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Is the use of ICT in education leading to higher student outcomes? Analysis from the Spanish Autonomous Communities

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ABSTRACT

The impact of ICT on educational achievements is a controversial issue which has attracted increasing attention from both policy makers and researchers. Policy makers have shown great enthusiasm over the positive impact of ICT on teaching and learning, investing substantially in this area. However, scientific evidence does not clearly support this effort.

This paper analyses the impact of the use of ICT at school on students' outcomes in compulsory secondary education in maths, reading and science. It uses data from three rounds of PISA (2009, 2012, 2015) for Spanish regions (Autonomous Communities). From this, the paper analyses whether, in those Autonomous Communities which have taken greater steps in increasing the use of ICT at school, educational outcomes have improved more than in the others. This analysis takes advantage of the availability of representative samples for Spanish Autonomous Communities in PISA, together with autonomy and variability across them as regards the use of ICT at school. This makes it possible to capture the effect of the different policies adopted by Spanish Autonomous Communities on the use of ICT at school.

The results show that an increase in the use of ICT at school in an Autonomous Community does not render positive effects on PISA scores in maths and reading, whilst we do find a positive effect on PISA scores in science. These results suggest that the impact of ICT on educational outcomes depends on the subject and on the type of use of the technologies. As a result, policies oriented at increasing the educational use of ICT should require a careful evaluation, to identify in which fields, for which uses and for which methods of use, it may render a positive effect on educational outcomes.

1. Introduction

The use of Information and Communication Technologies (ICT) in teaching and learning has increased substantially over the last few years in most developed countries (Comi et al., 2017; Falck et al., 2018). Many governments have made large investments in equipping schools with ICT devices and tools. As a result, the use of ICT-related tools (such as computer-based learning, email and websites) in teaching practices has rapidly spread. Policy makers have often been enthusiastic about the positive effects of ICT on learning outcomes. However, research has not found any clear evidence to support this (Spiezia, 2010; Livingstone, 2012; OECD,

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2015a). In this context, the impact of ICT on educational achievements has become a highly controversial issue.

Theoretical arguments in favour of a positive effect of ICT on educational achievements point out that they can improve student outcomes by increasing access to information and to a wider range of resources for learning (Spiezia, 2010). Also, the use of ICT may promote individualised instruction and a better monitoring of student progress (Falck et al., 2018). According to views in favour of ICT, technologies would increase students' flexibility and autonomy, whilst also improving their learning attitudes and experiences (De Witte & Rogge, 2014; Alderete et al., 2017). ICT may be used to enhance teaching material, and to make lessons more complete, attractive or interactive (Comi et al., 2017). As a result, the use of ICT would improve students' educational outcomes whilst, at the same time, serving to reduce educational costs in the long run (De Witte & Rogge, 2014).

In contrast, arguments against the use of ICT for educational purposes claim they may distract students from learning (Spiezia, 2010; De Witte & Rogge, 2014) and undermine the need for work and discipline (Falck et al., 2018). Moreover, ICT are criticised for restricting students' creativity (Spiezia, 2010). Critical views on the use of ICT in education are also sceptical on the technologically-mediated relation between teacher and learner, and the negative consequences of a reduction in human interaction resulting from ICT (Livingstone, 2012; De Witte & Rogge, 2014). For instance, many ICT-based applications identify which questions students get wrong, but teachers can better identify why students make mistakes and reteach them (Cromley, 2000). Additionally, the benefits of ICT would also depend on the capability of schools to adapt their organisation and teaching methods (Spiezia, 2010), and on the skills teachers and students have for using ICT effectively (De Witte & Rogge, 2014). Taking into account the arguments of both the positive and negative views on the use of ICT in education, Falck et al. (2018) argue that there may be some activities in which ICT-based education is superior to traditional instruction, whilst the opposite may be true for other activities.

The effect of the use of ICT on educational outcomes is still an open question, both from a theoretical and from an empirical point of view. It constitutes a crucial concern for research and for policy making, given the large investments being made in this area (Angrist & Lavy, 2002; Spiezia, 2010; Comi et al., 2017). In spite of this, very few studies have examined the impact of policies on the use of ICT on educational outcomes by using large-scale international surveys. Some experimental analyses have been carried out on this issue, consisting of small-scale ad-hoc studies (mostly at class-level, school-level or regional-level), which limits their external validity (De Witte & Rogge, 2014). Studies based on large-scale international surveys, however, have largely been limited to exploring statistical associations between educational outcomes and individual, school or country characteristics related to ICT, without specific research designs which allow the impact of ICT on educational outcomes to be measured (Biagi & Loi, 2013).

This paper analyses the policy impact of the use of ICT in teaching practices on educational outcomes in maths, reading and science, using data from three different rounds of PISA (2009, 2012 and 2015) for the Spanish regions (Autonomous Communities). The policy impact is analysed by calculating the average use of ICT at school in each year and each Autonomous Community. From this, we evaluate whether those Communities which have taken greater steps in increasing the use of ICT at school have achieved higher improvements in students' PISA scores. This empirical strategy takes advantage of three characteristics of PISA data for the Spanish Autonomous Communities: 1) PISA provides representative samples for most Communities in all the three rounds under analysis (2009, 2012 and 2015), 2) Communities are autonomous in deciding on the endowments and use of ICT in education, 3) There exists, in practice, broad variability across Communities in the extent of use of ICT at school. Spain is the unique case in PISA in which these three characteristics, which are essential to capture differences in regional policies on the educational use of ICT within a single educational system, are simultaneously fulfilled.[1] From this approach, this paper contributes to the literature on the policy impact of ICT on educational outcomes by providing evidence on this issue from an internationally equivalent large-scale survey: PISA.

The paper is structured as follows. After this introduction, the next section provides a detailed review of the literature on the relationship between ICT and educational achievements. The third section explains the data, variables and methodology used in our analysis. The fourth section describes the results of the econometric analysis on the impact of the use of digital devices in teaching practices on educational outcomes. The fifth section concludes the study, summarising and discussing the main results obtained, as well as their implications for educational policies.

2. The use of ICT and educational outcomes: literature review

Over the last two decades, a significant number of studies have analysed the relationship between the availability and use of ICT and educational outcomes. These studies can be classified in two groups: on the one hand, experimental and quasi-experimental studies, based on research designs which allow causal effects of the availability and/or use of ICT on educational outcomes to be inferred; and on the other hand, empirical analyses based on large international data sets on cognitive outcomes (such as PISA, PIRLS and TIMMS), which enable evidence representative at the student population level and comparable across countries to be obtained.

2.1. Evidence from experimental and quasi-experimental analyses

Experimental and quasi-experimental analyses on the relationship between ICT and educational outcomes are based on sophisticated research designs which allow the causal relation between both issues to be captured. However, they are also typically based on

[1] PISA includes representative samples at the regional level in 2009, 2012 and 2015 for Belgium, Italy and the UK, in addition to Spain. However, Italian regions do not hold autonomy in educational policies, whilst the number of regional units available in PISA in Belgium and the UK (2 and 3, respectively) do not provide sufficient variability for the analysis. Finally, PISA includes representative samples of the 10 Canadian regions in 2012 and 2015, but not in 2009; and representative samples of the Australian and Mexican regions in 2012, but not in the rest of the years considered.

ad-hoc small-scale studies, which limits their external validity (De Witte & Rogge, 2014): i.e., to obtain findings generalizable across different contexts and different countries. In fact, as these studies use different sources and different variables (in particular, for measuring both the use of ICT and educational outcomes), it is difficult even to compare their findings across different contexts and different countries.

