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Computers and students' achievement: An analysis of the One Laptop per Child program in Catalonia

Toni Mora[a,*], Josep-Oriol Escardíbul[b], Giorgio Di Pietro[c,d]

[a] Research Institute for Evaluation and Public Policies, Universitat Internacional de Catalunya, Spain
[b] University of Barcelona & IEB, Spain
[c] University of Westminster, United Kingdom
[d] IZA, Germany

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ABSTRACT

We analyse the impact of a One Laptop per Child program introduced by the Catalan government on student achievement. Using longitudinal population data for students in secondary education during the period 2009–2016, our identification strategy exploits variations across cohorts within schools. Although participation into the program was not random, we control for a number of school characteristics that influenced school participation. The empirical results consistently indicate that this program had a negative impact on student performance in Catalan, Spanish, English and mathematics. Test scores fell by 0.20–0.22 standardised points, which represent 3.8–6.2% of the average test score. This negative effect was stronger among boys than it was among girls (differences ranging from 10% to 42%).

1. Introduction

Education has moved into the digital era, and laptops and other technologies have been progressively introduced into classrooms around the world. This diffusion has been partly fostered by public authorities, often as part of the One Laptop per Child (OLPC) program, whereby an education authority provides laptops to children (for free or at a subsidized cost) instead of traditional textbooks. The value of OLPC programs is rarely questioned, as they appear to be modernising schools and boosting pupils' acquisition of information and communication technology (ICT) skills. However, in the economics literature, no consensus has yet been reached about the impact of OLPC programs in particular, and the use of computers in general, on student skills and academic performance.

In this study, we analyse a program implemented by the Catalan government (known first as eduCAT1 × 1 and later as eduCAT2.0), aimed at providing laptops, wireless connectivity and digital boards to participating schools. Specifically, we study the impact that this program had on student performance in Catalan, Spanish, English and mathematics.

This paper adds to the existing literature on the effect of computer use on academic achievement in two main aspects. First, there are only a few studies examining the impact of an OLPC program on student performance in Europe. Second, our analysis considers population data for students in secondary education for an entire educational administration (the region of Catalonia) and not just a local experience limited to a few schools.

Our results consistently show that the eduCAT program had a small, but statistically significant negative effect on student performance. This negative effect is greater among boys than among girls. In order to check the robustness of these findings,

* Corresponding author at: Research Institute for Evaluation and Public Policies, Universitat Internacional de Catalunya, Immaculada, 22, 08017, Barcelona, Spain.

E-mail address: tmora@uic.es (T. Mora).

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administrative data are combined with information on school time-varying confounding characteristics derived from a survey we conducted in almost 70% of all schools. Results are robust to the inclusion of this additional information.

The remainder of this paper is organised as follows. Section 2 provides an overview of the related literature. In Section 3, we outline the program and provide a description of the data used. Section 4 describes the econometric methodology and presents the empirical results. Section 5 concludes.

2. Literature review

Many studies have examined the effects of computer use at school on student achievement: some have analysed pioneer experiences, such as the program run in Maine (United States), although it involved only a few schools (Penuel, 2006); others have attempted to evaluate the OLPC program, the aim of which is to distribute low-cost, low-power laptop computers to children in less developed countries. According to Beuermann, Cristia, Cueto, Malamud, and Cruz-Aguayo, (2015), in 2015, there were around 50 OLPC projects in operation around the world.

Jiménez–Martín and Vilaplana (2014) evaluated the impact of a program (Escuela 2.0) similar to eduCAT. Such a program was implemented between the end of the 2000s and the beginning of the 2010s in the vast majority of the Spanish autonomous communities. Participants were public school students in their last two years of primary school and in their first two years of secondary school. Using a difference-in-differences strategy, the authors find that not only did Escuela 2.0 fail to boost student performance in mathematics, but there were actually negative consequences.

De Melo, Machado, and Miranda, (2014) analysed the impact of one of the largest deployments of an OLPC program. Known as the Plan Ceibal, it provided a laptop to every student attending primary and secondary schools in Uruguay. The variation in the date of laptop delivery across students within the same school was used to identify the program's impact. Difference-in-differences estimates indicate that the Plan Ceibal had no effect on mathematics and reading scores two years after its implementation. The authors argue that the lack of training programs for teachers may account for this outcome, plus the fact the laptops might have been used primarily to conduct internet searches. Mo et al. (2013) examined the effectiveness of an OLPC program that targeted 13 migrant schools in suburban areas of Beijing (China). Notwithstanding the small sample size (i.e. 300 third-grade students) and the participants' lack of internet access at home, the authors concluded that this program enhanced student computer skills and self-esteem and led to a reduction in the number of hours spent watching TV.

Various studies have examined the effect of other programs (i.e. other than OLPC programs) involving the distribution of computers. For instance, Carrillo, Onofa, and Ponce, (2011) evaluated a program providing computer-aid assistance in mathematics and reading to primary school students in the Guayaquil municipality (Ecuador). Their findings show that while this program had a positive impact on mathematics test scores, no statistically significant effect was found on language test scores. Barrera-Osorio and Linden (2009) conducted a two-year experiment involving the random provision of free computers to 97 Colombian schools (5201 students). These computers were donated by the private sector in an attempt to improve the academic performance of public school students. Overall, the program appears to have had little impact on students' test scores. The main reason for this may lie in the teachers' failure to incorporate the computers into the curriculum.

Most of the aforementioned studies concluded that computers have little or no effect on student performance. The main reason for this outcome seems to be the failure to incorporate the use of computers in day-to-day classroom activities due to the teachers' lack of training. This argument is further supported by Alonso-Cano, Romeu-Fontanillas, and Guitert-Catasús, (2014), who claim that in Catalonia teachers appear to be reluctant to use technology in the classroom. Given the crucial role played by teachers in the educational process, Slater, Davies, and Burgess, (2012) argued that future research on the effect of computer use at school needs to account for the heterogeneity of teachers. According to Bietenbeck (2014), a further reason why computer use appears not to have any impact on student academic performance is that while modern teaching practices involving computers may boost reasoning skills, these are often not tested on standardised tests.

