewise positively related to our outcomes.

4.1 Gender Differences

From the descriptive statistics in Table 1, female students perform better than males in reading, but worse in mathematics and science. This is also confirmed by the corresponding signs of our estimated coefficients for the variable indicating the student's gender as female, seen in tables A1 to A3 – positive for reading and negative for mathematics and science. This finding resembles that of Dee (2007). However, our focus here is to investigate whether the link between duration of ECE attendance and test outcomes at age 15 is similar for male and female students. We therefore estimate the same specification as column 5 above with all the covariates interacted with the gender variable. Full estimation results are reported in Table A4 in the Appendix. Table 6 reports a test of parameters equality across gender on groups of covariates to verify whether there are gender significant differences.[4]

Table 6. Results on Tests of Parameters on a Model Interacted with Gender

	Reading	Mathematics	Science
Female gender dummy variable interacted with:			
All covariates, plus gender dummy	0.0000	0.0000	0.0000
ECE duration	0.3075	0.1223	0.1474
Student characteristics	0.0342	0.0153	0.0398
Parents characteristics	0.0063	0.0156	0.0008
Home environment	0.0006	0.0010	0.0031
School characteristics	0.0005	0.0022	0.0048
Country, Year, Country-by-year FE	Yes	Yes	Yes

Apart from ECE duration, each of the characteristics has p-values below 0.05, indicating statistical significance in gender difference in the parameters at 95% and 99% confidence intervals. Instead, the significance of the joint test of ECE variables interacted with gender is not statistically significant, which indicates that although male and female students perform differently on the tests, the link between ECE attendance and test scores is not different between the two groups.

Given these results, we estimate a model where all the covariates are interacted with gender, except for the variables indicating ECE duration. The estimated coefficients are shown in columns 1 to 3 of Table 7. Our results show evidence of a non-differential gender link between ECE attendance and assessment outcomes at 15 years of age. This is in line with the findings in the literature (see Dietrichson et al., 2020, which provides a systematic review on preschool programs and long-run outcomes).

Table 7. Results on a Model Interacted with Gender

	(1)	(2)	(3)
VARIABLES	Reading	Math	Science

[4] With 4,983 schools in our sample, a fully interacted model with gender is not possible with School FE.

ECE 1 to <2 years	19.1512***	12.6306***	14.8039***
	(2.137)	(1.095)	(1.939)
ECE 2 to <3 years	24.8029***	20.3722***	20.7531***
	(3.536)	(2.850)	(3.558)
ECE 3 to <4 years	27.7071***	24.4802***	24.0579***
	(3.801)	(2.770)	(3.810)
ECE 4 to <5 years	19.0287***	16.3553***	14.6407***
	(3.179)	(2.513)	(3.032)
ECE 5 or more years	12.6057**	8.0134*	7.4065
	(4.631)	(3.972)	(4.381)
Female	133.6574***	69.0922**	83.0785***
	(29.233)	(23.477)	(27.489)

Note: This table reports the estimated coefficients of the ECE variables for regressions on reading, mathematics, and science tests as the dependent variables, with all covariates interacted with the student gender variable. Students' characteristics include age, gender, and migration background. Parents' characteristics include mother's education, father's education, and highest parental ISEI. Home environment includes the number of books and language spoken at home. School characteristics include school size, public/private school, share of funding from the government, proportion of fully certified teachers, and school location. Robust standard errors are clustered by country in parentheses. *** p<0.01, ** p<0.05, * p<0.10

With this model, we find the same non-constant patterns previously described. The largest magnitudes are at 3 to <4 years, with 27.71, 24.48, and 24.06 for reading, mathematics, and science, respectively. These results are similar to those in Columns 5 in Tables 3 to 5. The lowest are at 5 or more years of participation.

4.2 The Characteristics of the Institutional Context of ECE Provision

All the countries in our sample analysis provide full-time ECE provision. Two of them – the UK and Ireland – provide an additional part-time care option. Apart from those in Finland, Ireland, and the UK, children start primary school (ISCED-1) at age 6. Meanwhile, the average starting age for ISCED-0 is 3 years old. Children from Denmark and Finland can start earlier (0 years) but most do so at 1 year old. Those from Spain, Italy, and the UK can also start at 0 years, but usually do so at 2 years old. The variations in starting ages eventually lead to a range of 1 (e.g. Greece and Ireland) to 5-6 (e.g. Denmark and Finland) years of ECE attendance, but most eventually spend 3 years (OECD, 2016). The structures of ECE settings also differ in terms of organisation and governance and can be classified as either unitary or separate (European Commission/EACEA/Eurydice, 2019).

The service provided by the separate setting system focuses on (non-educational) childcare for younger children, usually until the age of 3, before transitioning older children to a pre-primary school set-up with educational goals. Unitary settings, on the other hand, cover the entire age range until the start of primary schooling, and include both care and early education. With a unitary setting, governance falls under a single entity, usually the Ministry of Education, though other rules and conditions may also apply. Separate settings are instead governed by multiple authorities, creating disparities in provision in terms of access, legal entitlement, and staff qualifications (Vandenbroeck et al., 2018). The lack of continuity evident in separate settings also affects the quality of programming and may disrupt students'

learning (Kaga et al., 2010). One can view the separate setting as corresponding to the ISCED-01 and ISCED-02 system described above.