Several of these experimental or quasi-experimental analyses have found non-significant effects of the use of ICT on educational outcomes.

As an early example, Angrist and Lavy (2002) used a natural experiment to estimate the effect of the installation of computers on both its use for educational purposes and on students' achievements. These authors took the case of a large-scale computerisation in Israeli schools, carrying out a controlled comparison between schools that participated in the program and schools that did not. They found that the installation of computers increased the use of this tool for instruction. However, it did not improve students' scores in tests on maths and language knowledge. These authors even found a negative effect on maths scores among 4th grade students.

In another paper, Rouse and Krueger (2004) undertook an experimental analysis in four US schools on the effects of an instructional computer program on language and reading ability of students with learning difficulties. They found that the program improved a few aspects of students' language skills, measured according to tests developed by the company which produced the program. However, these gains were not detected in measures of language or reading skills when using standardised tests.

Goolsbee and Guryan (2006) evaluated the effect of a subsidy on Internet investment in Californian public schools, exploiting the variation in the subsidy rate across schools. The authors used a regression discontinuity design, controlling for the schools' socio-demographic characteristics that determined the variation in subsidy rates. They complemented it with an estimation using an ordinary regression framework. The authors found that the subsidy significantly increased investment in Internet technology among schools. However, using a variety of test scores on maths, reading and science skills, they did not find any significant effect of the program on student performance.

In a more recent paper, Craig et al. (2013) implemented an experiment in four US schools for evaluating the effects of an intelligent tutoring system for after-school classes of maths. They found that students' performance, as well as their conduct and involvement, remained at similar levels in the treated group and in those following traditional teaching methods. Nevertheless, students using the ICT-based system required less assistance.

There are other studies, however, which have found a negative effect of the use of ICT on educational outcomes in specific settings.

Leuven et al. (2007) evaluated the effect of a subsidy on the acquisition of computers and software in the Netherlands, which was targeted at schools with a high presence of students from ethnic minorities or from families with a low educational attainment. These authors followed a regression discontinuity design, from the cut-off used for assigning the subsidy to schools, and they estimated the effects of the subsidies on students' academic results, as measured in national tests. They found a negative effect of the subsidy on both language and maths achievements, which was particularly high among girls.

More recently, Mora et al. (2018) analysed the impact of a program run by the autonomous government of Catalonia, in Spain, which provided laptops, wireless connectivity and digital boards to participating schools. These authors used information on students' performance at the end of primary education and at the end of compulsory secondary education, obtained from achievement tests implemented by the Catalan government, and compared the evolution of the results of students in schools which participated in the program and in schools which did not. They found that participation in the program was associated with a reduction in scores in maths, English, Spanish and Catalan language.

In contrast, other experimental studies have found a positive effect of ICT on educational outcomes in certain settings.

Banerjee et al. (2007) implemented an experiment in urban schools in India, focused on evaluating the impact of a computer-assisted learning program for maths on the educational outcomes of children from poor families. They found that the program increased students' scores in maths in its first and second year of implementation. This result differs from previous studies in developed countries, something which the authors of this paper accounted for on the basis of the specific context of India and, in particular, the wide social gap between students from poor families and their teachers.

Barrow et al. (2009) carried out an experimental analysis of the effects of an instructional computer program for algebra in three US urban school districts with a high proportion of students from ethnic minorities. The program was accompanied by an increased attention of teachers to individual instruction when students required additional assistance. Using a variety of tests, these authors found that students assigned to computer-aided instruction scored significantly higher than those assigned to traditional instruction, although this was not observed in all of the districts. They associated this result to the more individualised instruction, as they found the effects were higher in larger and more heterogeneous classes, and in classes with high absenteeism.

Bartelet et al. (2016) also used an experimental design to evaluate the effectiveness of an optional web-based maths tutoring system offered for homework by a school in the Netherlands. They found that this tool was associated with a higher improvement in achievements, especially among low achievers, although the effect depended on the mathematical domain considered.

The evidence from these last studies suggests that it might not be ICT *per se*, but rather the use of ICT which may render positive effects of ICT on educational outcomes in specific cases, such as where ICT served to increase individual instruction (Barrow et al., 2009), or where it was offered as an optional tool for homework (Bartelet et al., 2016).

Lei and Zhao (2007) also highlighted that the effect of ICT on educational outcomes may depend on the type of use of ICT. These authors, using data from a school in Ohio (US), examined the frequency and types of technologies used by students, as well as their impact on academic achievement. To do so, they measured the changes in students' academic results and their relation to their exposure to technology, using pre-test and post-test surveys. They found that students' results improved with the time spent on computers up to 3 h a day, but worsened significantly over that threshold. Notwithstanding, these authors stressed that the most important dimension was not the quantity of technology, but its uses: uses of technology which provide ways of learning not accessible in traditional classes (such as creating websites) showed positive results, whilst the opposite was observed for other uses which led to distraction (such as using computers to take notes in class).

In a more recent paper, Comi et al. (2017) analysed the effects of ICT-related practices on students' achievements in the Italian region of Lombardy, using two surveys on ICT and national tests on students' achievements in maths and language. Their research design was based on a within-student between-subject estimator, using information available for two different subjects for each student, in order to control for students' unobservable factors. They found that the effect of ICT on student outcomes depended on their type of use. Computer-based teaching methods oriented to enhance communication and student awareness in ICT increased student performance. In contrast, ICT-related practices which required an active involvement of students in the classroom showed negative effects, whilst those developed outside the classroom had non-significant effects. The effects of activities related to knowledge transmission were positive but non-robust.

Finally, some studies have found that the effect of ICT on educational outcomes may not only depend on the use of ICT, but also on the subject or field for which the outcomes are measured.

Machin et al. (2007) analysed the impact of expenditure on ICT on student outcomes in England, using an instrumental variable which exploited a change in the rules on ICT funding by local school districts. They found that expenditure on ICT by local school districts showed a small positive impact on national test scores in language, a positive albeit non-significant impact on scores in sciences and no relationship with results in maths.

This mixed evidence, depending on the subject, has also been found in developing countries. Cristia et al. (2017) used an experiment implemented in Peruvian rural schools to evaluate a program which provided children with laptops for use at school and at home. They measured the outcomes of the program using a test based on standard national examinations, as well as different cognitive tests. These authors found that the program increased the use of computers both at home and at school. However, they found non-significant effects of the program on test scores in maths and language. In contrast, they found positive effects of the program on the tests measuring cognitive skills.

2.2. *Evidence from international surveys*

Other studies have analysed the relationship between ICT and educational outcomes by exploiting the information on educational outcomes available in large-scale international surveys such as PISA, PIRLS and TIMMS. These studies, in general, have focused on the analysis of cross-sectional data from these surveys, controlling for a range of characteristics at the individual and school levels available in them. This approach has allowed statistical associations between indicators on the availability and/or use of ICT and student outcomes to be estimated. However, these analyses face a major limitation derived from a problem of endogeneity: a non-observable factor (e.g., students' skills, intelligence or motivation) may be associated with students' availability and/or use of ICT and, at the same time, with their educational outcomes. As a result, a statistical association between ICT variables and educational outcomes at the student level cannot be interpreted as a causal impact of the first on the second, as it may be the non-observable factor what has an impact on educational outcomes (Spiezia, 2010; Biagi; Loi, 2013). Fariña et al. (2015) demonstrated the existence of endogeneity in a study of the relationship between computer use for reading activities and students' reading performance in Chile, Uruguay, Spain and Portugal, using data from PISA-2009.