Additional research has examined the impact of specific software programs on student achievement. Banerjee, Cole, Duflo, and Linden, (2007) showed that a computer assistance-learning program focusing on mathematics improved the mathematics scores of fourth-grade students in Mumbai and Vadodara (India). Similarly, Barrow, Markman, and Rouse, (2009) ran an experiment involving the random assignment of a specific algebra software program in three US urban districts. They found that treated students had higher scores on pre-algebra and algebra tests than those who did not use this software program. In contrast, Campuzano, Dynarski, Agodini, and Rall, (2009) concluded that the provision of specific software products did not affect student test scores after one school year. This result is consistent with that of Rouse and Krueger (2004) who studied the impact of a well-known software program (Fast ForWord) designed to improve language and reading skills.

Several studies have investigated the impact of home computers on educational outcomes. For instance, Malamud and Pop-Eleches (2011) looked at the effect of a program in Romania that allocated vouchers for the purchase of a home computer to children of more disadvantaged families. This program was found to have a negative impact on educational performance, but it improved computer skills. Similarly, Fairlie and Robinson (2013) did not find any evidence of a significant impact of home computers on mathematics and reading test scores in several schools in California. Again, no impact on student achievement was found in a study by Beuermann et al. (2015), in which about 1000 laptops were provided for home use to students randomly selected from those attending primary schools in Lima, Peru.

Finally, a few papers have analysed the impact of investment in ICT on school performance. Machin, McNally, and Silva, (2007) studied the effect of ICT expenditure on pupil outcomes in the UK, exploiting exogenous variations in ICT funding across different school districts. Their estimates identified a positive impact on science and English grades, but not on mathematics grades. Leuven, Lindahl, Oosterbeek, and Webbink, (2007) examined the effect of extra funding for computers and software on the academic performance of low-income students in several Dutch primary schools. They found evidence of negative effects. Finally, Goolsbee and Guryan (2006) showed that while a major subsidy for ICT investment in schools in California increased internet access in classrooms, it did not improve student achievement.

3. The eduCAT program

The Catalan education system, which is part of the Spanish state system, comprises: (a) six years of primary school, (b) four years of compulsory secondary education (known as ESO, *Educación Secundaria Obligatoria*) and (c) two years of non-compulsory secondary education. As regards the latter, students may choose a vocational track (*ciclos formativos de grado medio*) or an academic track (*bachillerato*).

In the academic year 2009–10, the Education Department of the Catalan regional government initiated a program (i.e. eduCAT1 × 1) aimed at promoting the use of technology in secondary schools. This program, which was financed by the Spanish Ministry of Education, was managed by the Catalan Department of Education that had autonomy in its implementation. EduCAT1 × 1 consisted of three main actions: (i) providing laptops as a learning device, (ii) providing interactive digital boards and wireless connectivity (local and internet) and (iii) freely and progressively replacing traditional hard copies of textbooks with e-books. Half the cost of each laptop was covered by the regional government and the other half by the student's parents. However, financial assistance was given to those parents who could not afford to pay for this. Students were, of course, able to take their laptops home with them. All secondary schools in Catalonia were invited to participate in the program. EduCAT1 × 1 was addressed only to students in the first year of compulsory secondary education.

One year after its implementation, eduCAT1 × 1 was replaced by eduCAT2.0. This new version of the program was identical to the earlier version with the exception that schools could choose whether to provide one laptop per student (the only option in the first version) or have two students sharing a laptop (which would be owned by the school). Students starting compulsory secondary education in the academic years 2010-11 and 2011–12 were potentially exposed to eduCAT2.0. However, this program did not continue in the academic year 2012–13 because a lack of funding.

Table 1 shows student participation rates in the program across the three academic years. In the academic year 2009–10, 25% of students took part in eduCAT, while, with the introduction of the second version of the program in the academic years 2010–11 and 2011–12, this figure increased a further 35%. Out of the 60% of the students who participated in eduCAT, only 10% of them shared a laptop with another student. This means that the large majority of students participating in the program received their own laptop.

3.1. Academic performance database

In Catalonia, all students take a standardised test at the end of primary education (grade 6) and at the end of compulsory secondary education (grade 10). In both tests, four skills are tested: proficiency in the Catalan language, proficiency in the Spanish language, foreign language skills (mainly English, although some students choose French) and mathematical skills. These tests are designed and implemented by the Catalan government.

Information on student performance is contained in two different datasets: one includes the results of the tests taken at the end of primary education, while the other records the outcomes of the tests taken at the end of compulsory secondary education. The first dataset is merged with the second so that for each student completing primary education we have data about his/her academic performance at grade 10 (matching is possible, as both datasets contain the student's name, surname, gender and date of birth). However, we were only able to access information on the results of the tests taken at grade 10 for around 81% of the students that completed primary education between the academic years 2008–09 and 2010–11. This is attributable to consistently high repetition rates and waves of immigrants leaving Catalonia and even Spain. Thus, our final sample contains information on 175,493 students.

Table 2 provides descriptive statistics for student performance on both tests. For each student cohort, the average student performance on the tests at the end of primary education is compared with the average student performance on the tests at the end of compulsory secondary education. A score between 0 and 100 is used for each subject (unfortunately scores on the English test are not available for those students who started secondary education in the academic year 2009–10). It can be seen that the difference between the average primary and secondary school test scores is smaller in the case of Catalan and Spanish than in the case of mathematics and English.