While separate systems are prevalent in Europe, as reported by Bertram and Pascal (2016), some countries like Austria, Denmark, Germany, and Spain, commonly have both types of systems. There is a recent trend in countries with separate settings to move towards a unitary model, with the aim of providing a more coherent and higher-quality programme that is also more universal and affordable (Bennett, 2008).

We followed the grouping by Eurydice, as reported by the OECD (2019), and distinguished between the unitary/mixed and separate/split systems. Countries with separate ECE settings include Belgium, France, Greece, Ireland, Italy, Luxembourg, Netherlands, and Portugal. The others (Austria, Denmark, Finland, Germany, Sweden, and UK) have either unitary or mixed settings. We then performed analyses similar to those above to investigate whether the impact of ECE duration differs according to the type of institutional setting.

We ran a regression model with all the covariates interacted with a dummy variable indicating whether the ECE setting is separate or unitary/mixed. The p-values resulting from the Wald tests on the different groups of variables all indicate statistical significance, showing differences between the two institutional settings in how ECE duration affects the assessment outcomes of 15-year-olds. Given these results, Table 8 contains the estimated coefficients of the ECE variables differentiating between unitary and separate settings. The magnitudes indicate a similar "peak" at 3 to <4 years of attendance. This is true for both ECE settings and for all three outcomes. Comparing the unitary and separate systems, it can be noticed that having attended ECE in a separate setting corresponds to greater magnitudes of the estimated coefficients, resulting in a stronger impact on test outcomes than having attended ECE in a unitary setting. However, this is only true up to 3 to <4 years of attendance, which is also the maximum effect. In the unitary ECE setting instead, the magnitudes for the unitary ECE setting parameters are greater after 4 or more years, implying an inflection point at the maximum. Considering the educational component related to the different ECE settings, we do not find our results overly surprising. While a unitary setting shows smaller magnitudes, the positive effects are consistently evident in all years, with the exception of 5 or more years of ECE participation for science. Meanwhile, a separate setting proves to be advantageous up until <5 years of ECE attendance, with the magnitudes for 4 to <5 years of attendance comparable to those of 1 to <2 years. These results indicate that the strongest benefits provided by the educational component in unitary settings occurs during the first two years of ECE.

Table 8. Results on a Model Interacted with ECE Institution

	Reading		Mathematics		Science	
	Unitary	Separate	Unitary	Separate	Unitary	Separate
ECE 1 to <2 years	16.8068***	20.2560***	12.6824***	12.0572***	13.3807***	15.5622***
	(4.410)	(1.5869)	(2.1542)	(1.6099)	(3.8362)	1.595829
ECE 2 to <3 years	20.6394***	27.6790***	17.1407***	23.0367***	17.4394**	23.2131***
	(5.355)	(3.8906)	(3.0710)	(3.6736)	(6.2523)	(3.1444)
ECE 3 to <4 years	25.3890***	29.1101***	24.2798***	24.5596***	23.5621***	24.3047***

	(6.133)	(4.8625)	(3.1215)	(4.4015)	(6.8086)	(3.9629)
ECE 4 to <5 years	19.4817***	17.0773***	17.9788***	14.3000***	15.2228**	13.5365***
	(5.065)	(4.3172)	(2.8932)	(3.9647)	(5.2318)	(3.9341)
ECE 5 or more years	14.4381*	8.6219	10.8634**	3.7775	9.8696	3.8089
	(6.800)	(7.4906)	(4.7652)	(7.7860)	(6.9798)	(6.0582)

To test for the robustness of our results, we performed estimations using the other available plausible values in the PISA data as dependent variables. We obtained similar nonlinear partial effects in the duration of ECE attendance. We also get similar results in the heterogeneity patterns. This confirms that estimates will be similar using other plausible values, so long as the sample is large. We also estimated the models excluding students who are first-generation migrants, given that we do not have information on where they attended ECE (i.e. in the current country or the country of origin). Again, the results we obtained are similar.

5.Conclusions

Supporting early childcare availability and attendance is considered one of the most effective policies for promoting the development of children's human capital and reducing socio-economic disparities. Our study provides new insights into this important issue. We provide new evidence on the link between duration of early childcare attendance and later cognitive outcomes. More specifically, we exploit PISA 2015 and 2018 data to explore the long-term effects of ECE by looking at assessment of Reading, Mathematics and Science skills measured at 15 years of age. We estimate the partial effects of years of attendance of ECE within a very broad specification in which we control for a number of fixed effects and include a rich set of student- and household-specific covariates. We document statistically significant positive non-constant partial effects of ECE duration on test outcomes, which peak at 3 to <4 years of participation. Allowing for heterogeneity of the effects across genders we shows that this pattern is present in both male and female students, and no gender differences emerge in the relationship between ECE and assessment outcomes in later years. Finally, we explore the role of different institutional characteristics of the ECE system, and find evidence that educational components in the unitary setting provide the strongest benefits. Our results have potential implications to inform policies relating to investment in early education, especially in terms of the duration of ECE provision, and the educational and schooling components associated with it.