Some of the studies on ICT and educational achievements based on international surveys have explored the relationships between the availability and/or use of ICT at school, at home or in both settings, and educational outcomes. In general, their findings show that the availability of ICT tends to be positively associated with educational outcomes, whilst a higher use of these technologies tends to show a negative relationship with educational outcomes.

Mediavilla and Escardíbul (2015), using PISA-2012 data for Spain, found that the amount of ICT at home and the availability of ICT at school were positively associated with scores in maths, although not in reading or in problem solving. In contrast, they found that the use of ICT at school was negatively associated with outcomes in maths and, among boys, also with outcomes in reading. Among girls, time using ICT was negatively associated with outcomes in the three competencies. Erdogdu and Erdogdu (2015), using PISA-2012 data for Turkey, found that the availability of internet connection at school was positively associated with academic results in science, whilst the frequency of browsing the Internet at school was negatively related with results in maths, science and reading. Zhang and Liu (2016), using data from five waves of PISA (from 2000 to 2012) for a broad set of countries, found that the availability of ICT resources at school was positively related to students' scores. In contrast, the use of ICT software and the Internet was negatively associated with outcomes.

Studies based on international surveys have also shown more negative evidence on the use of ICT at school than at home. Alderete et al. (2017), using data from PISA-2012 for Spain, found that access to and use of ICT at home were positively related to PISA scores in maths, reading and science. However, the opposite was observed for access to and use of ICT at school. Also Petko et al. (2017), using data from PISA-2012 for 39 countries, found that in the majority of countries, the use of ICT at school was associated with lower test scores in maths, reading and science, whilst the use of ICT at home for school-related purposes showed a positive correlation with scores in most countries and subjects. Skryabin et al. (2015), using data from TIMSS 2011, PIRLS 2011 and PISA 2012 for a broad set of countries, found that these effects may also depend on students' grades. Among students in 8th grade, these authors found that ICT use at home was positively related to achievements in PISA, whilst the opposite was observed for ICT use at school. Among students in 4th grade, however, ICT use both at school and at home was positively related to achievements in TIMSS and PIRLS. Escardíbul and Mediavilla (2016) explored differences in the effects of ICT depending on the ownership of the centre. They found that the relationship between the availability, time and frequency of use of ICT and educational achievements did not show any noticeable difference between public and private centres.

Moreover, studies from international surveys have found that students' attitudes and experience towards ICT are closely related to educational outcomes. Luu and Freeman (2011), using data from PISA-2006 for Canada and Australia, obtained that prior experience in using ICT, frequency of access to the Internet at home and confidence in using ICT were associated with higher scores in the survey. Zhang and Liu (2016) also found that individual self-confidence in ICT use was positively associated with educational achievements, whilst Petko et al. (2017) found that more positive attitudes towards ICT were associated with higher scores in the majority of countries. Hu et al. (2018), using data from PISA-2015 for 44 countries, found that students' interest, competence and autonomy in using ICT were positively correlated with PISA scores, whilst the opposite was observed for students' enjoyment of social interaction around ICT. After controlling for these factors, these authors obtained that ICT availability at school was not associated with educational achievements, whilst ICT availability at home was negatively associated with them. In addition, ICT use at school (for maths, reading and science) and ICT educational use at home (for reading and science) were negatively correlated with performance.

Research from international surveys has also shown that the relationships between ICT and educational outcomes may depend on the type of use, as noted by Luu and Freeman (2011). Biagi and Loi (2012), using data from PISA-2009 for the European Union countries, found that uses of ICT for communication and collaboration activities, for technical operations and information retrieval, and for creation of content and knowledge problem solving, were all negatively correlated with students' scores. However, breadth of use (the number of different activities carried out) was associated with higher scores. Meggiolaro (2018), using data from PISA-2012 for Italy and focusing on scores in maths, found that both ICT use for information management and technical operations and for gaming were positively associated with scores. In contrast, ICT use for communication and collaboration activities and computer use during maths lessons were, in general, negatively associated with scores in this competence.

Other papers, also using data from international surveys on educational outcomes, have tried to address endogeneity problems by applying specific research designs. Spiezia (2010) assessed whether the use of ICT had an impact on student performance, using data from PISA-2006 for a broad set of countries, and controlling for students' observable characteristics and self-selection. This author first estimated the frequency of computer use, at home and at school, as a function of observable characteristics of students, their families and their schools. Then, he estimated students' performance in science as a function of all the observable characteristics, the frequency of computer use and a measure of students' unobserved heterogeneity from the residuals estimated in the first step. This paper found a positive and significant effect of the frequency of computer use on science scores. However, this was driven by a positive effect of computer use at home, whilst the effect of computer use at school was non-significant in most countries.

Some other studies applied matching techniques for estimating the effect of ICT-related variables on student outcomes. De Witte and Rogge (2014), using TIMMS-2011 data for the Netherlands, applied matching techniques to define a control group with similar student, teacher, school and regional characteristics to a treated group. These authors concluded that the estimated impact of ICT was considerably altered depending on whether these characteristics were taken into account or not. However, matching techniques do not solve the problem of endogeneity of ordinary regressions, as they take into account only observable variables, but not non-observable factors.

In another study, Agasisti et al. (2017) also applied methods of matching to analyse the relationship between students' use of ICT at home for school-related purposes and their scores in maths, reading and science, using data from PISA-2012 for 12 EU countries. In addition, they estimated this relationship using instrumental variables, by taking the use of ICT at home for entertainment as an instrument. They found that, in most countries, the use of computers at home for school-related purposes was associated with lower scores in the three subjects under analysis.

In a different approach, Cabras and Tena Horrillo (2016) estimated the effect of investment in ICT on student performance in maths, using PISA-2012 data for Spain, by employing Bayesian Regression Trees (BART). This is a non-parametric method, which allows the probability distribution of the estimated causal effect to be calculated. These authors found that, with a high probability, there was a moderate positive effect of the use of ICT on students' achievements, which was particularly high among students from a low socioeconomic background. Ferraro (2018) also applied a BART method to analyse the effects of ICT on test scores in maths, using data from PISA-2012 for Italy. She obtained a positive effect of the use of ICT on test scores in this subject.

Finally, Falck et al. (2018) used information from TIMSS for 30 countries to estimate the effect of classroom computers on student achievement. To do so, they exploited within-student between-subject variation, taking advantage of the information on two different subjects (maths and science) for the same individuals available in this source. Considering different types of computer use, these authors found positive effects of using computers to practice skills and procedures on educational achievements, whilst the effects of using classroom computers to process and analyse data were non-significant. These effects were generally found to be greater for students with high socioeconomic status.

In summary, the existing literature (taking both experimental and quasi-experimental studies and studies from international surveys) has obtained mixed evidence on the impact of ICT on educational outcomes. From experimental and quasi-experimental studies, the impact of ICT was found to be non-significant, negative or positive depending on the setting in which the research was carried out, which ICT variables were considered and how educational outcomes were measured, among other issues. The impact of ICT was also found to depend on the type of ICT use and the field or subject under analysis, a result which was also pointed out by studies based on international surveys. On the other hand, studies based on international surveys provided evidence which is comparable across countries, but rarely went beyond finding statistical associations between ICT-related variables and educational outcomes. This poses a problem of endogeneity. For instance, the availability of ICT was found to be positively associated with educational outcomes, but this does not mean that ICT has a positive impact on educational outcomes: it may be that there are unobservable factors at the student level (such as higher students' skills or motivation) simultaneously associated with the higher availability of ICT and higher outcomes. Few studies based on international surveys have tried to address this methodological problem, and not all of them were able to overcome it. The lack of sufficient empirical evidence on the impact of ICT on educational outcomes based on data from international surveys is a major shortcoming of the existing literature on the educational impact of ICT, one which we address in this study.