Table 3 indicates that the average number of students in their last year of compulsory secondary education per school and per cohort is about 43. Unfortunately, we do not have any information about how many classes there were within each school (note that

Table 1
eduCAT participation at student level.

	Proportion
eduCAT in 2009–10	0.25
eduCAT in 2010–11 & 2011–12	0.35
eduCAT modality A (one laptop per student)	0.50
eduCAT modality B (one laptop per two students)	0.10
Matched students	175,493

Table 2
Descriptive statistics on academic performance.

Student cohort (1st year of compulsory secondary education) (A)	Subject (B)	Average test score at the end of primary education (i.e. grade 6) (C)	Average test score at the end of compulsory secondary education (i.e. grade 10) (D)	Difference (D)-(C) (E)
2009–10	Catalan	79.54 (13.42)	76.59 (14.22)	−2.95
	Spanish	77.40 (14.48)	76.04 (14.06)	−1.36
	mathematics	80.79 (13.36)	68.38 (22.73)	−12.41
2010–11	Catalan	75.76 (13.25)	77.14 (13.77)	1.38
	Spanish	73.19 (15.33)	76.39 (12.44)	3.2
	mathematics	80.37 (14.39)	69.10 (19.55)	−11.27
	English	74.35 (19.57)	66.86 (18.19)	−7.49
2011–12	Catalan	79.06 (13.25)	76.29 (14.91)	−2.77
	Spanish	75.45 (14.52)	75.15 (14.40)	−0.3
	mathematics	82.71 (13.45)	68.66 (18.19)	−14.05
	English	82.17 (14.65)	69.28 (20.65)	−12.89

Note: Means and standard deviations (in parentheses) are reported.

Table 3
Overall population characteristics at student level.

	Mean
Average number of students per school per cohort at grade 10	43.11 (22.01)
Public schools	0.60
More disadvantaged schools	0.13
Disadvantaged schools	0.16
Less disadvantaged schools	0.71
Student age at grade 10	15.88 (0.57)
Female students	0.50
Not matched students	0.19
N	175,493

Note: Standard deviations are reported in parentheses.

there is a legal threshold of 35 students per class in Catalonia). Students were aged about 16 when they took the test at the end of compulsory secondary education, and 50% of them were female. Students in public schools accounted for 60% of the total number of students. Additionally, schools are classified according to their socioeconomic status into: ‘less disadvantaged’, ‘disadvantaged’, and ‘more disadvantaged’. The following criteria are used for this classification: first, the socioeconomic conditions of the area in which the school is located; second, the students’ socioeconomic background; and, third, the number of students with special educational needs as well as the number of foreign students. Some schools fall quite clearly into the category of ‘more disadvantaged’. These are, for instance, public schools for special education, rural schools and adult education schools located in prisons. In Catalonia, 13% of all schools are classified as ‘more disadvantaged’, 16% as ‘disadvantaged’, and the rest (i.e. 71%) can be considered as ‘less disadvantaged’.

3.2. Selection into treatment

Table 4 shows the differences in academic ability (measured in terms of the average test scores at the end of primary education) between students enrolled at schools that participated in eduCAT and those enrolled at nonparticipating schools. As can be seen, these differences are statistically significant across all subjects and all cohorts. Students with lower academic ability at the end of primary education are more likely to attend schools that decided to participate in the program. However, the differences are quite small, i.e., between one and three percentage points.

Not only were students with lower academic ability more likely to have been exposed to eduCAT, but selection into the treatment was also driven by school characteristics. School participation was, in fact, initially promoted at a meeting attended by all school

Table 4
Test score differences in grade 6 based on treatment status.

Subject	Treated	Not treated	Difference
Cohort starting secondary education in the academic year 2009–10			
Catalan 2009	78.56 (14.03)	79.86 (13.19)	−1.30***
Spanish 2009	76.33 (15.19)	77.75 (14.22)	−1.42***
mathematics 2009	79.63 (14.01)	81.18 (13.12)	−1.55***
Cohort starting secondary education in the academic year 2010–11			
Subject	Treated	Not treated	Difference
Catalan 2010	75.38 (15.00)	76.38 (14.34)	−1.00***
Spanish 2010	72.71 (15.47)	73.95 (15.06)	−1.24***
English 2010	73.41 (19.75)	75.88 (19.18)	−2.47***
mathematics 2010	80.08 (14.52)	80.84 (14.16)	−0.76***
Cohort starting secondary education in the academic year 2011–12			
Subject	Treated	Not treated	Difference
Catalan 2011	78.79 (13.42)	79.51 (12.98)	−0.72***
Spanish 2011	74.88 (14.63)	76.37 (14.29)	−1.49***
English 2011	81.57 (14.72)	83.12 (14.49)	−1.55***
mathematics 2011	82.46 (13.58)	83.11 (13.24)	−0.65***

Note: Means and standard deviations (in parentheses) are reported. ***, ** and * represent statistical significance differences at 1%, 5% and 10%, respectively.

headmasters and those that signed up first were the ones selected, based on the budget available at that time. Although it is a priori unclear which school variables could have affected participation in the program, school status (public or private), school size and the school socioeconomic status might have played an important role in this context.

Table 5 shows estimates of the main characteristics associated with those schools opting to participate in the eduCAT program. Public schools and schools with more students are found to have been more likely to take part in eduCAT. The school socioeconomic status is also found to have had an effect. In fact, compared to the 'more disadvantaged' schools, their 'less disadvantaged' counterparts show a lower statistically significant probability of participation. Average student characteristics in the school (e.g. test score at the end of primary education in different subjects and age at grade 10) are also included as additional regressors. It is, however, interesting to note that none of the coefficients on these variables is statistically significant at conventional levels. All these results

Table 5
Treatment as function of school characteristics: Logit estimates.