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APPENDIX

Table A1. Full Regression Results for Reading

	Reading					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
ECE 1 to <2 years	32.7460***	27.0150***	21.9838***	19.0699***	19.1764***	16.0845***
	(3.169)	(2.343)	(2.472)	(2.120)	(2.143)	(1.581)
ECE 2 to <3 years	44.5562***	37.4520***	29.3182***	24.9384***	24.7410***	20.5190***
	(4.794)	(3.881)	(3.652)	(3.520)	(3.532)	(1.523)
ECE 3 to <4 years	53.7561***	44.3520***	33.8633***	27.9495***	27.6128***	23.8181***
	(4.698)	(3.791)	(4.013)	(3.735)	(3.801)	(1.499)
ECE 4 to <5 years	46.0424***	37.1050***	24.9883***	19.7497***	18.9480***	17.1046***
	(4.074)	(3.480)	(3.353)	(3.105)	(3.169)	(1.603)
ECE 5 or more years	39.4685***	30.2652***	18.1509***	14.2004**	13.2266**	12.7800***
	(6.400)	(6.015)	(5.046)	(4.856)	(4.775)	(1.869)
Age		18.0005***	18.1616***	16.8467***	16.5390***	14.8546***
		(1.329)	(1.329)	(1.390)	(1.351)	(0.838)
Female		22.6151***	23.5941***	20.2207***	20.1264***	17.3202***
		(2.334)	(2.368)	(2.217)	(2.208)	(0.528)
first-generation migrant		-39.8823***	-27.4729***	-6.7237*	-9.4087**	-8.6423***
		(5.416)	(4.432)	(3.648)	(4.232)	(1.465)
second-generation migrant		-31.1586***	-15.3790***	-1.5506	-4.5587	-4.5871***
		(5.142)	(3.174)	(3.105)	(3.199)	(1.180)
Mother's education: ISCED-3, 4			14.4793***	8.6498***	8.4257***	4.8888***
			(1.826)	(1.446)	(1.649)	(0.779)
Mother's education: ISCED-5, 6			11.6776***	2.4533*	1.8865	-0.9110
			(1.915)	(1.342)	(1.357)	(0.799)
Father's education: ISCED-3, 4			9.2213***	5.5129***	4.9340***	2.4439***
			(1.172)	(1.077)	(1.232)	(0.733)
Father's education: ISCED-5, 6			8.8555***	2.0886	0.7628	-1.9464***
			(1.776)	(1.436)	(1.347)	(0.730)
Highest parental occupation status			1.1120***	0.7610***	0.6989***	0.4520***
			(0.085)	(0.055)	(0.047)	(0.014)
11-25 books at home				27.6527***	27.2302***	18.1909***
				(1.441)	(1.277)	(0.927)
26-100 books at home				53.6303***	53.0296***	37.4843***
				(2.079)	(1.962)	(0.895)
101-200 books at home				71.1046***	70.0102***	50.8135***
				(2.467)	(2.410)	(0.990)
201-500 books at home				89.2800***	87.6382***	64.6648***
				(3.369)	(3.128)	(1.055)
more than 500 books at home				89.9007***	88.2618***	65.2730***
				(4.724)	(4.453)	(1.284)
same language at home and test				17.6003***	15.7419***	13.8018***
				(3.732)	(4.026)	(1.031)
School size					0.0094**	
					(0.004)	
Public school					0.4120	

					(3.174)	
Share of funding from government					-0.1318**	
					(0.051)	
Proportion of fully certified teachers					9.9962*	
					(5.403)	
School community in a small town					6.1610*	
					(3.153)	
School community in a town					10.9680***	
					(3.608)	
School community in a city					16.4177***	
					(4.590)	
School community in a large city					15.8506**	
					(5.572)	
Constant	445.9556***	163.6078***	94.5259***	76.3217**	73.7872**	163.5681***
	(3.683)	(20.128)	(23.991)	(26.509)	(26.656)	(13.377)
Country, Year FE	Y	Y	Y	Y	Y	Y
Country-by-year FE	Y	Y	Y	Y	Y	Y
School FE						Y
Observations	109,012	109,012	109,012	109,012	109,012	109,012
R-squared	0.017	0.049	0.136	0.212	0.220	0.112
Number of countries	14	14	14	14	14	
Number of schools						4,983

Robust standard errors clustered (by country in columns 1-5, by school in column 6) in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Table A2. Full Regression Results for Mathematics