3. Methodological strategy

Our study analyses the impact of the use of ICT on educational outcomes in maths, reading and science, using data from PISA for the Spanish Autonomous Communities. Our empirical strategy is based on the calculation of the average use of ICT at school in each Community in three different years: 2009, 2012, 2015. This variable captures the different policies carried out by each Community as regards the use of ICT in teaching practices. By so doing, we address the following research question: have those Communities which have further increased the use of ICT at school achieved higher improvements in PISA scores?

3.1. Data source

We address this research question using data from three different rounds of PISA, corresponding to the years 2009, 2012 and 2015. By doing so, we are able to capture the changes both in the use of ICT at school and in educational outcomes across Autonomous Communities, and thus to measure the impact of changes in the use of ICT on educational outcomes.

The PISA survey, carried out every three years, provides standardised data to assess the competencies of a representative sample of 15-year-old students in maths, reading and science. Spain has participated in all the PISA editions since the assessment was first carried out in 2000. In 2015, Spanish students obtained, on average, 486 points in maths, 496 in reading and 493 in science. Despite being close to the OECD average of 500 points, the Spanish results show a chronic stagnation: Spain has not improved its results since 2000. The spatial analysis of the tests results shows a wide gap between the participating Autonomous Communities.

The PISA dataset has some technical advantages. Besides the estimates of students' competencies, which are used as indicators of educational outcomes, PISA offers wide-ranging data at student and school level that helps to explain differences in performance. The data include a wide variety of socioeconomic and educational composite indicators, built by the PISA project work group. Cronbach's alpha is used to check the internal consistency of each scale. The coefficients range from 0.7 to 0.9, which indicate high internal consistency (OECD, 2017, p. 295). Moreover, PISA uses plausible values that give the dataset a high degree of validity and reliability and enable international comparisons (OECD, 2013).[2] In the particular case of Spain, there is an additional advantage: PISA provides samples representative of the student population at the level of the Spanish Autonomous Communities.[3]

Despite its advantages, PISA is not immune to criticisms. Some authors argue that PISA narrows down education to a mere reproductive process under authoritarian teaching, and warn against a process of worldwide educational standardisation in the name of economic efficiency (Meyer and Benavot, 2013; d'Agnese, 2017). Some of the criticisms of PISA are also of a technical nature. As Hanushek and Woessmann (2008) point out, PISA tests may suffer from a variety of issues related to the sampling of knowledge in different academic areas, measurement errors, the reliability of questions, and the impact of test-taking conditions. Also the plausible values methodology (which PISA outlines as a key methodological advantage) is a subject of great controversy, because it allows the data for students in a particular subject to be imputed when students have not taken a single item in that subject (Kreiner and Christensen, 2014).

3.2. Variables

Our selection of variables is based on the use of the educational production function. This function establishes a statistical relation of an empirical nature between two types of variables: the educational outcomes (dependent variable) and the learning factors (predictors).

3.2.1. Dependent variable

The dependent variables in our study are students' outcomes in maths, reading and science, measured by test scores in PISA.

3.2.2. Predictors

The election of the predictors is conditioned by the fact that they have to be available and homogeneous in the three editions of PISA we are working with. Our selection follows the educational production function proposed by Hanushek et al. (2013), which can be considered a standard model in the empirical literature.

We group the predictors of educational outcomes into three levels: the student-level (which contains the individual and household

[2] The methodology of plausible values consists of two steps. In the first one, distributions of the scores (denoted as posterior distributions) are computed around the reported values in the tests. In the second one, a set of random values drawn from the posterior distributions are assigned to each observation (OECD, 2009, p. 95). Kuger, Klieme, Jude & Kaplan (2016) provide detailed information about the design of the PISA questionnaires, the analytical framework behind it and their psychometric properties.

[3] Representative samples are not available for the Autonomous Communities of Castile-La Mancha, Extremadura and Comunidad Valenciana in PISA-2009, neither for Canary Islands (in addition to Castile-La Mancha and Comunidad Valenciana) in PISA-2012. For this reason, these four Autonomous Communities are not included in the analysis. The 13 Autonomous Communities with available data, jointly represent around 78% of the Spanish population. Table A1 of the statisitical appendix shows them and their sample sizes.

characteristics), the school-level (which contains the characteristics of the school), and the Autonomous-Community-level (which contains ICT use). The definition and descriptive statistics of all the predictors is shown in the Table A2 of the Statistical Appendix.

3.2.2.1. Student-level. As individual characteristics we include gender (*ST004D01T*, according to PISA code), age (*AGE*), and country of birth of the students (*ST019AQ01T*). These variables are widely used in empirical studies on students' outcomes based on PISA data. Female students usually outperform male students in reading, but underperform them in technical subjects (OECD, 2015b). As a consequence, in secondary and higher education, male students tend to be over-represented in the fields of mathematics, physical science and computing (Charles and Grusky, 2004). Being older (there can be a difference of up to 11 months in the students that do the PISA survey) is considered an advantage (OECD, 2014; 2016). Students born abroad are vulnerable to language and integration problems that make them lag behind native students in terms of academic achievement (OECD, 2012a).

As a proxy of the household socioeconomic and cultural level, we include the number of books at home (*ST013Q0*1TA), parental occupation (*HISEI*), parental highest educational level attained (*PARED*), and the amount of ICT available at home (*ICTHOME*).[4],[5],[6] The importance of household characteristics was already revealed by the well-known Coleman report (1966), which found that the difference in school results in the United States was due more to cultural and socioeconomic reasons than to the allocation of educational resources. This finding was corroborated by recent empirical studies for very different countries (Currie & Goodman, 2010; Rothstein, 2010).

3.2.2.2. School-level. A substantial proportion of the variation in test scores within countries participating in PISA is associated with the school that students attend and their teaching practices (Freeman and Viarengo, 2014; Castro Aristizábal et al., 2018). The school characteristics that we include are whether the school is public or private (*SC013Q0*1TA), the size of the community in which the school is located (*SC001Q0*1TA), the level of responsibility of school staff in allocating resources (*RESPRES*), school truancy (*SC061Q0*2TA), and a peer effect at school level (constructed from PISA variable *ESCS*).[7],[8] A large part of the differences in students' performance between schools can be explained by the quality of resources and by whether they are used efficiently or not (Rivkin et al., 2005). Private schools usually have more autonomy in issues as designing teaching activities and managing the school, which can lead to their students achieving better results (Fuchs and Wossmann, 2007). However, several studies warn that the supposed positive effect of private education becomes weaker or vanishes once the socioeconomic characteristics of students are introduced as control variables (Gamoran, 1996; Altonji et al., 2005). School location is linked to the access to health, educational and economic infrastructures that can contribute to students' success and, in general terms, urban schools can provide better infrastructures and attract better teachers (Pegg and Panizzon, 2007; Sullivan et al., 2013; Gimenez et al., 2018). School truancy has been identified as crucial in building an adequate learning environment. Schools with higher truancy have a worse disciplinary climate that has negative effects on student performance (Fantuzzo et al., 2005). Given that parental background is the single most important determinant of academic achievement, the family background of one's peers is usually considered the most relevant peer effect (Ammermueller and Pischke, 2009). A higher peers' socioeconomic status has positive externalities that improve learning environment and student performance (Raitano and Vona, 2013).