Independent Variable	Coeff. St. Err.
Public school	0.552*** (0.16)
School size	0.002*** (0.00)
% of female students	0.477 (0.43)
Average student age at grade 10	0.637 (0.52)
School socioeconomic status (Reference is More disadvantaged)	
Less disadvantaged	−0.762*** (0.27)
Disadvantaged	−0.105 (0.20)
Average standardised test scores at the end of primary education	
Catalan	0.148 (0.19)
mathematics	0.267 (0.17)
Spanish	−0.200 (0.16)
Cohort (Reference is 2009-10)	
Cohort 2010-11	1.719*** (0.08)
Cohort 2011-12	1.713*** (0.08)
Average proportion of not matched students	0.143 (0.32)
Constant term	−9.867 (6.16)
Sample size	3,069
Wald Chi^2 (p-value)	533.04 (0.00)

The logit estimation was computed with panel data structure. We do not include English standardised test scores among the explanatory variables as they are unavailable for the cohort starting secondary education in the academic year 2009-10. ***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

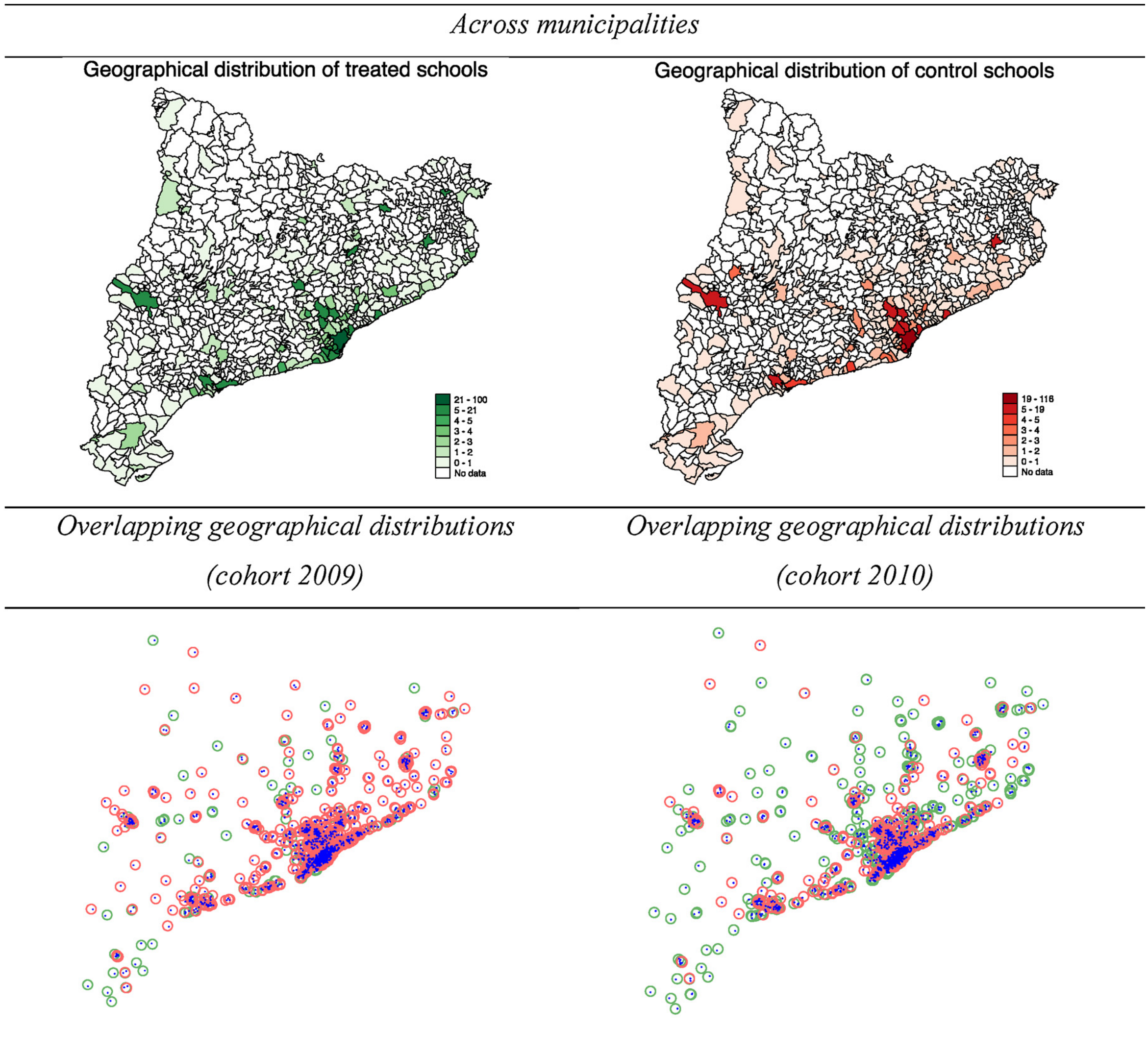

Fig. 1. Geographical distribution of treated and control schools.
Note: Green circles correspond to treated schools whereas red ones represent control schools (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

were robust to the inclusion or otherwise of the non-matched individuals.

These results are in line with our expectations, given that the overall intention of the eduCAT was to provide laptops, wireless connectivity and digital boards to public schools, namely those depending wholly on public policy-makers' decisions. Moreover, another rationale behind the program was to provide laptops to students that could not otherwise afford them, that is, children studying at schools that might be labelled as being 'more disadvantaged'.

We also tested whether there is any evidence of a geographical pattern in the distribution of untreated and treated schools. However, Fig. 1, shows that there are no marked spatial differences between the two distributions (treated and untreated schools). Additionally, Appendix A shows that no spillover effects are found across schools.