	Math					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
ECE 1 to <2 years	24.3786***	20.0803***	15.0247***	12.6447***	12.7006***	10.4652***
	(1.890)	(1.353)	(1.451)	(1.215)	(1.095)	(1.454)
ECE 2 to <3 years	37.6151***	32.4114***	24.2876***	20.4854***	20.3830***	16.6917***
	(3.508)	(3.106)	(2.929)	(2.896)	(2.849)	(1.374)
ECE 3 to <4 years	46.4589***	40.3638***	29.9036***	24.7308***	24.4193***	20.6811***
	(3.485)	(2.761)	(2.867)	(2.738)	(2.769)	(1.367)
ECE 4 to <5 years	39.3643***	33.7839***	21.6658***	17.0621***	16.3189***	13.7533***
	(3.673)	(3.044)	(2.698)	(2.494)	(2.512)	(1.475)
ECE 5 or more years	30.1437***	24.8270***	12.6908**	9.2120**	8.4772*	7.6279***
	(5.499)	(5.584)	(4.314)	(4.161)	(4.118)	(1.720)
Age		17.2254***	17.4268***	16.2070***	15.9524***	14.2508***
		(1.319)	(1.177)	(1.323)	(1.291)	(0.792)
Female		-12.6191***	-11.6378***	-14.6975***	-14.7858***	-15.9542***
		(1.731)	(1.834)	(1.673)	(1.650)	(0.486)
first-generation migrant		-37.4755***	-25.2634***	-8.7433**	-10.6958***	-8.9386***
		(5.320)	(4.143)	(3.071)	(2.797)	(1.306)
second-generation migrant		-32.8076***	-17.1047***	-6.2798**	-8.3770***	-7.5132***
		(5.189)	(3.475)	(2.480)	(2.486)	(1.074)
Mother's education: ISCED-3, 4			15.1424***	9.8061***	9.5764***	5.3180***
			(1.579)	(1.184)	(1.304)	(0.747)
Mother's education: ISCED-5, 6			13.3378***	4.8469***	4.2681***	0.8629
			(1.621)	(1.338)	(1.191)	(0.777)
Father's education: ISCED-3, 4			10.1389***	6.6779***	6.1865***	3.1627***
			(0.858)	(0.722)	(0.794)	(0.693)
Father's education: ISCED-5, 6			10.2581***	4.0267**	2.8611*	-0.1493
			(1.743)	(1.648)	(1.596)	(0.704)
Highest parental occupation status			1.0717***	0.7520***	0.6950***	0.4596***
			(0.064)	(0.038)	(0.037)	(0.013)
11-25 books at home				24.5798***	24.1078***	15.3664***
				(1.729)	(1.628)	(0.907)
26-100 books at home				50.0529***	49.3293***	34.1090***
				(2.246)	(2.222)	(0.852)
101-200 books at home				66.9324***	65.6713***	46.5147***
				(1.990)	(1.943)	(0.957)
201-500 books at home				81.1752***	79.4018***	56.8025***
				(2.518)	(2.256)	(1.003)
more than 500 books at home				83.2389***	81.4620***	58.1152***
				(3.620)	(3.488)	(1.204)
same language at home and test				9.0204**	7.1169	6.9341***
				(3.682)	(4.177)	(0.920)
School size					0.0102***	
					(0.003)	
Public school					-2.7123	

					(3.333)	
Share of funding from government					-0.1673**	
					(0.063)	
Proportion of fully certified teachers					8.0981	
					(4.751)	
School community in a small town					4.8324*	
					(2.280)	
School community in a town					5.1990*	
					(2.833)	
School community in a city					8.9369**	
					(3.375)	
School community in a large city					8.1692*	
					(4.332)	
Constant	453.0635***	198.4303***	128.7728***	117.9638***	126.2040***	201.7036***
	(2.464)	(20.544)	(20.529)	(23.850)	(26.170)	(12.646)
Country, Year FE	Y	Y	Y	Y	Y	Y
Country-by-year FE	Y	Y	Y	Y	Y	Y
School FE						Y
Observations	109,012	109,012	109,012	109,012	109,012	109,012
R-squared	0.014	0.038	0.135	0.208	0.215	0.107
Number of countries	14	14	14	14	14	
Number of schools						4,983

Robust standard errors clustered (by country in columns 1-5, by school in column 6) in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Table A3. Full Regression Results for Science

	Science					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
ECE 1 to <2 years	27.2598***	22.5279***	17.4567***	14.7843***	14.7934***	11.9882***
	(2.689)	(2.220)	(2.304)	(1.960)	(1.967)	(1.531)
ECE 2 to <3 years	38.9436***	33.1959***	25.0093***	20.8177***	20.6831***	16.5897***
	(4.613)	(3.964)	(3.748)	(3.549)	(3.550)	(1.445)
ECE 3 to <4 years	47.4618***	40.5041***	29.9513***	24.2279***	23.9290***	19.9076***
	(4.746)	(4.177)	(4.208)	(3.747)	(3.822)	(1.426)
ECE 4 to <5 years	38.9505***	32.5017***	20.2659***	15.1834***	14.5553***	12.3942***
	(3.972)	(3.518)	(3.229)	(2.935)	(3.034)	(1.535)
ECE 5 or more years	30.8994***	24.6630***	12.3977**	8.5737*	7.9090	6.9284***
	(5.871)	(5.857)	(4.781)	(4.603)	(4.597)	(1.829)
Age		16.5031***	16.7190***	15.3622***	15.1347***	13.2578***
		(1.515)	(1.461)	(1.614)	(1.571)	(0.823)
Female		-4.9409**	-3.9415	-7.3184***	-7.4078***	-8.6106***
		(2.208)	(2.339)	(2.097)	(2.088)	(0.521)
first-generation migrant		-38.7907***	-26.4810***	-7.4819*	-9.1702*	-7.6631***
		(5.441)	(4.240)	(3.962)	(4.596)	(1.404)
second-generation migrant		-36.4211***	-20.5759***	-7.9976**	-9.8203**	-9.0177***
		(5.570)	(3.664)	(3.490)	(3.795)	(1.160)
Mother's education: ISCED-3, 4			14.5811***	8.7442***	8.5546***	4.8102***
			(1.587)	(1.328)	(1.416)	(0.760)
Mother's education: ISCED-5, 6			13.2480***	3.9095***	3.4460**	0.6564
			(1.717)	(1.231)	(1.167)	(0.794)
Father's education: ISCED-3, 4			9.9534***	6.1803***	5.7497***	2.7905***
			(1.052)	(0.929)	(1.042)	(0.720)
Father's education: ISCED-5, 6			10.5034***	3.6201**	2.6445*	-0.3468
			(1.856)	(1.440)	(1.328)	(0.726)
Highest parental occupation status			1.0838***	0.7297***	0.6821***	0.4496***
			(0.082)	(0.052)	(0.045)	(0.014)
11-25 books at home				25.7488***	25.3076***	16.3276***
				(1.558)	(1.375)	(0.920)
26-100 books at home				53.1386***	52.4887***	36.9610***
				(2.090)	(1.962)	(0.881)
101-200 books at home				72.2527***	71.1790***	51.7609***
				(2.655)	(2.664)	(0.982)
201-500 books at home				89.2706***	87.7888***	64.2485***
				(3.836)	(3.532)	(1.032)
more than 500 books at home				90.1908***	88.7391***	64.9619***
				(4.877)	(4.591)	(1.272)
same language at home and test				12.3927**	10.7692*	10.7935***
				(4.530)	(5.095)	(0.995)
School size					0.0090**	
					(0.004)	
Public school					-2.2738	