3.2.2.3. Autonomous-Community-level. ICT use at school is the key variable in our study. We measure it through the PISA use of ICT at school index (*USESCH*). PISA asked students "How often do you use digital devices for the following activities at school?" (questions *IC06*, *IC10* and *IC011*, respectively, in the 2009, 2012 and 2015 rounds): chatting online; using email; browsing the internet;

[4] Occupational data for both the student's father and student's mother were obtained from responses to open-ended questions. The responses were coded to four-digit ISCO codes and then mapped to the international socioeconomic index of occupational status (ISEI) (Ganzeboom & Treiman, 2003). The highest occupational status of parents (*HISEI*) corresponds to the higher ISEI score of either parent or to the only available parent's ISEI score. For all three indices, higher ISEI scores indicate higher levels of occupational status.

[5] Indices on parental education were constructed by recoding educational qualifications into the following categories: (0) None, (1) ISCED 1 (primary education), (2) ISCED 2 (lower secondary), (3) ISCED Level 3B or 3C (vocational/pre-vocational upper secondary), (4) ISCED 3A (general upper secondary) and/or ISCED 4 (non-tertiary post-secondary), (5) ISCED 5B (vocational tertiary) and (6) ISCED 5A and/or ISCED 6 (theoretically oriented tertiary and post-graduate). The index of highest educational level of parents (*HISCED*) corresponds to the higher ISCED level of either parent. The index of highest educational level of parents was recoded into estimated number of years of schooling (*PARED*).

[6] The *ICTHOME* index is calculated on the sum of the availability and use at home of the following items: desktop computer, portable laptop, tablet computer, internet connection, video games console, cell phone, portable music player, printer, and USB (memory) stick. Higher values on the scale indicated higher levels of ICT availability and use.

[7] The index of the relative level of responsibility of school staff in allocating resources (*RESPRES*) was derived from six items of the school principals' report regarding who had considerable responsibility for tasks related to resource allocation ("selecting teachers for hire", "firing teachers", "establishing teachers' starting salaries", "determining teachers' salary increases", "formulating the school budget", "deciding on budget allocations within the school"). The index was calculated on the basis of the ratio of "yes" responses for school governing board, principal or teachers to "yes" responses for regional/local education authority or national educational authority. Higher values on the scale indicated relatively higher levels of school responsibility in this area.

[8] We generated a peer effect variable calculated as the school average of the PISA economic, social and cultural status index (*ESCS*). This index was built via principal component analysis, using the indicators parental education (*PARED*), highest parental occupation (*HISEI*), and home possessions (*HOMEPOS*). *ESCS* was defined as the component score for the first principal component. The higher the score was, the higher *ESCS* is, and the more positive externalities derived from the peer effect.

downloading, uploading or browsing material from school's website; posting work on school's website; playing simulations; practicing and drilling; doing homework on a school computer; and using school computers for group work and communication with other students. The possible answers were "never or hardly ever", "once or twice a month", "once or twice a week", "almost every day" and "every day". From this information, PISA applies item response theory (IRT) scaling to calculate a standardised single index of use of ICT at school at the student level (*USESCH*). The IRT scaling procedure and reliability tests are explained in depth in OECD (2017: 127–186).

The method for calculating the index, as well as the nine activities considered, are constant across the three rounds of PISA we analyse (2009, 2012 and 2015), which allows for its comparability across time. The OECD average in each year is equal to 0 and a higher value of the index indicates greater ICT use at school.

Unobservable school and student characteristics may exist which simultaneously affect the use of ICT at school and students' educational outcomes. In particular, ICT may tend to be more intensively introduced in schools where educational outcomes are lower, or to students whose educational outcomes are lower, while these lower educational outcomes are due to factors which are not observable (such as poor students' motivation). In fact, when exploring simple correlations from PISA data, we find that in all the years under analysis, the use of ICT was higher in those schools where student's outcomes in maths (except for 2015), reading and science were lower than the average. This effect cannot be isolated when considering merely either the use of ICT at student level or the school's average use of ICT, given that the students and the schools included in the samples are not the same across different waves of PISA. This makes it impossible to control for students' and schools' unobserved heterogeneity, leading to a problem of endogeneity, which constitutes the main limitation of most of the studies on the effect of ICT on educational outcomes based on large international surveys, as explained in Section 2. However, this is solved in this paper by using Autonomous Community's average use of ICT in the estimations.

Spanish Autonomous Communities have almost exclusive competences in education, which includes total autonomy over the resources they dedicate to different educational inputs, as well as broad competences in the organisation of service provision. This includes competences in deciding on how much ICT is available and used in schools. The decisions on the availability and use of ICT are essentially made by the Communities, although schools have some autonomy in deciding to participate in certain programs which may increase ICT use. Our empirical analysis focuses on the average use of ICT at school in each Community as a predictor of educational outcomes, in order to capture the policy made in each Community as regards this issue. At the same time, we control for unobservable heterogeneity across Autonomous Communities, by including this level in the multilevel model we estimate.

Table 1 shows the average value of the USESCH index for each Autonomous Community in 2009, 2012 and 2015. As observed, there is a wide variety across Autonomous Communities in the level of ICT use at school, as well as in its variation during this period. Most Communities increased the use of ICT at school, particularly between 2009 and 2012. Between 2012 and 2015, the growth of ICT use at school was lower. The variability in the index across Communities, which already existed in 2009, increased notably between 2009 and 2015. Some Communities, such as Catalonia, the Balearic Islands and the Basque Country, moved further in the use of ICT at school, which is reflected in greater increases in the index in the period. Other Communities did not opt for such an increase in the use of ICT at school. In fact, in Communities such as Andalusia, Castile and Leon and Murcia, the index decreased in the period of analysis, which indicates that the use of ICT at school increased in them less than in the OECD average.

3.3. Statistical model and analysis

We use a Hierarchical Linear Model (HLM), in order to obtain unbiased estimators of the effect of the use of ICT at school on students'achievements.[9] HLM models assume a hierarchically structured population, and are composed of two parts: one general, common to all contexts (which is the so-called fixed-effects) and another that represents the specificity of each context (random-effects). Two-level models (students and schools) are commonly applied to PISA data. Additionally, in our model we include a third level: Autonomous Communities.

Our multilevel modelling is given by two equations. In the first equation, Eq. (1), Y_{ijk} is the expected test score (in maths, reading and science) of student i enrolled in school j in an Autonomous Community k;$\boldsymbol{X}_{ijk}$ and $\boldsymbol{Z}_{jk}$ are vectors of control variables at the individual and school level, respectively; $Usesch_k$ is average use of ICT at school in the Autonomous Community k, and ε_{ijk} is the unexplained component.

$$Y_{ijk} = \beta_0 + \boldsymbol{\beta_1 X}_{ijk} + \boldsymbol{\beta_2 Z}_{jk} + \beta_3 Usesch_{jk} + \varepsilon_{ijk} \tag{1}$$

Eq. (1) is supplemented with Eq. (2), which is estimated simultaneously and allows us to model the school and Autonomous Community specific intercepts and the associated complex error structure.

$$\beta_0 = \gamma_{00} + \nu_{0k} + \mu_{0jk} \tag{2}$$

In Eq. (2),ν_{0k} andμ_{0jk} are the respective deviation of the schools' and the Autonomous Communities' means from the overall meanγ_{00}They are assumed to be normally distributed, with mean 0, and uncorrelated withε_{ijk} . By controlling for school and Autonomous-Community-effects, we mitigate any bias from differences across schools and across Autonomous Communities,

[9] Gelman and Hill (2006) provide an introductory account of HLM and Rabe-Hesketh and Skrondal (2012) explain how to implement the methodology in Stata, the software package that we use.