4. Econometric procedure and results

Our econometric strategy consists of three steps. First, we examine whether in evaluating the effect of eduCAT there is a bias attributable to the exclusion of those students whose test scores at the end of compulsory secondary education could not be matched up with their earlier test scores, i.e. those at the end of primary education. Second, using the test scores at the end of compulsory secondary education as our dependent variable, we look at the effect of eduCAT on student academic achievement while controlling for a number of student and school characteristics. Taking advantage of the panel data structure of the dataset, we also include student fixed effects. Third, school time-varying characteristics affecting student performance that might be correlated with the

Table 6
Student's probability of not having matched test scores on grades 6 and 10: Logit estimates.

Independent Variable	*Coeff. St. Err.*
eduCAT participation	0.003 (0.02)
Student age	7.045*** (2.05)
Student age^2	−0.125* (0.06)
Female	−0.174*** (0.01)
Public school	0.324*** (0.02)
School size	−0.000*** (0.00)
School socioeconomic status (Reference is More disadvantaged)	
Less disadvantaged	−0.465*** (0.02)
Disadvantaged	−0.483*** (0.03)
Cohort (Reference is 2009-10)	
Cohort 2010-11	−0.014 (0.02)
Cohort 2011-12	−1.171*** (0.02)
Constant term -81.924*** (16.66)	
Sample size	173,501
Wald Chi^2 (p-value)	22,634.2 (0.00)
Pseudo R^2	0.357

***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

timing of eduCAT are added as additional regressors to our model.

4.1. Non-matched individuals

Unfortunately, for some students (i.e. around 19% per cohort) we were unable to match their grade 10 test scores with the scores they obtained in grade 6. Although, as argued above, this can be explained in terms of repetition, dropout and the impact of immigration waves, it is important to determine if this matching rate is related in some way to eduCAT, that is, whether, conditional on school and student characteristics, a student's probability of having matched test scores differs across treated and untreated schools. In an attempt to address this question, we ran a logit model explaining the probability of not having matched test scores as a function of treatment, student and school characteristics. The results are shown in Table 6. The most important result is the statistically nonsignificant coefficient associated with participation in the program. This indicates that there is no bias in the evaluation of eduCAT resulting from the exclusion of those students for whom grade 10 test scores could not be matched with grade 6 test scores.

Estimates reported in Table 6 show that, in terms of student characteristics, being male and older increase the likelihood of not being able to match grade 10 test scores with grade 6 test scores. Additionally, in terms of school characteristics, students attending public schools were found to be more likely to be non-matched than their private school counterparts. The opposite occurred for students enrolled in 'less disadvantaged' schools compared to those attending both 'more disadvantaged' and 'disadvantaged' schools.

4.2. Program's impact

4.2.1. Cross-sectional results

The following equation is estimated using cross-sectional student level data:

$$G_{ijk} = \alpha_0 + \gamma E_{ijk} + \varphi m_{ik} + x_i^{'}\beta_1 + x_j^{'}\beta_2 + \theta Co_k + \alpha_j + \varepsilon_{ijk} \tag{1}$$

where G_{ijk} represents the standardised test score obtained on each of the four subjects (Catalan, Spanish, English and mathematics) taken by student i at school j in cohort k at the end of compulsory secondary education. E is a dummy variable for student participation in eduCAT. Co_k and α_j represent cohort fixed effects and school fixed effects, respectively. $x_i^{'}$ is a vector of student characteristics (i.e. age and gender), while $x_j^{'}$ is a vector of school characteristics (i.e. public or private, socioeconomic status and size) that are thought to influence academic performance. m_{ik} is a dummy variable representing missing cases (i.e. students whose grade 10 test scores could not be matched up with their grade 6 scores). Our parameter of interest is γ. It measures the average effect of participation in the program on student performance.

Table 7a shows estimates for Catalan test score. Column 1 of Table 7a considers participation in the program as the only determinant of the Catalan test score, in addition to the constant. The corresponding coefficient is statistically significant and has a negative sign (-0.118), and this result holds even after adding the dummy representing missing cases (-0.106) in column 2. This estimate is also robust to the inclusion of student characteristics (column 3). However, when school characteristics are accounted for (column 4), the coefficient becomes statistically significant at the 10% level and is considerably smaller in magnitude (-0.026). Next, we interact Catalan grade 6 test scores with the eduCAT dummy in an attempt to eliminate differences in earlier test scores based on treatment assignment. Our coefficient of interest is extremely close to zero and is no longer statistically significant at conventional levels (column 5). In column 6 grade 6 test scores are included as additional regressors. Including grade 6 test scores allows us to control for those unobserved factors affecting both grade 6 and grade 10 test scores. Again, the relevant coefficient is statistically