					(4.077)	
Share of funding from government					-0.1135*	
					(0.057)	
Proportion of fully certified teachers					9.2735*	
					(4.627)	
School community in a small town					3.4102	
					(2.619)	
School community in a town					4.8268	
					(3.202)	
School community in a city					7.8648*	
					(4.134)	
School community in a large city					6.5908	
					(4.730)	
Constant	465.2730***	219.0302***	148.7450***	136.1963***	138.5892***	207.8482***
	(3.594)	(24.007)	(26.289)	(28.968)	(29.611)	(13.142)
Country, Year FE	Y	Y	Y	Y	Y	Y
Country-by-year FE	Y	Y	Y	Y	Y	Y
School FE						Y
Observations	109,012	109,012	109,012	109,012	109,012	109,012
R-squared	0.014	0.034	0.126	0.207	0.212	0.106
Number of countries	14	14	14	14	14	
Number of schools						4,983

Robust standard errors clustered (by country in columns 1-5, by school in column 6) in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Table A4. Full Regression Results for the Gender-Interacted Model

VARIABLES	(1) Reading	(2) Math	(3) Science	(1) Reading	(2) Math	(3) Science
ECE 1 to <2 years	19.3614***	11.9092***	14.8451***	19.1512***	12.6306***	14.8039***
	(3.019)	(1.601)	(2.901)	(2.137)	(1.095)	(1.939)
ECE 2 to <3 years	26.2757***	21.3773***	22.2480***	24.8029***	20.3722***	20.7531***
	(4.679)	(3.423)	(4.533)	(3.536)	(2.850)	(3.558)
ECE 3 to <4 years	29.6051***	25.5223***	26.4549***	27.7071***	24.4802***	24.0579***
	(4.776)	(3.711)	(4.423)	(3.801)	(2.770)	(3.810)
ECE 4 to <5 years	20.4062***	16.0383***	16.3657***	19.0287***	16.3553***	14.6407***
	(3.721)	(2.461)	(3.402)	(3.179)	(2.513)	(3.032)
ECE 5 or more years	12.4332**	6.5210	7.5704	12.6057**	8.0134*	7.4065
	(5.328)	(4.280)	(5.184)	(4.631)	(3.972)	(4.381)
Female	136.5470***	71.1945***	85.6559***	133.6574***	69.0922**	83.0785***
	(27.571)	(22.847)	(25.998)	(29.233)	(23.477)	(27.489)
ECE 1 to <2 years x Female	-0.6219	1.3882	-0.3253			
	(2.406)	(2.209)	(2.483)			
ECE 2 to <3 years x Female	-3.1670	-2.0812	-3.2595			
	(3.377)	(2.894)	(3.200)			
ECE 3 to <4 years x Female	-3.9978	-2.1308	-5.0296			
	(3.294)	(3.487)	(3.149)			
ECE 4 to <5 years x Female	-2.9949	0.4273	-3.7326			
	(2.627)	(2.864)	(2.624)			
ECE 5 or more years x Female	-0.1259	2.5938	-0.8252			
	(2.852)	(3.333)	(3.302)			
Age	19.9677***	18.8444***	18.0900***	19.9559***	18.7957***	18.1046***
	(1.795)	(1.626)	(1.954)	(1.808)	(1.653)	(1.982)
Age x Female	-6.4162***	-5.4399***	-5.5400***	-6.4030***	-5.3538***	-5.5804***
	(1.888)	(1.437)	(1.706)	(1.959)	(1.513)	(1.798)
First-generation migrant	-9.6036***	-9.7649***	-8.1558*	-9.8524***	-9.9483***	-8.4676**
	(3.042)	(2.545)	(3.838)	(3.082)	(2.553)	(3.876)
Second-generation migrant	-5.6088	-9.4832***	-10.6908**	-5.6049	-9.4728***	-10.6885**
	(3.598)	(2.300)	(3.896)	(3.605)	(2.308)	(3.898)
First-generation migrant x Female	0.5899	-1.5034	-1.7305	1.1202	-1.1276	-1.0579
	(2.797)	(2.120)	(2.085)	(2.702)	(1.991)	(1.944)
Second-generation migrant x Female	1.9335	2.0658	1.6164	1.9267	2.0489	1.6106
	(2.314)	(1.446)	(2.494)	(2.313)	(1.437)	(2.492)
Mother's education: ISCED-3, 4	7.2806***	9.7468***	8.3808***	7.2990***	9.7503***	8.4025***
	(1.983)	(2.065)	(1.677)	(1.997)	(2.080)	(1.691)
Mother's education: ISCED-5, 6	-0.1801	2.8895**	1.7868	-0.1707	2.8725**	1.8021
	(1.277)	(1.154)	(1.433)	(1.277)	(1.155)	(1.446)
Mother's education: ISCED-3, 4 x Female	2.2904	-0.2294	0.4550	2.2637	-0.2193	0.4192
	(1.593)	(1.833)	(1.671)	(1.604)	(1.861)	(1.685)
Mother's education: ISCED-5, 6 x Female	4.0185**	2.7066*	3.1944	4.0053**	2.7542*	3.1637
	(1.444)	(1.489)	(2.197)	(1.454)	(1.504)	(2.204)
Father's education: ISCED-	4.5860*	6.8650***	5.4956**	4.5806*	6.8456***	5.4892**