Table 1
ICT Use at School Index (*USESCH*), average by Autonomous Community and year.

	2009	2012	2015
Andalusia	0.072	0.167	−0.132
Aragon	−0.045	0.074	−0.074
Asturias	0.117	0.271	0.015
Balearic I.	−0.055	0.308	0.115
Canary I.	0.138	–	0.012
Cantabria	0.002	0.113	−0.146
Castile and Leon	−0.093	−0.046	−0.263
Castile-La Mancha	–	–	−0.191
Catalonia	0.287	0.598	0.427
Extremadura	–	0.102	−0.165
Galicia	−0.159	0.126	−0.150
La Rioja	0.143	0.280	0.027
Madrid	−0.110	0.127	−0.140
Murcia	0.058	0.081	−0.190
Navarre	0.072	0.187	−0.019
Basque C.	0.003	0.279	0.118
C. Valenciana	–	–	−0.081

respectively, which are correlated with test scores. This makes it possible to obtain more accurate inferences about the fixed effects of interest in Eq. (1), and specifically about the impact of the use of ICT at school on students' achievements, estimated by β_3 .

In the light of the mixed evidence obtained in the above-mentioned literature, we do not have an ex-ante hypothesis on which is the sense of the correlation between the use of ICT at school and PISA scores. With respect to the other predictors, our expectations, based on the literature, are for PISA tests scores to be positively related to students' age; living in homes with higher socioeconomic status (this is, higher parental occupation and educational level, more books at home and better access to ICT); and attending schools that are private, are located in larger cities, have more autonomy in the allocation of their resources, and have positive externalities from peers (measured through peers' socioeconomic status). Conversely, we expect test scores to be negatively related with having been born abroad and attending schools with higher truancy. We also expect male students to outperform female students in maths and science, but underperform them in reading.

The entire analysis was conducted using a sample of 61,042 students that studied in 2,195 schools distributed in 13 Autonomous Communities.

With respect to the missing data, we follow the missing data treatment suggested by Sun et al. (2012): although missing data were found in our database, our sample size is so large that the estimation results will not be very different without the cases with missing data. For this reason, missing data were list-wise deleted when running the analyses.

The Maximum Likelihood Estimations are carried out using version 16 of the Stata Software, combining the multilevel option with the use of the multiple imputation analysis necessary when working with PISA plausible values. These estimations are very computationally demanding, due to our large number of observations and the characteristics of the PISA database. The database and the routines carried out can be found in the supplementary material that accompanies this article.

To estimate robust standard errors, we specify the standard errors to allow for intragroup correlation, relaxing the usual requirement that the observations are independent. This procedure assumes that the observations are independent across groups (clusters) but not necessarily within groups. According to the Stata Users' Manual (p. 290) the option *can produce "correct" standard errors (in the measurement sense), even if the observations are correlated.*[10] In addition, the standard errors of the coefficients obtained by this technique are also robust in the presence of heteroscedasticity.

4. Results

Table 2 shows the results of the estimations of Eqs. (1) and (2) for maths, reading and science. The estimations include the fixed-and-random-effects. The latter, at the bottom of the table, show the standard deviations from the overall mean, with origin in the school-and-Autonomous-Community-level variance unaccounted for in the model.

The results are consistent with previous empirical evidence in the literature on educational outcomes. First, male students score higher than female students in maths and science and lower in reading, and the coefficients are significant (as found by Lietz, 2006 and OECD, 2015b). Second, the age correlates positively and significantly with the scores (as found by OECD, 2014; 2016). Third, immigrant students obtain worse results than students born in Spain, and the coefficients are significant. Students of immigrant origin,

[10] In our 3-level model, we chose to establish clusters at the level of Autonomous Communities, since it is at this level at which educational policy decisions are made in Spain. That means that we assume there exist unobservable characteristics, inherent to each Autonomous Community, which would cause arbitrary correlations between students belonging to the same Autonomous Community. If this is not controlled for, it would lead to uncorrelated estimation errors between the different Autonomous Communities but correlated within each of them. With the introduction of clusters, we avoid a misinterpretation of the significance of the coefficients of the estimates and, therefore, of the explanatory power of the model variables.

Table 2
Multiple-imputation HLM estimates of education production function with use of ICT at school (Autonomous Community's average). Dependent variables: PISA math, reading and science scores.

Group variable	No. of groups	Observations per Group		
		Minimum	Average	Maximum
Autonomous Communities	13	3,760	4,695.5	10,739
Schools	2,195	1	27.8	76

Fixed-effects parameters	Maths				Reading				Science			
	Coef.	Std. Err.	t	P>|t|	Coef.	Std. Err.	t	P>|t|	Coef.	Std. Err.	t	P>|t|
Use of ICT at school (Autonomous Community's average)	6.614	9.329	0.71	0.478	16.899	11.062	1.53	0.127	38.181***	10.376	3.68	0.000
Gender												
Male	16.852***	1.210	13.92	0.000	−23.488***	1.217	−19.30	0.000	10.911***	0.817	13.36	0.000
AGE	10.848***	1.427	7.60	0.000	11.621***	1.403	8.28	0.000	11.820***	1.127	10.49	0.000
Country of Birth - Self												
Other country	−31.613***	3.120	−10.13	0.000	−20.693***	2.235	−9.26	0.000	−24.844***	2.164	−11.48	0.000
How many books at home												
11–25 books	21.929***	1.939	11.31	0.000	26.545***	2.160	12.29	0.000	22.148***	2.375	9.33	0.000
26–100 books	52.117***	2.413	21.60	0.000	53.768***	2.279	23.59	0.000	50.311***	2.875	17.50	0.000
101–200 books	69.410***	2.799	24.80	0.000	70.758***	2.333	30.33	0.000	67.434***	3.724	18.11	0.000
201–500 books	83.768***	3.176	26.37	0.000	84.547***	2.598	32.54	0.000	82.292***	3.689	22.31	0.000
More than 500 books	84.779***	3.231	26.24	0.000	82.747***	3.592	23.04	0.000	84.446***	4.092	20.64	0.000
Highest parental occupational status	0.387***	0.017	23.19	0.000	0.369***	0.020	18.78	0.000	0.390***	0.021	18.75	0.000
Highest parental education in years	1.341***	0.191	7.02	0.000	1.234***	0.204	6.04	0.000	1.323***	0.159	8.32	0.000
ICT available at Home Index	0.509	0.340	1.50	0.135	1.210***	0.286	4.23	0.000	0.722***	0.259	2.79	0.005
Public or private school												
A private school	1.288	2.509	0.51	0.608	6.552**	3.021	2.17	0.030	3.186	3.178	1.00	0.316
Which of the following definitions best describes the community in which your school is located												
A small town (3000 to about 15,000 people)	5.825**	2.315	2.52	0.012	7.299***	2.804	2.60	0.009	4.989*	2.857	1.75	0.081
A town (15,000 to about 100,000 people)	6.121*	3.388	1.81	0.071	9.938***	3.851	2.58	0.010	6.546**	3.179	2.06	0.039
A city (100,000 to about 1,000,000 people)	9.601***	3.290	2.92	0.004	15.118***	2.928	5.16	0.000	10.147***	2.985	3.40	0.001
A large city (with over 1,000,000 people)	12.874***	3.795	3.39	0.001	17.035***	4.278	3.98	0.000	11.754***	4.565	2.58	0.010
Responsibility for school resources	2.508	1.547	1.62	0.105	2.848*	1.722	1.65	0.098	1.683	1.757	0.96	0.338
Extent to which student learning is hindered by students skipping classes												
Very little	−3.072	2.169	−1.42	0.157	−0.984	2.006	−0.49	0.624	−1.608	1.779	−0.90	0.366
To some extent	−6.456***	2.487	−2.60	0.009	−3.790*	2.153	−1.76	0.079	−3.219*	1.946	−1.65	0.098
A lot	−9.308	7.327	−1.27	0.204	−6.350	6.524	−0.97	0.330	−6.988	5.348	−1.31	0.191
Peer effect (measured as school's average of PISA social and cultural status index)	6.557***	1.841	3.56	0.000	4.625***	1.191	3.88	0.000	4.439***	1.345	3.30	0.001
Constant	226.905***	23.521	9.65	0.000	224.741***	24.127	9.31	0.000	215.515***	20.922	10.30	0.000