Table 7a
Determinants of Catalan test score at grade 10: OLS estimates (cross-sectional results).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
eduCAT participation	−0.118*** (0.02)	−0.106*** (0.02)	−0.106*** (0.02)	−0.026* (0.01)	−0.016 (0.01)	−0.014 (0.01)	−0.028 (0.02)
eduCAT·Catalan test score at grade 6					0.003 (0.01)		
Missing indicator		−0.804*** (0.01)	−0.558*** (0.01)	−0.500*** (0.01)			
Catalan test score at grade 6					0.497*** (0.01)	0.235*** (0.00)	0.220*** (0.00)
mathematics test score at grade 6						0.197*** (0.00)	0.189*** (0.00)
Spanish test score at grade 6						0.213*** (0.00)	0.217*** (0.00)
Student age			1.961*** (0.35)	1.799*** (0.29)	2.127*** (0.69)	1.337*** (0.51)	1.505*** (0.44)
Student age^2			−0.069*** (0.01)	−0.062*** (0.01)	−0.073*** (0.02)	−0.047*** (0.02)	−0.052*** (0.01)
Female			0.120*** (0.01)	0.127*** (0.01)	0.100*** (0.00)	0.141*** (0.00)	0.142*** (0.00)
Public school				−0.213*** (0.02)	−0.122*** (0.01)	−0.094*** (0.01)	
School size				0.000** (0.00)	0.000 (0.00)	−0.000 (0.00)	
School socioeconomic status (Reference is More disadvantaged)							
Less disadvantaged				0.590*** (0.03)	0.269*** (0.02)	0.217*** (0.02)	
Disadvantaged				0.453*** (0.03)	0.208*** (0.02)	0.176*** (0.02)	
Cohort (Reference is 2009-10)							
Cohort 2010-11				0.013 (0.02)	0.032** (0.01)	0.038*** (0.01)	0.041*** (0.01)
Cohort 2011-12				−0.005 (0.02)	0.008 (0.01)	0.015 (0.01)	0.019 (0.01)
Constant term	0.059*** (0.02)	0.206*** (0.01)	−13.727*** (3.02)	−13.086*** (2.32)	−15.551*** (5.50)	−9.492** (4.09)	−10.767*** (3.49)
School FE	NO	NO	NO	NO	NO	NO	YES
Sample size	168,300	168,300	168,300	168,300	134,563	133,476	133,476
F (p-value)	47.9 (0.00)	2,557.0 (0.00)	1,363.7 (0.00)	805.5 (0.00)	1,884.5 (0.00)	2,268.5 (0.00)	2,756.5 (0.00)
R^2	0.004	0.101	0.121	0.169	0.333	0.394	0.437

Note: Standard errors are in parentheses. ***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

Table 7b

Determinants of Spanish, mathematics and English test scores at grade 10: OLS estimates (cross-sectional results).

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Spanish	*eduCAT participation*	−0.128*** (0.02)	−0.119*** (0.01)	−0.120*** (0.01)	−0.044*** (0.01)	−0.033*** (0.01)	−0.034*** (0.01)	−0.024 (0.02)
	eduCAT· Spanish test score at grade 6					0.000 (0.01)		
mathematics	*eduCAT participation*	−0.132*** (0.02)	−0.120*** (0.01)	−0.116*** (0.01)	−0.035*** (0.01)	−0.026*** (0.01)	−0.028*** (0.01)	−0.020 (0.01)
	eduCAT·mathematics test score at grade 6					−0.015 (0.01)		
English	*eduCAT participation*	−0.163*** (0.02)	−0.152*** (0.02)	−0.152*** (0.02)	−0.036*** (0.01)	−0.016 (0.01)	−0.016 (0.01)	−0.024 (0.02)
	eduCAT·English test score at grade 6					0.015 (0.01)		

Note: This Table replicates the estimates of Table 7a, but for Spanish, mathematics and English test scores. Estimates are shown following the same structure as of Table 7a. Standard errors are in parentheses. ***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

insignificant. Finally, in column 7, we account for school fixed effects. Although we recognise that an estimation of this kind might be inefficient, we need to know what happens when we include a dummy for each school to capture its idiosyncrasy, specific tuition configuration and social environment. All these characteristics might condition a school's final decision to participate in the program. As can be seen, the relevant coefficient rises to -0.028, but it is still not statistically significant, although this could be a consequence of inefficiency. Table 7b displays the corresponding estimates for the test scores in the other subjects (Spanish, mathematics and English). The relevant coefficient is still consistently negative, but with a higher statistical significance.

Next, we employ a propensity score matching procedure to find a subset of students of schools that did not participate in the program who are similar to the treated students in all relevant pre-treatment characteristics. The propensity score was defined by Rosenbaum and Rubin (1983) as the probability of treatment assignment conditional on observed baseline covariates. We use the nearest neighbour matching method, whereby a student from the control group is selected as a matching partner for a treated student that is closest in terms of propensity score (Caliendo & Kopeinig, 2008). Nearest neighbour matching allows us to directly address the source of omitted variable bias: self-selection into the program. Given our large dataset and the small number of covariates, we find a large number of possible neighbours and match students according to school characteristics (public or private, size and socio-economic status) and individual characteristics (age and gender), which influenced participation in the eduCAT program. This procedure also allowed us to reduce sample variance in the treatment effect estimates.

Table 8a presents neighbouring matching results using student cross-sectional data, where the Catalan test score is once again used as our measure of student performance. Our estimation results through matching are not far from those obtained using OLS. The coefficient related to eduCAT participation is again statistically significant and has a negative sign, ranging from -0.056 to -0.030 (columns 1–3). After accounting for school fixed effects in column 4, this coefficient remains negative and statistically significant but its magnitude increases (-0.100). Our matching estimates account for individual and school characteristics, but they also control for grade 6 test scores in Catalan, Spanish and mathematics. Table 8b shows the estimation results for the other subjects (apart from English). Again, results are quite similar to those reported in Table 8a.

4.2.2. Longitudinal results

We now take advantage of the panel structure of our data that allows us to include student fixed effects. We also continue to use matching techniques to account for selection. Thus, the following equation is estimated:

Table 8a

Determinants of Catalan test score at grade 10: Neighbouring matching results (cross-sectional results).

	(1)	(2)	(3)	(4)
eduCAT participation	−0.051*** (0.01)	−0.030*** (0.01)	−0.056*** (0.00)	−0.100*** (0.02)
Catalan test score at grade 6	NO	YES	YES	YES
mathematics test score at grade 6	NO	NO	YES	YES
Spanish test score at grade 6	NO	NO	YES	YES
Student characteristics	YES	YES	YES	YES
School characteristics	YES	YES	YES	YES
Cohort dummies	YES	YES	YES	YES
School FE	NO	NO	NO	YES
Sample size	168,300	134,563	133,476	133,476

Note: Student characteristics include: age, age^2, female and cohort. School characteristics include: public or private school, school size and school socioeconomic status. Neighbouring matching at the individual level considered 30 neighbouring units and an exact match for public schools, school size and school socioeconomic status. Standard errors are in parentheses and are clustered at school level. ***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

Table 8b
Determinants of Spanish and mathematics test scores at grade 10: Neighbouring matching results (cross-sectional results).