3, 4						
	(2.201)	(1.245)	(2.055)	(2.199)	(1.244)	(2.056)
Father's education: ISCED-5, 6	-0.5979	1.9331	1.5832	-0.6049	1.9180	1.5760
	(1.970)	(2.102)	(1.760)	(1.966)	(2.099)	(1.757)
Father's education: ISCED-3, 4 x Female	0.6817	-1.2151	0.4578	0.6832	-1.1994	0.4648
	(2.165)	(1.684)	(2.115)	(2.160)	(1.670)	(2.114)
Father's education: ISCED-5, 6 x Female	2.6144	1.8593	2.0336	2.6286	1.8823	2.0552
	(2.121)	(1.537)	(1.866)	(2.108)	(1.528)	(1.854)
Highest parental occupation status	0.7375***	0.7241***	0.7219***	0.7386***	0.7247***	0.7233***
	(0.053)	(0.045)	(0.052)	(0.053)	(0.045)	(0.052)
Highest parental occupation status x Female	-0.0765**	-0.0592**	-0.0776**	-0.0786**	-0.0604*	-0.0805***
	(0.026)	(0.027)	(0.026)	(0.026)	(0.028)	(0.026)
11-25 books at home	28.6507***	24.2741***	26.0306***	28.6950***	24.3136***	26.0843***
	(1.487)	(1.746)	(1.468)	(1.480)	(1.738)	(1.459)
26-100 books at home	53.2312***	49.8638***	52.4227***	53.3041***	49.9220***	52.5146***
	(2.272)	(2.757)	(2.464)	(2.272)	(2.753)	(2.473)
101-200 books at home	70.0607***	66.3168***	71.3444***	70.1570***	66.3950***	71.4709***
	(2.860)	(1.845)	(3.039)	(2.837)	(1.835)	(3.039)
201-500 books at home	87.0232***	80.6194***	87.4568***	87.1277***	80.7090***	87.5914***
	(3.935)	(2.930)	(4.436)	(3.916)	(2.926)	(4.431)
more than 500 books at home	82.5087***	76.2570***	82.4651***	82.5816***	76.3095***	82.5659***
	(4.155)	(3.537)	(4.299)	(4.147)	(3.531)	(4.300)
11-25 books at home x Female	-2.8122*	-0.4579	-1.5014	-2.9174*	-0.5412	-1.6342
	(1.487)	(1.424)	(1.590)	(1.459)	(1.406)	(1.581)
26-100 books at home x Female	-0.4557	-1.1583	0.0644	-0.6049	-1.2755	-0.1230
	(1.996)	(1.605)	(1.877)	(1.955)	(1.575)	(1.886)
101-200 books at home x Female	-0.2341	-1.3664	-0.4406	-0.4144	-1.5092	-0.6754
	(2.709)	(1.777)	(2.256)	(2.624)	(1.693)	(2.200)
201-500 books at home x Female	0.7368	-2.5273	0.2496	0.5373	-2.6843	-0.0107
	(3.323)	(2.627)	(2.742)	(3.242)	(2.550)	(2.691)
more than 500 books at home x Female	10.7270***	9.6627***	11.6427***	10.5682***	9.5330***	11.4310***
	(3.150)	(2.209)	(3.211)	(3.101)	(2.134)	(3.206)
same language at home and test	18.0838***	8.2627*	12.7678**	18.1178***	8.2929*	12.8079**
	(4.032)	(4.259)	(5.202)	(4.009)	(4.234)	(5.191)
same language at home and test x Female	-4.7139**	-2.2964*	-3.9343***	-4.7648**	-2.3348*	-3.9918***
	(1.878)	(1.238)	(1.090)	(1.882)	(1.204)	(1.066)
School size	0.0106**	0.0109***	0.0095**	0.0106**	0.0109***	0.0095**
	(0.004)	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)
School size x Female	-0.0023***	-0.0013	-0.0010	-0.0023***	-0.0013	-0.0010
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Public school	0.1941	-3.6863	-3.9117	0.1819	-3.6676	-3.9447
	(4.041)	(4.030)	(5.199)	(4.058)	(4.061)	(5.214)
Public school x Female	0.1697	1.7643	2.9707	0.1842	1.7245	3.0182
	(3.358)	(3.034)	(3.434)	(3.364)	(3.061)	(3.441)