Random-effects parameters	Maths	Reading	Science
Autonomous Community: Identity sd(_cons)	8.549	7.580	11.154
School: Identity sd(_cons)	20.195	22.200	21.352
sd(Residual)	72.115	72.446	71.479

Notes: Robust standard errors adjusted for clustering at Autonomous Community. ***$\rho < 0.01$, **$\rho < 0.05$, *$\rho < 0.1$.

especially first-generation immigrants, consistently perform worse on the PISA tests (Schleicher, 2006) and this has important consequences in terms of their social and occupational mobility (Buchmann & Parrado, 2006). Fourth, the number of books at home, parents' education and occupation correlate positively and significantly with students' scores. Fifth, ICT availability at home correlates positively and significantly with scores on science and reading, although the coefficient is non-significant on maths. The empirical literature has found a very strong relationship between socioeconomic status and students' outcomes, either if socioeconomic status is measured as parental occupation (Jerrim, 2012), parental education (Martins & Veiga, 2010), ICT available at home (Alderete et al., 2017), or multidimensional measures based on home possessions like books (Oppedisano & Turati, 2015). Sixth, students of private schools score higher in reading, although the coefficient is non-significant on maths and science. These results are in line with OECD (2012b), which highlights that the effect of schools' private (versus public) ownership on performance is inconclusive. While some studies show that higher private school enrolments are related to better performance, others report little, negative or non-significant effects, and the results often depend on methodological choices (Woessmann et al., 2009 offers a detailed review of the literature). Seventh, students that attend schools situated in larger cities score higher, and the coefficients are significant. This is in line with the findings of Pegg and Panizzon (2007) and Sullivan et al. (2013), who point out that students in urban schools get significantly higher outcomes than those in rural schools due to differences in the quality of infrastructures and teachers. Eighth, the level of responsibility of school staff in allocating resources correlates positively with students' scores (coefficient significant at 10% level) in reading, although the correlation is non-significant in maths and science. The absence of a clear effect of this variable could be due to the fact that the positive effects of school autonomy are found to be more related with factors as planning of the curriculum and the design of the evaluations than with the flexibility in the use of resources (Clark, 2009). Ninth, truancy has a negative and significant correlation with student performance. Regular truancy has been found to have adverse consequences for students' outcomes as it deteriorates the disciplinary climate, and truants are more likely to fall behind in class (Aucejo & Romano, 2016). And tenth, the peer effect (measured as school's ESCS) has a positive and significant correlation with student performance. Using a similar measure of peer effect, Raitano and Vona (2013) obtain analogous findings and note, additionally, that the peer effect is even stronger in the case of low-ability students.

As regards our central variable of study, the use of ICT at school (Autonomous Community average), the estimated effects are close to zero and clearly non-significant for PISA scores in maths and reading. That is, an increase in the use of ICT at school in an Autonomous Community does not have a positive effect, but neither a negative effect, on educational outcomes in maths and reading, as measured by PISA test scores. As regards scores in science, we find a positive effect of the use of ICT at school, significant at a level of 1%. An increase of one standard deviation in the average use of ICT at school in an Autonomous Community (whose value is 0.18) is associated with an increase of 6.87 points (38.18 * 0.18) in PISA scores in science. This is equivalent to about 34 school days in an academic year (OECD, 2017).

5. Discussion and conclusions

ICT has become a major focus of attention for educational policies and, subsequently, for research in the field of education. Governments are making substantial investments in equipping schools with ICT and, as a result, the use of technologies for teaching practices has increased significantly in most OECD countries. However, research has not yet found clear evidence on whether the use of ICT has positive effects on educational outcomes. Experimental analyses have found mixed evidence, depending on the setting in which ICT were used, and which variables were considered to measure ICT use and educational outcomes. In addition, studies based on international surveys have rarely attempted to capture the impact of ICT on educational outcomes, beyond statistical correlations. This paper analysed the impact of the use of ICT at school on outcomes in maths, reading and science, using data from three rounds of PISA (the most well-known international survey on cognitive outcomes) for the Spanish Autonomous Communities. By calculating the average use of ICT at school in each year and each Community, we tested whether those Communities which further increased the use of ICT at school achieved higher improvements in PISA scores.

A main conclusion of our study is that the impact of ICT on educational outcomes differs depending on the subject. This result was also obtained by Machin et al. (2007) in their study on expenditure on ICT in England and by Cristia et al. (2017) in their evaluation of a program which provided laptops to children in Peru. In our study, we find a higher use of ICT at school in an Autonomous Community has non-significant effects on students' outcomes in maths and reading, whilst it has a positive effect on outcomes in science.

Our finding showing that the use of ICT does not have an impact on educational outcomes in maths and reading is in agreement with results from a significant number of the experimental studies on this issue. Similar evidence had been previously obtained by Angrist & Lavy (2002), Goolsbee and Guryan (2006) and Cristia et al. (2017) for both maths and reading, Machin et al. (2007) for maths (albeit not for reading, where they found a positive effect), Craig et al. (2013) also for maths, and Rouse and Krueger (2004) for reading. Nevertheless, other experimental studies had found different results in specific settings. Leuven et al. (2007) found a negative impact of ICT on students' outcomes in both maths and language for schools with a high presence of students in disadvantaged positions in the Netherlands, whilst Mora et al. (2018) found a negative impact of a program which provided laptops, wireless connectivity and digital boards in Catalonia. In contrast, other studies had found settings in which ICT had a positive impact on outcomes in maths: Banerjee et al. (2007) in a study in the particular context of India, Barrow et al. (2009) for a program providing more individualised instruction in some US schools, and Bartelet et al. (2016) for an optional web-based tutoring system in the Netherlands.

Science, where we find a positive impact of ICT on students' outcomes, had received less attention from the literature. Machin et al. (2007) obtained a positive albeit non-significant impact of expenditure on ICT on science outcomes in England. Spiezia (2010) found a positive and significant effect of the frequency of computer use on science outcomes, using data from PISA-2006 for a broad set of countries, although it was basically driven by the effect of computer use at home. In contrast, Goolsbee and Guryan (2006) found that a subsidy on Internet investment in Californian schools had no impact on science outcomes, nor on maths and reading.