		(1)	(2)	(3)	(4)
Spanish	*eduCAT participation*	-0.071^{***} (0.01)	-0.055^{***} (0.01)	-0.083^{***} (0.00)	-0.119^{***} (0.02)
mathematics	*eduCAT participation*	-0.055^{***} (0.01)	-0.049^{***} (0.00)	-0.073^{***} (0.00)	-0.132^{***} (0.02)

Note: This Table replicates the estimates of Table 8a, but for Spanish and mathematics test scores. Estimates are shown following the same structure as of Table 8a. Standard errors are in parentheses and are clustered at school level. ***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

$$G_{ijkt} = \alpha_{i0} + \varphi m_{ik} + \gamma E_{ijk} + \lambda d_t + \delta(E_{ijk} \cdot d_t) + x_{it}^{'}\beta_1 + x_{jt}^{'}\beta_2 + \theta Co_k + \alpha_{kj} + \varepsilon_{ijkt} \quad (2)$$

where G_{ijkt} represents the standardised test score obtained on each of the four subjects (Catalan, Spanish, English and mathematics) taken by student i in grade t (6 or 10) and cohort k at school j. The fixed constant term (α_{i0}) indicates the student's test score in grade 6 and d_t represents a time trend. Thus, whereas λ represents time effects and γ the initial differences in test scores based on their participation in the program, the association of the eduCAT program with educational performance in grade 10 is captured by δ.

The results, which are shown in Table 9, are consistent with those reported in Tables 7a, b, 8a and b. They indicate that eduCAT had a detrimental impact on student achievement. Specifically, looking at the estimates reported in the second row of Table 9, this program reduced students' Catalan test scores by 0.22 standardised points, that is, around 4% of the average test score. This program had also a similar negative impact on student performance in mathematics (-0.21), Spanish (-0.21) and English (-0.20), which mean a reduction in the average test score by 4.1% in Catalan, 3.8% in Spanish, 6.4% in English and 6.2% in mathematics.

4.3. Survey information

The estimates reported so far rest on the assumption that there are no other factors affecting student performance that have changed at the same time as the launch of eduCAT. One concern, however, is the possibility that schools experienced changes in the curricula, teaching methods (including the use of ICT) and staff concomitantly with the introduction of the program.

In attempt to gather information on time-varying school characteristics potentially influencing academic achievement, we contacted the headmasters of all the schools included in our analysis and asked them to complete a survey. This comprises three sets of questions referring to the academic years 2009-10, 2010-11 and 2011-12. The first set refers to ICT resources and how these were used for teaching activities. Schools were asked to give information on the percentage of the total budget spent on ICT, on the reliability and quality of digital textbooks and on which courses technological devices (e.g. laptops, tablets, e-books and specific software) were regularly employed in classroom activities. The second block includes questions on teachers and teaching. Schools were asked to report the average number of hours of specific training in ICT teachers had received, the average age of teachers, and whether there had been any changes in teaching practices (if so, specifying what were the changes involved). Finally, in the last set of questions schools were asked to report information on their students including the rates of absenteeism, immigrant status and dropouts from compulsory secondary education.

Responses were obtained from 693 schools, that is, 69% response rate. This sample is representative of the whole school population in terms of the school characteristics discussed earlier (public or private status, size and the socioeconomic status).

Table 10 depicts the proportion of schools not reporting any changes in the way students were taught in classrooms by eduCAT participation status during the period in which the program was implemented. It shows that during these academic years this proportion has not significantly changed across neither the schools that participated in the program nor those that did not. Although these descriptive statistics would seem to suggest that our earlier results are robust to omitted time-varying school characteristics, it is important to estimate new regressions that include these characteristics among the explanatory variables.

Column 1 of Table 11 replicates the estimates shown in Table 9 on the effect of eduCAT on student performance, but only for those schools that responded to the survey. In column 2 we add time-varying school characteristics derived from the survey to the specification of the model. All the results confirm that this program had a detrimental effect on student performance. It is also interesting to note that the magnitude of the effect shown in Table 11 is similar to that reported in Table 9.

Finally, we test whether the effect of eduCAT on student performance is different across gender. Table 12 reports these estimates

Table 9
Determinants of Catalan, Spanish, English and mathematics test scores at grade 10: Neighbouring matching results (Longitudinal results).

		Catalan	*Spanish*	*English*	*mathematics*
eduCAT participation	*Not including test scores at grade 6 in other subjects*	-0.029^{***} (0.00)	-0.158^{***} (0.00)	-0.150^{***} (0.01)	-0.172^{***} (0.00)
eduCAT participation	*Including test scores at grade 6 in other subjects*	-0.220^{***} (0.00)	-0.212^{***} (0.00)	-0.204^{***} (0.00)	-0.210^{***} (0.00)
	N	299,604	299,604	251,576	299,604

Neighbouring matching at student level considers 30 neighbouring units and an exact match for school status, school size and school socioeconomic status. We also include a dummy variable denoting missing grade 6 test scores and we account for cohort and school fixed effects. Standard errors are in parentheses and are clustered at school level. ***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

Table 10
Proportion of schools not reporting any changes in teaching practices by academic year and eduCAT participation status.

Academic year	*Schools participating in eduCAT*	*Schools not participating in eduCAT*
2009-10	0.830	0.888
2010-11	0.792	0.895
2011-12	0.761	0.903

Table 11
Determinants of test scores at grade 10 including information from an ad-hoc survey: Neighbouring matching results (Longitudinal results).