Share of funding from government	-0.1091*	-0.1601**	-0.0973	-0.1089*	-0.1598**	-0.0971
	(0.055)	(0.069)	(0.058)	(0.055)	(0.069)	(0.059)
Share of funding from government x Female	-0.0406	-0.0138	-0.0301	-0.0406	-0.0141	-0.0301
	(0.024)	(0.028)	(0.024)	(0.024)	(0.029)	(0.024)
Proportion of fully certified teachers	11.7546*	9.2665	11.2845*	11.7725*	9.2828	11.3024*
	(6.595)	(5.738)	(5.516)	(6.592)	(5.739)	(5.515)
Proportion of fully certified teachers x Female	-3.2552	-2.1774	-3.7762	-3.2833	-2.2065	-3.8058
	(2.861)	(2.085)	(2.456)	(2.859)	(2.090)	(2.456)
School community in a small town	7.6948*	5.4835*	4.0939	7.7129*	5.4780*	4.1206
	(3.724)	(2.802)	(3.223)	(3.715)	(2.782)	(3.206)
School community in a town	13.1843***	6.1853	6.3323	13.2057***	6.1717	6.3673
	(4.262)	(3.588)	(3.988)	(4.263)	(3.590)	(3.994)
School community in a city	19.9202***	10.7020**	9.8999*	19.9310***	10.6743**	9.9270*
	(5.334)	(3.954)	(4.968)	(5.324)	(3.944)	(4.957)
School community in a large city	18.7100**	11.7771**	10.3064*	18.7187**	11.7456**	10.3251*
	(6.310)	(4.609)	(5.113)	(6.290)	(4.575)	(5.092)
School community in a small town x Female	-3.1796	-1.2793	-1.3738	-3.2109	-1.2789	-1.4261
	(2.245)	(1.921)	(1.922)	(2.259)	(1.898)	(1.930)
School community in a town x Female	-4.4726	-1.8826	-2.9264	-4.5039	-1.8711	-2.9854
	(2.755)	(2.607)	(2.466)	(2.788)	(2.614)	(2.508)
School community in a city x Female	-6.9171**	-3.4159	-4.0065	-6.9370**	-3.3742	-4.0625
	(3.022)	(2.481)	(2.552)	(3.022)	(2.466)	(2.562)
School community in a large city x Female	-5.9202	-7.1822**	-7.4865**	-5.9355	-7.1340**	-7.5266**
	(3.683)	(2.587)	(2.678)	(3.682)	(2.566)	(2.699)
Constant	10.6597	77.2172**	86.8837**	12.0004	78.3229**	88.0200**
	(30.258)	(29.740)	(33.110)	(30.653)	(30.014)	(33.176)
Country FE x Gender	Y	Y	Y	Y	Y	Y
Year FE, Year FE x Gender	Y	Y	Y	Y	Y	Y
Country-by-year FE, Country-by-year FE x Gender	Y	Y	Y	Y	Y	Y
Observations	109,012	109,012	109,012	109,012	109,012	109,012
R-squared	0.223	0.217	0.215	0.223	0.217	0.215
Number of countries	14	14	14	14	14	14

Robust standard errors clustered by country in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Table A5. Full Regression Results for the ECE Institution-Interacted Model

VARIABLES	(1) Reading	(2) Math	(3) Science
ECE 1 to <2 years	16.8068***	12.6824***	13.3807***
	(4.410)	(2.154)	(3.836)
ECE 2 to <3 years	20.6394***	17.1407***	17.4394**
	(5.355)	(3.071)	(6.252)
ECE 3 to <4 years	25.3890***	24.2798***	23.5621***
	(6.133)	(3.121)	(6.809)
ECE 4 to <5 years	19.4817***	17.9788***	15.2228**
	(5.065)	(2.893)	(5.232)
ECE 5 or more years	14.4381*	10.8634**	9.8696
	(6.800)	(4.765)	(6.980)
ECE 1 to <2 years x Separate ECE setting	3.4492	-0.6252	2.1815
	(4.687)	(2.689)	(4.155)
ECE 2 to <3 years x Separate ECE setting	7.0396	5.8960	5.7737
	(6.619)	(4.788)	(6.998)
ECE 3 to <4 years x Separate ECE setting	3.7211	0.2798	0.7427
	(7.826)	(5.396)	(7.878)
ECE 4 to <5 years x Separate ECE setting	-2.4044	-3.6788	-1.6864
	(6.655)	(4.908)	(6.546)
ECE 5 or more years x Separate ECE setting	-5.8161	-7.0859	-6.0607
	(10.117)	(9.128)	(9.242)
Age	16.7314***	15.5165***	13.0033***
	(1.937)	(1.745)	(1.579)
Age x Separate ECE setting	0.5949	1.2800	4.5446*
	(2.502)	(2.297)	(2.467)
Female	21.3658***	-15.2068***	-6.5392*
	(3.892)	(2.436)	(3.520)
Female x Separate ECE setting	-2.9374	0.5797	-2.1411
	(4.282)	(3.198)	(4.061)
First-generation migrant	-5.5552	-8.4351*	-2.4091
	(4.559)	(4.694)	(3.585)
Second-generation migrant	2.7204	-4.2128	-2.2050
	(2.174)	(3.920)	(3.611)
First-generation migrant x Separate ECE setting	-8.4333	-4.1558	-12.8315**
	(5.096)	(5.448)	(4.985)
Second-generation migrant x Separate ECE setting	-12.1091***	-6.2010	-11.9985**
	(3.317)	(4.305)	(4.423)
Mother's education: ISCED-3, 4	5.1502**	7.8389***	7.3052**
	(2.298)	(1.941)	(2.736)
Mother's education: ISCED-5, 6	0.1592	4.4872***	3.5901**
	(1.101)	(0.544)	(1.243)
Mother's education: ISCED-3, 4 x Separate ECE setting	5.7477**	3.0833	2.4265
	(2.527)	(2.451)	(2.976)
Mother's education: ISCED-5, 6 x Separate ECE setting	2.6780	-0.5771	-0.2395
	(2.522)	(2.686)	(2.501)
Father's education: ISCED-3, 4	2.5239**	5.3818***	3.1969***
	(1.142)	(0.669)	(0.389)
Father's education: ISCED-5, 6	0.1015	3.5334**	2.7716**
	(1.124)	(1.506)	(1.114)