The key to explaining why the impact of ICT differs depending on the subject is an insight consistently found by the literature: the effect of ICT on educational outcomes depends on the type of use of the technology (Barrow et al., 2009; Bartelet et al., 2016; Biagi & Loi, 2012; Comi et al., 2017; Lei & Zhao, 2007; Luu & Freeman, 2011; Meggiolaro, 2018). As summarised by Falck et al. (2018), taking into account the arguments of both optimistic and pessimistic views on the use of ICT in education, there may be activities in which ICT-based education is superior to traditional instruction, whilst the opposite occurs in other activities. For pedagogical reasons, teaching science allows more advantageous uses of ICT than teaching maths or reading. Spiezia (2010) pointed out that one of the advantages of the educational use of ICT is to improve access to information and to a wider range of resources for learning. Lei and Zhao (2007) found that uses of technology which provide ways of learning not accessible in traditional classes were those which had a positive effect on students' outcomes. Both circumstances are much more common for science than for maths or reading. For science, ICT may easily bring access to richer and more attractive information, resources and ways of learning than traditional classes. For maths and for reading, these potential advantages of ICT are much harder to find, and to overcome the negative consequences of the educational use of ICT including students' distraction (De Witte & Rogge, 2014; Spiezia, 2010), restriction of their creativity (Spiezia, 2010) and the reduction of human interaction (De Witte & Rogge, 2014; Livingstone, 2012). In fact, in the case of Spain, science is the subject (among these three) where the use of ICT is most frequent: taking data from PISA-2009,[11] 16.3% of Spanish students used a computer for science lessons in a typical week, whilst only 10% and 12.3%, respectively, did it for maths and language lessons. This suggests that science is the subject for which the teachers themselves are more familiarised with the use of ICT and find it is more advantageous.

This paper contributes to the existing literature on the impact of ICT on educational outcomes, by providing evidence on this regard based on data from an international survey, PISA. Previous literature based on PISA had found a negative statistical correlation between students' use of ICT at school and their educational outcomes, both using data for a broad set of countries (Hu et al., 2018; Petko et al., 2017; Zhang & Liu, 2016) and for the specific case of Spain (Mediavilla & Escardibul, 2015; Alderete et al., 2017). These findings, however, faced a problem of endogeneity: unobservable individual and/or school characteristics may be simultaneously associated with a higher use of ICT and with lower educational outcomes. By considering the average use of ICT at the Autonomous Community level, we avoid this bias, and find that the effect of ICT on educational outcomes is non-significant for maths and reading, and positive for science. Our evidence is consistent with that from several previous experimental studies on this issue. Nevertheless, our study has one advantage over them: as it is based on an internationally equivalent survey, its results could be more easily comparable with those from prospective studies which may use the same variables to measure both the use of ICT and the educational outcomes.

The main limitation of our study is that whilst it provides evidence on the impact of policies on the use of ICT at school carried out by Spanish Autonomous Communities, this policy impact may differ in other countries, where the setting or the uses of ICT are not the same. Our selection of the Spanish case was conditioned by three requirements it fulfils: for Spain, PISA provides representative samples for sub-national units, they are autonomous in deciding on the use of ICT in education, and they show a broad variability in the use of ICT at school. These three criteria are not fulfilled for any other country from the existing rounds of PISA, and this hinders the extension of the analysis to other countries from the data currently available. In the future, our research design could be extended to other cases, in the event that the next PISA rounds or other international surveys provide data for other countries which fulfil these conditions. Besides, our research design can also be extended to analyse the differential effect of ICT on educational outcomes across countries.

Our main policy recommendation is derived from our finding that ICT can, but does not always, have a positive impact on educational outcomes: the impact varies depending on the subject, and the use of the technology. As a result, there is a need to intensify the evaluation of policies oriented at increasing the educational use of ICT. Further efforts in the evaluation of these policies should focus on the effects of specific programmes and inputs on specific student competences in order to identify for which uses, and for which ways of use, ICT may render a positive effect on educational outcomes. Besides, it is recommendable to carry out, for each policy intervention on this issue, a pilot test on a small scale, in order to minimise the risk of dedicating resources to ineffective interventions.

Declaration of competing interest

None.

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[11] PISA-2009 provided data to compare the use of ICT across maths, teaching and reading, from answers to the question: "In a typical school week, how much time do you spend using the computer during classroom lessons". The question is separately asked for mathematics, language and science. Possible answers are "No time", "0–30 min a week", "31–60 min a week" and "More than 60 min a week". This question was not included neither in PISA-2012 nor in PISA-2015.

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Statistical Appendix.

Table A1
PISA sample sizes for each Autonomous Community and year.

	2009	2012	2015
Andalusia	1,383	1,352	1,735
Aragon	1,487	1,335	1,687
Asturias	1,512	1,567	1,719
Balearic Islands	1,356	1,294	1,705
Canary Islands	1,385	–	1,716
Cantabria	1,500	1,481	1,875
Castile and Leon	1,501	1,524	1,806
Castile-La Mancha	–	–	1,821
Catalonia	1,341	1,291	1,694
Extremadura	–	1,449	1,708
Galicia	1,561	1,467	1,822
La Rioja	1,265	1,488	1,392
Madrid	1,428	1,465	1,766
Murcia	1,298	1,316	1,708
Navarre	1,476	1,448	1,774
Basque Country	4,648	4,431	3,407
C. Valenciana	–	–	1,553

Table A2
Descriptive statistics of covariates used in the empirical analysis.

Level	Variable	PISA code	Mean	SD	N	Missing
Student	Gender	ST004D01T		0.50	70,107	0
	Female (%)		49.56			
	Male (%)		50.44			
	Age	AGE	15.87	0.29	70,107	0
	Country of Birth – Self	ST019AQ01T		0.31	69,098	1009
	Country of test (%)		89.08			
	Other country (%)		10.92			
	How many books at home	ST013Q01TA		1.38	69,318	789
	0–10 books (%)		7.21			
	11–25 books (%)		12.66			
	26–100 books (%)		30.52			
	101–200 books (%)		21.48			
	201–500 books (%)		17.50			
	More than 500 books (%)		10.62			
	Highest parental occupational status index	HISEI	48.84	21.53	68,326	1781
	Highest parental education in years index	PARED	12.83	3.61	68,650	1457
	ICT available at Home index	ICTHOME	3.10	4.33	66,809	3298
School	Public or private school	SC013Q01TA		0.49	68,217	1890
	A public school (%)		60.46			
	A private school (%)		39.54			
	Which of the following definitions best describes the community in which your school is located	SC001Q01TA			68,271	1836
	A village, hamlet or rural area (fewer than 3000 people) (%)		5.23			
	A small town (3000 to about 15,000 people) (%)		26.22			
	A town (15,000 to about 100,000 people) (%)		29.63			
	A city (100,000 to about 1,000,000 people) (%)		34.13			
	A large city (with over 1,000,000 people) (%)		4.78			
	Responsibility for school resources index	RESPRES	−0.36	0.61	69,525	582
	Extent to which student learning is hindered by students skipping classes	SC061Q02TA			67,397	2710
	Not at all (%)		26.74			
	Very little (%)		51.42			
	To some extent (%)		18.01			
	A lot (%)		3.83			
		ESCS	−0.25	0.49	70,107	0

(*continued on next page*)

Table A2 (*continued*)

Level	Variable	PISA code	Mean	SD	N	Missing
	Peer effect (measured as school's average of PISA social and cultural status index)					
Autonomous Community	Use of ICT at school index (Autonomous Community's average)	USESCH	0.06	0.18	70,107	0

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compedu.2020.103969.

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