		Without school time- varying characteristics (1)	*With school time- varying characteristics* (2)
Catalan	*eduCAT participation*	-0.231^{***} (0.00)	-0.238^{***} (0.01)
	N	198,778	118,421
Spanish	*eduCAT participation*	-0.207^{***} (0.01)	-0.220^{***} (0.06)
	N	198,778	118,421
English	*eduCAT participation*	-0.204^{***} (0.01)	-0.209^{***} (0.07)
	N	166,597	99,362
mathematics	*eduCAT participation*	-0.211^{***} (0.00)	-0.228^{***} (0.06)
	N	198,778	118,421

Neighbouring matching at individual level considers 30 neighbouring units and an exact match for school status, school size and school socio-economic status. We also include a dummy variable denoting missing grade 6 test scores. Standard errors are in parentheses and are clustered at school level. ***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

Table 12
Determinants of Catalan, Spanish, English and mathematics test scores at grade 10 across gender: Neighbouring matching results (Longitudinal results).

		Catalan	*Spanish*	*English*	*mathematics*
Boys	*eduCAT participation*	-0.257^{***} (0.01)	-0.222^{***} (0.01)	-0.232^{***} (0.01)	-0.229^{***} (0.01)
Girls	*eduCAT participation*	-0.181^{***} (0.01)	-0.196^{***} (0.01)	-0.175^{***} (0.01)	-0.209^{***} (0.01)

Neighbouring matching at individual level considers 30 neighbouring units and an exact match for school status, school size and school socio-economic status. We include a dummy variable denoting missing grade 6 test scores. Each block based on student's performance contains around 90,000 students. Standard errors are in parentheses and are clustered at school level. ***, ** and * represent statistical significance at 1%, 5% and 10%, respectively.

for all the subjects considered. These estimates are again based on neighbouring matching and longitudinal data are used. Boys were more negatively affected by the program than girls in the case of Catalan and English, whereas the difference in average test score turns out not to be statistically significant in the case of Spanish and mathematics.

5. Discussion and conclusions

The debate remains very much ongoing as to whether the use of ICT in the classroom promotes student learning, with empirical results being mixed (although most of the evidence based on One Laptop per Child (OLPC) programs shows that these programs have no effect). In this paper, we contributed to this debate by analysing the effects of computer use at school on student achievement in Catalonia (Spain). Specifically, we evaluated the OLPC program implemented by the Catalan government, known as eduCAT.

The program, which was introduced in the academic year 2009–10, promoted the use of computers in secondary schools. It comprised several actions, the main one being the provision of laptops to students, with half the cost of the laptop being met by the government and the other half by the students' parents (grants being provided for those unable to pay). The program was curtailed at the end of the academic year 2011–12 for financial reasons.

This study evaluates the impact of the eduCAT program on secondary school students' performance. Specifically, our outcomes of interest are the test scores obtained by students in the following subjects: Catalan, Spanish, English and mathematics. The tests were designed and implemented by the Catalan government.

Although school participation in the program was not random, we control for several school characteristics that have influenced the participation of schools in the program. Several techniques are used in an attempt to determine the impact of the program on academic achievement. These include: (1) matching and cross-sectional regressions, which assume that treatment assignment is influenced only by observable characteristics for which one can collect data and accounts for in the analysis, (2) matching and longitudinal data methods that in addition to (1) also allow us to control for time-invariant student unobserved characteristics affecting student performance. Additionally, we also control for school time-varying confounding characteristics derived from a survey we carried out in almost 70% of all schools.

Our results consistently show that eduCAT negatively affected student performance. The magnitude of this effect is similar for each subject. Specifically, students in schools that implemented the program scored, on average, about three points less than those in nonparticipating schools (about 5.1% on average, from 3.8% to 6.2% depending on the subject). In terms of gender, the negative effect was smaller for girls relative to boys. Thus, eduCAT reduced male students' achievement significantly in some subjects (the differences ranged from 10% to 42%).

Although most international evidence shows that OLPC programs do not enhance academic achievement, the Catalan experience goes further, as our results show a negative effect exerted by eduCAT on student performance. Given that the adoption of technological devices in the classroom is set to continue in most countries, the results suggest a need for reflection as regards the introduction and diffusion of ICT in schools.

Our work cannot unfortunately shed light on why computers are not found to improve student performance. Several explanations have been however suggested by previous studies. As mentioned in Section 2, it is possible that no software directly supporting mathematics and language learning had been installed on the laptops and that teachers were not sufficiently trained to use computers in an educational setting (Cristia, Ibarrarán, Cueto, Santiago, & Severín, 2012). Additionally, as indicated by Linden (2008), completely replacing traditional ways of teaching with methods based on new technologies may have a detrimental effect on academic achievement. Vigdor, Ladd, and Martinez, (2014) argue that computer access at home is associated with higher student achievement only in households with more effective parental monitoring.

A few lessons can be learnt from the experience of OLP programs. First, when ICT is introduced, it is important to determine the relevance of a range of factors, including the type of program being promoted, whether students should be given their own computer or whether the computers should be shared among the students, and the use that is made of other ICT tools, etc. Second, the way in which the program is implemented is also important. Specifically, the initial situation (the availability of the ICT network in the school, specific training of teachers, degree of commitment of stakeholders, lack of online instructional materials, etc.) should be taken into careful consideration as should the way in which the government implements the program. Finally, it cannot be taken for granted that an ICT program will be successful. Consequently, the implementation of any program should include a system of evaluation. In this way, any adverse effects that might emerge can be rectified.

The present study has several limitations. On the one hand, the data are not experimental, so it is more difficult to demonstrate the causality of the observed effects. While the methodology used allows us to infer causality, it is, nevertheless, based on certain assumptions. On the other hand, the study provides an estimate of the impact of the program on a limited number of subjects. However, nothing can be said regarding the consequences of the program on other subjects, non-cognitive skills (teamwork, student engagement or student research skills, among others) or the degree of assimilation of new technologies.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ijer.2018.09.013.

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