Father's education: ISCED-3, 4 x Separate ECE setting	4.0228**	1.2008	4.3372***
	(1.801)	(1.462)	(0.919)
Father's education: ISCED-5, 6 x Separate ECE setting	0.7200	-1.6961	-0.6797
	(2.699)	(3.515)	(2.835)
Highest parental occupation status	0.6132***	0.6252***	0.5978***
	(0.034)	(0.015)	(0.028)
Highest parental occupation status x Separate ECE setting	0.1891***	0.1482**	0.1849***
	(0.051)	(0.049)	(0.051)
11-25 books at home	26.0594***	22.6032***	24.4192***
	(1.087)	(2.184)	(1.973)
26-100 books at home	52.0200***	49.4826***	53.2002***
	(2.637)	(3.004)	(2.142)
101-200 books at home	70.1964***	64.9271***	73.4743***
	(2.826)	(3.098)	(3.001)
201-500 books at home	88.5165***	78.8355***	89.9705***
	(3.820)	(2.761)	(4.491)
more than 500 books at home	86.8300***	80.3709***	89.3993***
	(5.296)	(3.120)	(5.970)
11-25 books at home x Separate ECE setting	1.4717	2.4243	1.1794
	(2.181)	(3.126)	(2.628)
26-100 books at home x Separate ECE setting	0.9484	-1.1873	-2.1346
	(3.524)	(4.047)	(3.335)
101-200 books at home x Separate ECE setting	-1.6746	0.6353	-5.7513
	(4.141)	(3.704)	(4.005)
201-500 books at home x Separate ECE setting	-3.3678	0.0839	-5.6977
	(5.990)	(4.447)	(6.603)
more than 500 books at home x Separate ECE setting	1.0495	0.8503	-2.7488
	(8.491)	(6.714)	(8.825)
same language at home and test	17.7511**	10.7797**	17.3499***
	(6.506)	(4.408)	(5.475)
same language at home and test x Separate ECE setting	-4.4489	-7.2602	-13.0671
	(8.586)	(7.507)	(8.723)
School size	0.0049	0.0068***	0.0048
	(0.003)	(0.002)	(0.003)
School size x Separate ECE setting	0.0072	0.0053	0.0064
	(0.006)	(0.005)	(0.006)
Public school	-2.6306	-2.8563	-2.6182
	(2.507)	(3.390)	(3.888)
Public school x Separate ECE setting	0.2153	-2.6310	-2.3542
	(5.390)	(5.658)	(5.803)
Share of funding from government	-0.1022	-0.2086***	-0.1249*
	(0.070)	(0.039)	(0.066)
Share of funding from government x Separate ECE setting	-0.0267	0.0820	0.0177
	(0.091)	(0.090)	(0.096)
Proportion of fully certified teachers	1.3412	0.8508	0.6765
	(2.210)	(1.925)	(1.912)
Proportion of fully certified teachers x Separate ECE setting	14.4174	12.8310	15.2503*
	(8.983)	(7.747)	(7.413)
School community in a small town	2.6638	3.4504	-0.3220
	(2.783)	(2.115)	(2.627)
School community in a town	7.0939*	3.0970	0.7574
	(3.339)	(3.272)	(3.373)

School community in a city	10.1490***	5.4245**	1.0647
	(3.017)	(2.327)	(2.348)
School community in a large city	4.8562	-1.7884	-4.6753*
	(3.152)	(1.902)	(2.521)
School community in a small town x Separate ECE setting	9.5743	4.0104	9.5403*
	(5.821)	(4.868)	(4.444)
School community in a town x Separate ECE setting	10.3049	5.4961	10.5801*
	(6.905)	(5.970)	(5.644)
School community in a city x Separate ECE setting	16.1280*	9.3160	17.1092**
	(8.298)	(6.840)	(6.346)
School community in a large city x Separate ECE setting	22.2704**	18.8743***	22.5324***
	(8.688)	(6.242)	(6.634)
Constant	82.6600***	133.0489***	139.2989***
	(24.120)	(22.310)	(23.621)
Year FE, Year FE x Institutional setting	Y	Y	Y
Observations	109,012	109,012	109,012
R-squared	0.222	0.216	0.215
Number of countries	14	14	14

Robust standard errors clustered by country in parentheses. *** p<0.01, ** p<0.05, * p<0.10